WHALE-WATCHING IMPACTS: SCIENCE, HUMAN DIMENSIONS AND MANAGEMENT

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WHALE-WATCHING IMPACTS: SCIENCE, HUMAN DIMENSIONS AND MANAGEMENT

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EDITORIAL
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Editorial: Whale-Watching Impacts: Science, Human Dimensions and Management

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Editorial on the Research Topic

Whale-Watching Impacts: Science, Human Dimensions and Management

Whale watching, the activity of sighting cetaceans in their natural habitat, and the basis of tourism industries worldwide, has been growing in the last decades. Although the growth of the industry has been beneficial in economic terms for the communities in countries where the activity takes place (Guidino et al., 2020), there is a great concern about how whale watching may negatively impact the behavior and physiology of the species being observed (Senigaglia et al., 2016) or even compromise their survival (Barragán-Barrera et al., 2017). There is a significant history of research on the impacts of whale watching due to the need to provide a scientific basis for regulations that seek to ensure the welfare of the species targeted by the industry (Corkeron, 1995; Parsons and Brown, 2018; Gleason and Parsons, 2019). Optimal management allowing sustainable whale watching remains a challenge for most countries. Lack of regulations, or guidelines not being followed by tour operators, are commonly reported (Higham et al., 2009). Failure to follow regulations is related to poor governmental monitoring, competition between operators for ensuring profit and, in some instances, lack of self-organization among operators. Currently, understanding site-specific idiosyncrasies of governance is crucial to minimize the negative impacts of whale and dolphin watching, including in countries with well-established regulations.

This Research Topic addressed ecological, management and economic issues surrounding whale watching in 14 contributions: 12 original research, one review and one perspective. Studies involved 13 species of cetaceans including, humpback (*Megaptera novaeangliae*), gray (*Eschrichtius robustus*), blue (*Balaenoptera musculus*), fin (*B. physalus*), Bryde's (*B. brydei*), sperm (*Physeter macrocephalus*) whales, Hector's (*Cephalorhynchus hectori hectori*), common (*Delphinus delphis*), dusky (*Lagenorhynchus obscurus*), common bottlenose (*Tursiops truncatus*), spotted (*Stenella attenuata*), spinner (*S. longirostris*) dolphins, and killer whales (*Orcinus orca*). Papers covered marine regions of Colombia, Chile, Italy, Mexico, New Zealand, Panama, Peru, and the United States reflecting the widespread and global importance of whale-watching research.

Most contributions have addressed the impacts of whale watching on several aspects of the cetacean's species behavior and ecology. Holt et al. demonstrated that female southern resident killer whales are more likely to assume a non-foraging state with vessels in proximity than males, compromising their energy available for reproduction. Given the precarious state of this population of killer whales, this is a significant conservation concern. Amrein et al. highlight the changes of

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movement direction in humpback whales in presence of three or four whale-watching boats. Also, Currie et al. show that the presence of vessels causes changes in swim speed, respiration rate, and path directness, as well as decreases in dive times in humpback whales. Similar results on changes of movement direction and resting behavior were observed in fin whales by Santos-Carvallo et al. off the central coast of Chile. Toro et al. studied group size and surface behavior of bottlenose dolphins comparing two data sets, one 18 years prior to and another after the onset of dolphin watching tourism. The results suggests both a substantial reduction in group size and surface activities in presence of dolphin-watching boats.

In a physiological study, Villagra et al. used a before-during-after design with non-vessel-presence controls to show that the simultaneous presence of several whale watching boats can affect the energy budget of humpback whales. Acoustic impacts were addressed by Perez-Ortega et al., using a paired-comparison study design. They demonstrated that bottlenose dolphins exposed to substantial dolphin-watching traffic increased their whistle frequency modulation, an indicator of stress. Rey-Baquero et al., used acoustic propagation models to show that humpback whales song communication can be masked up to 63% by a single whale-watching boat, even in an area with little other anthropogenic noise.

Soto-Cortés et al. examined the management of whale watching in a marine protected area in Colombia. They showed that the sustainability of the activity may be affected by socioeconomic problems among tour operators, inconsistency in the enforcement of regulations and a lack of communication among stakeholders including the authorities. Tepsich et al. studied the satisfaction levels of tourists participating in the whale watching industry in the Pelagos Sanctuary, a marine protected area in the northwest of the Mediterranean Sea. They reported high levels of satisfaction by tourists, but almost half of the tour operators were unaware that their activities were conducted in a marine protected area that could be used to enhance conservation actions. On the Pacific coast of Panama, Cárdenas et al. demonstrated that compliance by tour operators to regulations and the provision of information about the ecology of humpback whales produced higher levels of satisfaction for tourists participating in whale watching compared to those operators who did not comply with regulations.

Fumagalli et al. presented a historical review (ca. 30 years) of whale and dolphin-watching involving several species at different locations in New Zealand. They concluded that despite an early establishment in precautionary regulations, successful management depends in the socio-cultural factors as well as socio-economic dynamics. Not all places have succeeded in management of cetacean-based tourism and site-specific adaptation and governance is crucial. Urbán and Viloria-Gómora reviewed the situation of whale watching throughout the Mexican Pacific coast, highlighting successful cases of whale watching in marine protected areas, but in locations not under protection, whale watching does not follow rules currently imposed by Mexican authorities. Also, the authors pinpointed the need for a regulatory framework for tourism based on swimming with dolphins. Finally, Wiener et al. provided the first estimates of revenue generated by the tourism industry involved with swimming with spinner dolphins at two sites in the Hawaiian Islands. These researchers demonstrated that the industry provides significant funding into the local economy, with each individual dolphin worth between \$1.6 and \$3.3 million over its lifetime. The authors also call for further assessment of the impacts of the activity and the economic role in the tourism industry.

The contributions in this Research Topic show that research on whale-watching has developed into a well-organized scientific enterprise. The work collected here highlights the value of monitoring of biological impacts, the need for this work to continue internationally and the importance of the enforcement of regulations surrounding the whale watching industry.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Cashing in on Spinners: Revenue Estimates of Wild Dolphin-Swim Tourism in the Hawaiian Islands

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Wild dolphin-swim tourism has grown in specific locations where Hawaiian spinner dolphins (*Stenella longirostris*) have known resting habitat. The increased growth in dolphin-swim businesses has created an industry in Hawaii that earns an estimated $102 million (USD) annually in 2013. Semi-structured interviews with business owners, market research, and boat-based observations provide a platform for estimating revenue generated from dolphin tourism in two popular locations, Waianae, Oahu and Kailua-Kona, Hawaii Island. A revenue analysis of dolphin-swim tourism is presented using a peak season and utilization rate model. These predictions offer an accountability exercise based on a series of assumptions regarding wild dolphin-swim demand and an annual estimate of the number of viewing participants and revenue earned. The results show that dolphin viewing companies are making a larger profit than dolphin-swim businesses by approximately $19 million (USD) per year, however, both avenues are generating large earnings. Sizable differences between businesses in Kona and Waianae are discussed. The average lifetime revenue generated by a dolphin in 2013 is estimated at $3,364,316 (USD) for Waianae and $1,608,882 (USD) for Kona, and is presented as a first step in scenario analysis for policy makers looking to implement management in the bays where tourism occurs. This study offers the first revenue estimates of spinner dolphin tourism in Hawaii, which can provide context for further discussion on the impact and economic role of the dolphin-swim industry in the state.

Keywords: dolphin-swim, tourism, revenue analysis, Hawaiian spinner dolphin, utilization rate model, time area management

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INTRODUCTION

The wide-spread adoration of marine mammals over the past century is evidenced by their popularity in mass media (Burnett, 2010; Wiener, 2015a). This has trickled into wildlife tourism, leading to growth and expansion of whale and dolphin excursions (Delfour, 2007; Higham et al., 2009; Hu et al., 2009; Heenehan et al., 2015). Interaction with marine species in natural settings has become a critical aspect of the broader tourism industry (Catlin et al., 2013; Orams, 2013). In 2008, marine mammal tourism was offered in over 119 countries with an estimated value of $2.1 billion (USD) annually (O'Connor et al., 2009). In recent decades, dolphin-swim tourism has developed a similar path of expansion. Hot-spots for dolphin-swim tourism have become established in coastal communities with access to marine mammal populations (Wiener, 2015b). Developing countries such as the Philippines and Taiwan are increasingly using this type of tourism and now outnumber developed countries (Samonte-Tan et al., 2007; Mustika et al., 2013).

Escalating marine mammal tourism has led to investigation of how this growth is affecting whale and dolphin populations. Several studies have observed negative impacts (Lammers, 2004; Danil et al., 2005; Bejder et al., 2006; Courbis and Timmel, 2009; Heenehan et al., 2015; Higham et al., 2016; Tyne et al., 2018; Sprogis et al., 2020), yet communities advocate these activities for growth in local economies. With the majority of research focused on the biological impacts of dolphin-swim tourism, little attention has been paid to the social and economic effects. Few studies have identified the fiscal productivity of these activities and how the profits are distributed within local economies (Hoagland and Meeks, 2000; Yacob et al., 2007; Mustika et al., 2013; Guidino et al., 2020). Recent decline in fish catches and degradation of coastal ecosystems have led some fisheries to become involved in marine mammal tourism as a way to overcome economic challenges, while others have been driven away from traditional catch grounds due to expansion of tour boats (Orams, 2013). These shifts have contributed to a marine mammal tourism industry growing at a rate of 3.7% per year (Chen, 2011). This is why both economic and social costs must be considered in tandem, as there are benefits and losses derived from marine mammal tourism that cannot be measured individually (Bateman et al., 2010; Mustika et al., 2013). Location-specific studies are critical in marine mammal tourism as well, because most activities are based around particular populations that are attached to certain cultural contexts. As a result, economic analysis undertaken in one location cannot always be extrapolated to other settings (Catlin et al., 2013).

Currently, no estimates exist for dolphin-swim tourism either locally or globally, reflecting a gap in data. The goal of this research is to offer an accountability exercise based on a series of assumptions regarding wild dolphin-swim demand in Hawaii and an annual estimate of the number of viewing participants and revenue earned, as well as an estimated lifetime revenue that each individual dolphin may generate. With dolphin tourism continuously on the rise (Wiener, 2015b), it is important to capture a baseline of what this industry accrues to provide background for managers.

Natural systems and species are important contributors to economic activity and growing evidence shows increasing pressure on them from human tourism activity (Bateman et al., 2010). However, wildlife valuation is difficult and complex. An approximation of value is the best that can be achieved and typically involves many assumptions placed from an anthropocentric perspective (Knowles and Campbell, 2011; Orams, 2013). Many factors besides economics come into play when valuing a species, such as conserving habitat on which the species depends, or the environmental cost of the potentially negative effects of tourism activities (Dwyer et al., 2004; Orams, 2013). The ecological, sociocultural, and intrinsic values associated with Hawaiian spinner dolphins (*Stenella longirostris*) are explored by the authors in other research. However, for the purposes of this paper, the emphasis will be on the revenue generated from these activities.

Understanding the revenue of an under-studied industry such as dolphin-swim tourism is gravely needed before making policy decision. This requires studies that are focused on establishing a baseline of that ecosystem service or business (Baulcomb and Böhnke-Henrichs, 2011). This study presents a revenue analysis of Hawaiian spinner dolphin tourism as a first step in scenario analysis for dolphin-swim tourism in Hawaii and an expansion of the existing marine tourism literature. Revenue from ticket prices will provide a starting point for an evaluation of dolphin tourism in Hawaii and its significance for the state.

Estimates provided are based on participant observation, tour operator interviews, and market research conducted from July 2012 to June 2013. The market research included an online review of company websites, particularly tracking of ticket prices and tour frequencies. The resulting data in combination provide validity to the information shared through the interviews and strengthen the depth of analysis. One advantage of this approach is that it can be implemented in other locations to establish a baseline understanding of a relatively new or emerging industry where not a lot of information exists. However, there are also limitations to this work due to missing information from some of the operators and lack of clarity on operation costs; these shortcomings are discussed in the section "*Causes and Considerations*." This body of knowledge represents the first attempt at an assessment of the Hawaiian spinner dolphin industry as a whole and provides a starting point for further study.

The Hawaiian spinner dolphin is a small species commonly found in Hawaiian near-shore waters. Spinner dolphins hunt cooperatively at night and are most playful during early morning hours while winding down from evening activities (Lammers, 2004; Tyne et al., 2015, 2017). During mid-morning, the dolphins enter a resting state, moving closer together and swimming in unison along the sea floor (Norris et al., 1994; Tyne et al., 2017). During these critical mid-morning resting periods, spinner dolphins are most heavily disturbed by tourist vessels seeking to interact with the species (Heenehan et al., 2015; Tyne et al., 2018). Since 1972, the Marine Mammal Protection Act has forbid any indirect aggravation (Level B harassment) of marine mammals in United States waters. Dolphin-swim tourism can violate this policy; however, it is difficult to enforce. Concerns that tourist activities directed at dolphins may have population effects (such as habitat shifts, compressing resting times resulting in reduced reproduction, and shifting energy budgets) have been documented (Östman, 1994; Wursig, 1996; Danil et al., 2005; Courbis, 2007; Delfour, 2007; Timmel et al., 2008; Courbis and Timmel, 2009; Milette et al., 2011; Tyne et al., 2018).

This paper shares results from the first revenue assessment of commercial wild dolphin tourism in Hawaii. We approximate participant and company numbers, and direct revenue from two main dolphin-swim tourism locations, Waianae, Oahu and Kailua-Kona, Hawaii Island. An appraisal of exposure and revenue generated from each dolphin is also presented, providing an estimate of how much each dolphin contributes over their lifetime. This information will assist marine resource managers who need to consider regulations, the economic benefits, and community impacts of dolphin tourism.

MATERIALS AND METHODS

Sampling and Data Collection

Tour operator information was entered into a database gathered from marketing materials and internet inquiries. Vessel capacities, trip schedules, and prices were obtained from these sources and 77 tour companies were included. Four internet searches were conducted periodically between 2012 and 2013, and an additional update in 2018; any operator that advertised guided dolphin-swims, dolphin watching, or dolphin snorkeling was included in the database, resulting in four different operator categories (**Figure 1**). Annual revenues of each vessel were estimated by combining publicly available ticket prices, trip schedules, and capacity data with a utilization rate estimate based on interview data similar to other studies (Utech, 2000).

Semi-structured interviews were conducted with 26 dolphin-swim operators to assess the revenues generated from dolphin tourism and the perceptions toward the growth of the industry. Participants were selected using voluntary response sampling solicited through a community meeting and through cold calls to all dolphin-swim company owners. While the sample was not representative of the entire industry, this was the largest collection of operator interviews obtained from a reclusive group. Operators were asked to recall information about seasonal activity, revenue generated, the types and number of trips offered, number of passengers per trip, and vessel capacities. These data enabled calculation of vessel-specific estimates of direct revenues, also providing information about utilization rates, e.g., average number of passengers per trip, etc. Cooperative inquiry was included in transcription, allowing interviewees a final opportunity to confirm or re-clarify recorded notes (Braun and Clarke, 2006).

Additionally, field observations were made from July 2012-June 2013 on 40 days resulting in >257 h of observation. The tour boats on each island leave from the Ko Olina and Waianae Boat Harbor on Oahu and Honokohau on Hawaii Island, visiting known dolphin-swim sites (see map in **Figure 2**). The boat-based study allowed for observation of the number of boats and swimmers in the water with the spinner dolphins throughout the year. The observations served as a control for the utilization rate estimate or peak season timeline (*PST*) that was established based on company sales and operator experience. Observations also provided an assessment of human use.

Calculations

Dolphin-swim tourism revenue was calculated based on similar methods conducted in a study by Clua et al. (2011). The mean participation and direct revenue on boat-based dolphin-swim tourism in Kailua-Kona and Waianae were calculated using a PST model developed with information obtained from operator interviews and participant observation. Months were divided by mean boat trips per week and categorized into three periods of peak (an average of seven or more boat days per week), average (an average of four to six boat days per week), or slow (an average of zero to three boat days per week) seasons. Months were divided by mean weekly trip numbers to calculate the monthly average boat trips (see **Tables 1A,B**). This model gives a monthly average that provides conservative estimates to account for daily fluctuations in the number of participants. Interviewees cautioned, however, that variations occur from year to year depending on the economic conditions of the country. Additionally, the model assumes full capacity during the tours accounted for, which may round up or provide a best guess estimation. Based on observation and interview, the tour boats tend to operate at capacity. To ensure consistency of the interview and observation data used to input the model, the monthly changes were compared with the Hawaii Tourism Authority (HTA, 2013, 2018) visitor numbers for each island (see **Figure 3**).

Utilization rate estimates were calculated using the *PST* established below. For each individual company, the number of boats (b) was multiplied by the number of trips they conducted each day (t) and by the boat capacity (c). This total was then multiplied by the *PST* to produce an annual estimate of participants for each company and account for shifts in numbers based on season [$x = bt(c)(PST)$] (see **Table 2**).

Revenue was calculated by multiplying the utilization rate estimate to the ticket price (co) for each dolphin tourism company (see **Table 3**). This generated an annual estimate of revenues that could be added together to provide a revenue estimate for the dolphin tourism industry in Oahu and Hawaii Island. Separate analysis was run for Waianae, Oahu and Kailua-Kona, Hawaii Island because of the local differences in boat size and style of operators.

The lifetime revenues were estimated for an individual spinner dolphin. Using a similar method to Knowles and Campbell (2011) and Catlin et al. (2013) total revenue per dolphin over their lifetime (*DRL*) (see **Table 4**) was calculated using an estimated 26-year life expectancy of the whitebelly spinner dolphin (Larese and Chivers, 2008). It should be noted that other studies have shown spinner dolphins to potentially live 30 years or longer; however, for the purposes of this paper a more conservative

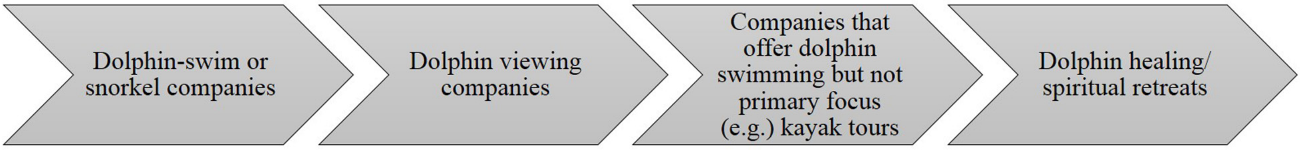

FIGURE 1 | Four dolphin operator categories.

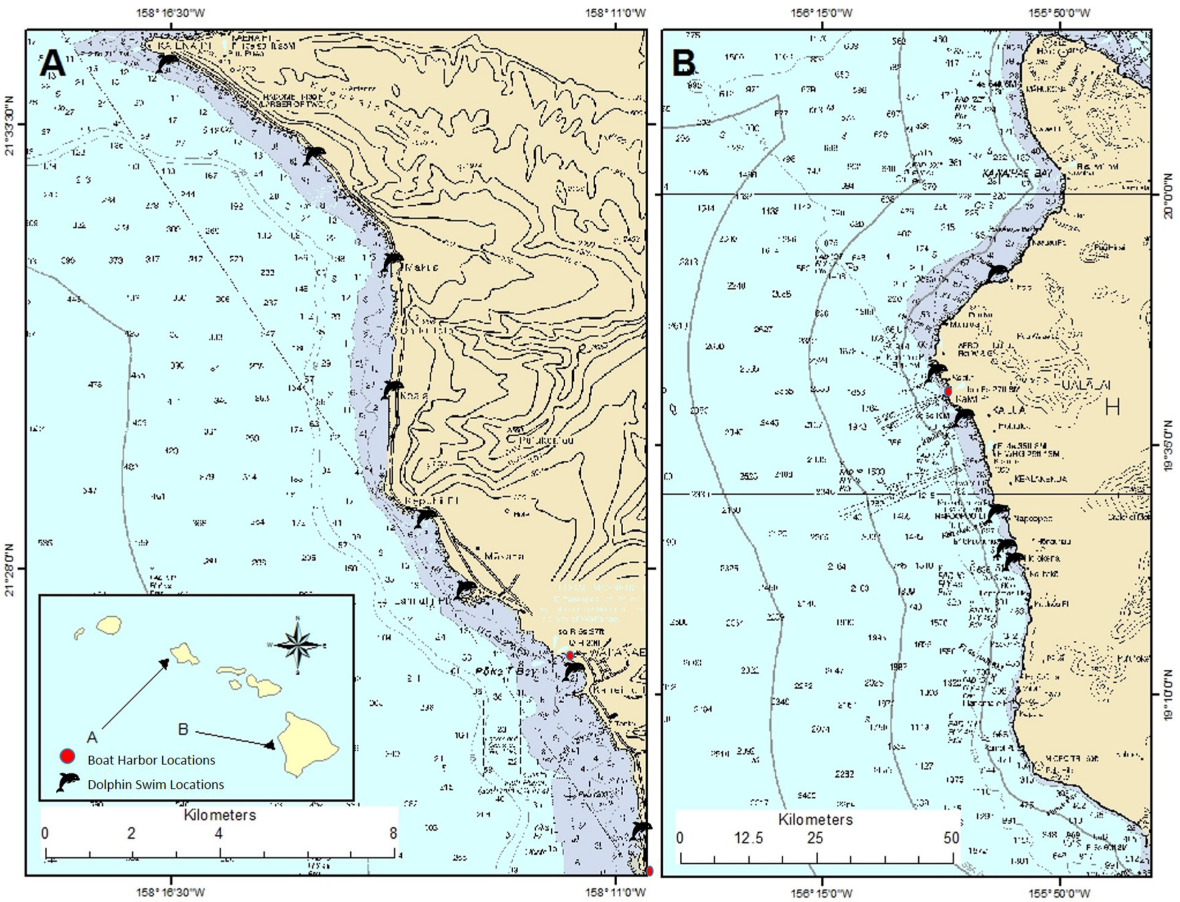

FIGURE 2 | Map of dolphin-swim locations on **(A)** Waianae, O'ahu and **(B)** Kailua-Kona, Hawai'i Island. Base map: NOAA created in ArcGIS (GIS Software).

estimate was selected. The lifetime revenue was calculated by dividing the estimated dolphin tour annual revenue by the estimated dolphin population to get the annual revenue per dolphin (*ER*). Once this was calculated for each island, the discount rate [2.65%] (*r*) plus one was calculated with each year of the average dolphin lifespan (*t*). The *ER* was then divided by this discount rate for each year and then all 26 years were totaled together to get the final *DRL*. This was done separately for each island to account for the differences in annual revenue and dolphin populations. The estimates here reflect dolphin-swim only and are an underestimation of what dolphin's lifetime potential revenue is in present day.

$$DRL = \sum \frac{ER}{(1+r)^t}$$

DRL, spinner dolphin revenue over lifetime; ED, Dolphin-swim tourism annual average revenue per dolphin; r, discount rate; t, life expectancy of average spinner dolphin.

Present value is used to estimate the capitalized value of lifelong revenues per dolphin by discounting future values at a certain rate (Clark, 2006; Clark, 2010; Knowles and Campbell, 2011). For every year that goes by in a dolphin's life, the chance that it is alive continues to decrease. Using a discount rate helps to account for the decreased risk of life expectancy; however, discount rates can vary. Previous marine-based discount rates have ranged from 10% for marine protected areas (Samonte-Tan et al., 2007), 8% for lemon sharks (Clua et al., 2011), 5% for reef sharks (Vianna et al., 2012), and 2.65% for humpback whales and whale sharks (Knowles and Campbell, 2011; Catlin et al., 2013). Lower discount rates place greater emphasis on future value (i.e., 2.65%), whereas the larger end of the scale (i.e., 10%), value present day. There are several rationales for a discount rate, usually based on private or social opportunity cost. Given that the literature shows no decline in dolphin tourism, with potential for growth in the industry, the social discount value of 2.65% was selected to represent the Hawaiian spinner dolphin.

RESULTS

Peak Season Timeline (PST)

A *PST* was calculated for each location to predict the number of annual participants in dolphin tourism; this was also used to determine an estimate of revenues for the wild Hawaiian spinner dolphin tourism industry (see **Tables 1A,B**). An average of 7,300 boat trips per year

TABLE 1A | Wild dolphin-swim industry peak season timeline (*PST*) for Waianae, Oahu.

Month	January	February	March	April	May	June	July	August	September	October	November	December
Period	Peak	Peak	Peak	Peak	Peak	Peak	Peak	Peak	Avg.	Avg.	Avg.	Peak
Avg. trip days/week	7	7	6.82	6.69	6.69	6.85	7	7	5.92	5.92	5.92	7
Avg. weeks/month	4.43	4	4.43	4.29	4.43	4.29	4.43	4.43	4.29	4.43	4.29	4.43
Avg. trip days/month	31.01	28.0	30.21	28.70	29.64	29.39	31.01	31.01	25.40	26.23	25.40	31.01

TABLE 1B | Wild dolphin-swim industry peak season timeline (*PST*) for Kailua-Kona, Hawaii Island.

Month	January	February	March	April	May	June	July	August	September	October	November	December
Period	Peak	Peak	Avg.	Avg.	Avg.	Avg.	Peak	Peak	Slow	Slow	Slow	Avg.
Avg. trip days/week	6.63	6.5	5.11	4.56	4.25	4.25	6.65	6.65	2.86	2.86	3	5.16
Avg. weeks/month	4.43	4	4.43	4.29	4.43	4.29	4.43	4.43	4.29	4.43	4.29	4.43
Avg. trip days/month	29.37	26.0	22.64	19.56	18.83	18.23	29.46	29.46	12.27	12.67	12.87	22.86

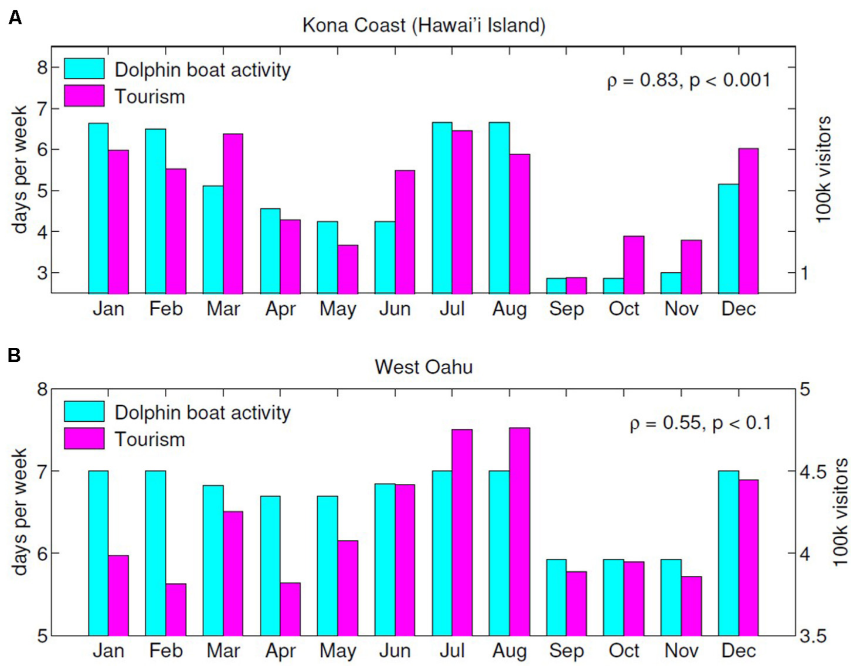

FIGURE 3 | (A) Comparison of HTA visitor numbers and the wild dolphin-swim industry peak season timeline (*PST*) for Waianae, Oahu. **(B)** Comparison of HTA visitor numbers and the wild dolphin-swim industry peak season timeline (*PST*) for Kailua-Kona, Hawaii Island.

was calculated for Waianae, Oahu and 14,235 for Kailua-Kona, Hawaii Island. Two peak periods were established during mid-winter (end of December, end of January to February) and mid-summer (July and August) for Kailua-Kona, while peak numbers were consistently seen in Waianae with the exception of a slowdown in the fall (September and October). The *PST* model was also run using average values for blank interview responses that populated the timeline content. There were no significant differences when the model was run this way.

The *PST* model was also contrasted with the Hawaii Tourism Authority (2013, 2018) visitor numbers for each island to see if the peak trends were consistent (see **Figure 3**). The HTA comparison does not provide absolute confirmation on the model, but rather an estimate of relative numbers based on the best information available.

Utilization Rate Estimates

A total of 77 dolphin tour companies were used in this evaluation, including 54[1] boats across both islands. At the time, this represented all of the dolphin tourism companies on Oahu and Kailua-Kona that were publicly advertising their services and, to the authors' knowledge, accounts for all of the legally registered companies operating out of the targeted harbors. The number of vessels operating in Waianae, Oahu (16 boats) was less when compared to the 38 based in Kailua-Kona, Hawaii; however,

[1] Some companies work from shore.

the vessels on Oahu were much larger, holding on average 27.7 people per trip. The total number of dolphin-tour companies was also smaller on Oahu; 12 companies, compared to the 65 in Kailua-Kona (see **Table 2**).

Primary Revenue

Overall ticket revenues for Waianae, Oahu have increased since 2006, jumping from an average dolphin-swim tour revenue of $111(USD) (Boehle, 2007) to $141.34 (USD) in 2013, and the prices in 2019 remain consistent with those from 2013 (see **Table 3**). Waianae, Oahu remains more expensive then Kailua-Kona. The higher average ticket total combined with the increase in participants resulted in $12,041,283 (USD) more in direct dolphin-swim revenue in Waianae, Oahu. The total estimated direct dolphin tour revenue for both Oahu and Hawaii Island in 2013 was $102,024,953 (USD); this does not include spiritual retreats or companies that offer dolphin-swims as secondary revenue. **Table 3** illustrates the average utilization rate estimates and ticket prices by activity and island, but does not demonstrate the actual ticket price for each company, which was used to calculate individual company revenues. Individual company calculations are not shown, but were used to calculate total annual revenue, average annual revenue, and range in **Table 3**.

Lifetime Revenue per Dolphin

There have been several spinner dolphin population studies conducted in Kailua-Kona (Norris et al., 1994; Östman, 1994); however; the most recent estimates of 524–761 dolphins on the Kailua-Kona coast predicted with 95% confidence by Tyne et al. (2014) will be used in this paper. Unfortunately, the Waianae coast on Oahu has not received the same attention as Kailua-Kona and no official population estimates are available. Based on preliminary studies, abundance estimates for the island of Oahu were estimated at 329 spinner dolphins (National Oceanic Atmospheric Administration [NOAA] - National Marine Fisheries Service [NOAA - NMFS], 2012). These island populations are genetically distinctive and are considered unique stocks (Andrews et al., 2010). **Table 4** provides an overview of the estimated revenue of spinner dolphins over their lifetime.

DISCUSSION

Dolphin swim-tourism is only one segment of Hawaii's multi-faceted ocean tour boat industry, and the spinner dolphins not only play a role in dolphin-swim tourism, but also other areas of the marine tourism industry as well, including snorkel and dive tours, whale watching, and charter fishing. According to the 2017 visitor activity and satisfaction report, 30% of all visitors to Hawaii on average participated in a boat-based marine mammal activity during their vacation; this equates to approximately 2.8 million tourists annually (Hawaii Tourism Authority, 2018).

Several dolphin-swim company owners expressed frustration with other marine tour businesses such as recreational fishing charters and scuba companies which began offering dolphin swims after the market reached "saturation." Concerns regarding dolphin company growth were reflected in the operator interviews. Most respondents felt there were too many boats and swimmers in the water with the dolphins and that the boats in Waianae were too large. There was also concern that the competitive shift among companies had led to boats piggy-backing off other businesses that are good at finding the dolphins and the dissolving of "unspoken regulations" or "gentlemen's agreements" among founding companies. Many of the operators complained of too many new businesses bringing on young or inexperienced captains who did not know the protocols.

TABLE 2 | Commercial dolphin tour and dolphin-swim utilization rate estimates.

Company type	Companies	Boats (*b*)	Daily trips (*t*)	Capacity (*c*)	Participants (utilization estimate)	Swim watch difference *p*-value (99% confidence)
Waianae, Oahu						
Total Tours	12	16	20	364	453,542	
Dolphin Swims	8	11	13	221	174,893	0.005
Dolphin Watch	4	5	7	143	278,649	
Kailua-Kona, Hawaii Island						
Total Tours	65	38	39	862	261,847	
Dolphin Swims	47	31	30	356	38,387	<0.001
Dolphin Watch	6	7	9	506	223,459	
Oahu and Hawaii Island						
Total Tours	77	54	159	1226	715,389	
Dolphin Swims	55	42	43	577	213,280	<0.001
Dolphin Watch	10	12	16	649	502,108	
Other Hawaii Island Dolphin Activities*						
Watch/swim** (secondary)	12	12****	13	203	36,989	
Spiritual retreats***	19	****	35 (annual trips)	192 (annual trips)	384 (annual trips)	N/A

*All costs estimated to the nearest US dollar. *Only calculated for Kailua-Kona, does not seem to occur in Oahu. **PST 127.11 [PST (254.22) divided by two because multi-purpose group]. ***PST 63.56 [PST (254.22) divided by four because multi-purpose group]. Retreats held yearly PST not available and average cost was used. ****Boat ownership for spiritual retreats may differ from other dolphin tour companies such as borrowed/rented boats from other companies. Trips are held at capacity for a set number of people and held between 1 and 4 times per year.*

TABLE 3 | Commercial boat-based dolphin-swim direct revenue estimates by operator categories.

Company type	Utilization rate estimate *x = bt(c)(PST)*	Avg. ticket price	Total annual revenue	Average annual revenue		Range
				Mean	Median	
Waianae, Oahu						
Total Tours (*n* = 12)	453,542	$139	$57,913,886	$5,655,135	$3,951,750	$864,055–$16,442,028
Dolphin Swims (*n* = 8)	174,893	$158	$25,625,994	$3,203,249	$2,446,768	$864,055–$6,509,908
Dolphin Watch (*n* = 4)	278,649	$120	$32,287,892	$8,071,973	$7,922,932	$6,051,854–$16,442,028
Kailua-Kona, Hawaii Island						
Total Tours (*n* = 34)	261,847	$122.34	$44,111,067	$1,154,136	$353,366	$152,532–$9,182,426
Dolphin Swims (*n* = 28)	38,387	$124.67	$13,584,711	$460,011	$313,708	$152,532–$1,586,333
Dolphin Watch (*n* = 6)	223,459	$120	$26,360,326	$4,393,388	$4,514,057	$167,785–$9,182,426
Oahu and Hawaii Island						
Total Tours (*n* = 46)	715,389	$130.67	$102,024,953	$1,882,330	$353,366	$152,532–$16,442,028
Dolphin Swims (*n* = 36)	213,280	$141.34	$39,210,705	$1,069,620	$465,223	$152,532–$6,509,908
Dolphin Watch (*n* = 10)	502,108	$120	$58,648,218	$5,864,822	$4,514,057	$167,785–$16,442,028
Other Hawaii Island Dolphin Activities*						
Watch/swim** (secondary)	36,989	$118	$4,166,030	$347,169	$296,103	$91,519–$1,112,213
Spiritual retreats***	384	$1547	$704,400	$38,051	$20,340	$534–$112,800

*All costs estimated to the nearest US dollar. *Only calculated for Kailua-Kona, does not seem to occur in Oahu. **PST 127.11 [PST (254.22) divided by two because multi-purpose group]. ***PST 63.56 [PST (254.22) divided by four because multi-purpose group]. Retreats held yearly PST not available and average cost was used.*

TABLE 4 | Annual and lifetime revenue estimates for the Hawaiian spinner dolphin.

Dolphin population	Total annual revenue (USD)	Est. dolphin population	Over lifetime – Discount rate (dolphin-swim only)
Waianae, Oahu	$57,913,886	329 (National Oceanic Atmospheric Administration [NOAA] - National Marine Fisheries Service [NOAA - NMFS], 2012)	$3,364,316
Kailua-Kona, Hawaii Island	$44,111,067	524–761 (Tyne et al., 2014)	$1,107,837 – $1,608,882

As demand for the activity grows and new companies become established, more and more pressure is placed on the dolphins, whose population is estimated to be decreasing (Tyne et al., 2014). An economic study was completed on dolphin-swim tourism in Hawaii by Boehle (2007); comparing the results of this study to the observations above, dolphin-swim businesses have grown by 33% on Oahu and 23% on Hawaii Island. Contrasting these results to other marine mammal tourism in Hawaii, dolphin-swim boats could potentially be generating the greatest revenue.

Peak Season Timeline (PST)

The PST established in this research showed only a slightly significant relationship between the model and the tourism numbers for Oahu ($\rho = 0.55$, $p \leq 0.1$); however, this was to be expected given that dolphin tourism remains constant for most of the year. Unlike humpback whales, which are a seasonal marine mammal species in Hawaii (peak season is November through March), Hawaiian spinner dolphins can be found reliably year-round. This demonstrates that the dolphin-swim businesses in Oahu are not influenced significantly by tourism fluctuations. During the slower fall season (September to mid-November), the HTA model also showed fewer visitors to the island. Kailua-Kona, Hawaii Island presented a very different dolphin-swim tourism pattern and this was reflected in the significant relation to the HTA visitor numbers ($\rho = 0.83$, $p \leq 0.001$).

Comparing the HTA numbers from 2013 when this research was completed to 2018 demonstrates consistency and validity of the trends. For Oahu, there was a 16% increase in yearly visitors with similar month to month trends. The only change observed was a slightly larger dip in visitor numbers in August 2018, which was not seen in 2017. Visitor numbers for Kailua-Kona did not increase at the same rate, showing only a 3% increase in 2018 and 4% increase in 2017. Numbers for both years were considered in relation to the volcanic activity on Hawaii Island in 2018 affecting visitor numbers. The trend lines were less consistent for Kailua-Kona, with much less growth. Oahu visitor trends highlight the need for greater attention to the Waianae dolphin populations and swim industry which historically have received less consideration than Kailua-Kona.

As demonstrated above, stark differences between islands exist for revenues generated and the number of dolphin-swim participants. Previous dolphin-swim tourism research in Hawaii have lacked any inter-island comparisons, lumping populations and businesses across the state or only focusing on one area. This is problematic as the research does not properly inform policy makers who are currently exploring implementation of new regulations (Wiener, 2015a). Not only are there dramatic differences in revenue generation, but also in boat numbers, boat sizes, the way dolphin-swim companies conduct their businesses, and even in observed behaviors between dolphin populations. Tour operator expenses such as fuel costs, boat maintenance, slip fees, and employee salaries were not collected in interviews and, therefore, are not deducted from total revenue. Future work should consider adding these costs to get a better estimate of actual revenue.

Utilization Rate Estimates

Using the utilization rate estimation, 174,893 participants in 2013 were found to be going out on the dolphin-swim boats in Waianae annually versus 38,387 in Kailua-Kona. The mean number of participants per company for Waianae is significantly more ($p \leq 0.001$) than the participants per company in Kailua-Kona. The greater number of participants on Oahu is somewhat surprising given the number of boats *(b)* and companies in Kailua-Kona. The smaller capacity on the small boats in Kailua-Kona is the main reason for the discrepancy in dolphin-swim participants. For both islands, 715,389 people are estimated to have participated in boat-based commercial dolphin tours (swim and watch) in 2013. This is 595,389 more than a preliminary estimate that was conducted statewide in 2008 (O'Connor et al., 2009), reflecting greater participation and dolphin tourism growth than previously predicted. There are also significant differences between the mean number of participants going out with dolphin-swim companies and the related dolphin watching tour boats. In both Waianae ($p = 0.005$) and Kailua-Kona ($p \leq 0.001$) the dolphin-watch boats had more participants, again most likely due to boat capacity.

The participant estimates for both islands grossly underestimate the number of people directly engaging with the dolphins and have major implications for dolphin-swim activities. Concerns over the increase in dolphin-swim boats have led federal marine managers to consider banning this activity; however, actual implementation of any regulations has been stalled for more than a decade (Tyne et al., 2018). Dolphin-swim operators and company owners argue that that dolphin-swims bring a lot of revenue into the local communities and that prohibiting people from interacting with the dolphins in the water would diminish their businesses. According to Lück and Porter (2019), dolphin tour participants are primarily interested in being able to get close to the dolphins (88.3%).

This research can give context to federal and state managers who are looking to better understand the growth and varying forms of the dolphin swim industry. The scenario analysis can be used as an accountability exercise prior to further study and regulation aimed at better protection for the dolphins. If in-water dolphin-swims become outlawed, it will be important to outline how lost revenue will be made up and the mechanisms for enforcing new laws in coordination with the commercial operators.

There are many interest groups in both resident and tourist communities that swim with dolphins outside of commercial boat-based tours. Most of the shallow bays where people swim with the dolphins can be accessed from shore as well as by boat, making it easy for people to reach the dolphins. The numbers do not account for private and rented boats that interact with the dolphins, as well as chance encounters. Unfortunately, there has not been a directed count of total human users, something that should be focused on in future study.

Some of the distinctions between Kailua-Kona, Hawaii Island and Waianae, Oahu may lie in the tour boats and company structure. There are fewer boats on Oahu; however, they cater to larger groups of participants and go out at least two times a day. This contrasts with the smaller six-person boats that operate once daily in Kailua-Kona. Many of the Kailua-Kona boats also expand operations to manta ray swims at night. Although these operations cater to a smaller clientele, there are more than double the number of companies, leading to significantly more boats in the water. These boat and company differences will have implications for how the rules affect the tour operators and dolphin-swim participants. Regulations capping boat size or the number of boat permits available could dramatically shift the impact on the dolphins. For example, if permit and boat size limits were put in place, this could drop the swimmer numbers considerably compared to Oahu where fewer large boats operate. If the large boats on Oahu had to decrease their size, this would impact fewer companies, but cause significantly lower capacity for participants.

Primary Revenue

When the 2013 direct annual revenue for both Waianae, Oahu and Kailua-Kona, Hawaii Island was broken down by commercial categories (see **Table 4**), wild dolphin-swim activities made $32,287,892 (USD) less on Oahu and $30,526,356 (USD) less on Hawaii Islands than wild dolphin viewing. There are triple the number of dolphin-swim companies and boats compared to dolphin watching; however, the dolphin watch boats are much larger than most dolphin-swim vessels and can accommodate a greater number of participants. The average dolphin-swim vessel has a capacity of six in Kailua-Kona and 20 in Waianae, whereas the dolphin-watch vessels have an average capacity of 50.

On both Oahu and Hawaii Island, the dolphin-watch companies brought in more direct revenue in 2013 than the dolphin-swim companies. This was extremely surprising given the small number of dolphin-watch boats compared to the dolphin-swim boats; however, the size of the dolphin watch boats was almost triple that of the other companies. This could provide an alternative to the numerous dolphin-swim boats that can only handle a small number. While fewer companies could benefit, more people could still view the dolphins while decreasing the impacts of numerous boats approaching the dolphins all at once.

Other companies that participate in either dolphin watching or swimming, but do not make the activity their primary focus, also brought in an estimated $4,166,030 (USD) in 2013. This is a large amount of revenue that is not accounted for when thinking about dolphin tourism and an underestimation as it only represents companies located on Hawaii Island and does not include private boat rentals. The healing and spiritual retreats that center on the dolphins are not often discussed in Hawaii dolphin tourism literature, yet embody an important group of stakeholders. These businesses are currently centered on Hawaii Island and, as shown above, were estimated to bring in $704,400 (USD) in 2013 in direct annual revenue.

Lifetime Revenue per Dolphin

The dolphin-swims in Hawaii generate a higher revenue than other dolphin-swim island locations such as Bali that have a similar spinner dolphin population with predictable behavior. In

Bali, dolphin-swim tours made US$4.1 million in direct revenue annually (Mustika et al., 2012). The wild dolphin-swim tours in Hawaii not only generate more revenue than dolphin-swims in other locations such as Lovina, Bali (Mustika et al., 2012) and Monkey Mia, Australia (Stoeckl et al., 2005), but are also making more than the local whale watching tourism (Utech, 2000). The data demonstrate a significant growth for the Hawaiian Islands in a short amount of time.

If the Hawaiian dolphin-swim industry reviewed here is compared to research conducted elsewhere (see **Table 5**), the market in Hawaii is among one of the largest generators of revenue annually. Individually, Hawaiian spinner dolphins produce more direct tourism revenue from dolphin-swims over their lifetime ($1,107,837 – $3,364,316) than other species examined, including some populations of humpback whales (Knowles and Campbell, 2011). However, they still are not amongst the top grossing marine animals over their lifetime compared with species such as the Sicklefish lemon shark ($2.64 million) or the reef shark ($2.31 million).

One of the problems that is not often considered with species-specific studies is the likelihood that some dolphins may be worth more than others. For this study, the entire population of dolphins per island was used to calculate lifetime revenue to account for inconsistencies in the number of dolphins in each bay daily. This does create some error as only certain bays have dolphin-swim boats and there may be individual dolphins that frequent bays with swimmers more than others. During operator interviews, there were individual dolphins that were called out by name and were familiar to residents. Certain dolphins may have individual characteristics either innate or learned that cause them to have greater exposure to swimmers. This is an important consideration, as some dolphins could be worth more than others, which also means that the impact to the population may be less if only a few pods are exposed to swimmers on a daily basis. While Tyne et al. (2014) have provided population estimates for the Hawaii Island dolphins, there has been relatively little effort to characterize the Oahu population, or bays outside of the Kailua-Kona coast on Hawaii Island. Without a complete population assessment, it will be hard to give an accurate measure of how many dolphins are involved in dolphin-swim activities.

Another component missing from species-specific analysis is the consideration of non-monetary benefits and costs. For example, this study found the Oahu dolphins to be worth considerably more than the Hawaii Island dolphins, but both have equal non-use values and are vital components of the coastal marine ecosystem. The Hawaiian spinner dolphins are appreciated not only by the commercial sector, but also by many residents and visitors who enjoy the mere presence of these dolphins. Some Native Hawaiians also believe that spinner dolphins are important family members and a living piece of their cultural heritage (Cressey, 2009).

A lack of government resources in Hawaii makes it difficult to adequately manage and enforce regulations pertaining to human interactions with wildlife. The tendency for marine conservation to be viewed as a cost to government budgets prevails in Hawaii, one which produces little return on investment (Catlin et al., 2013). As of this writing, the federal government has still not moved forward on any regulations after more than 10 years of proposed rules, public meetings and promises of action. In 2018, the NOAA Pacific Scientific Review Group

TABLE 5 | Previous marine tourism valuation studies.

Location	Marine tourism	Annual revenue (USD)*	Source
Oahu and Hawaii Is.	Spinner dolphins	$1,200,000	Wiener, 2016
Antarctic	Wildlife	$55,660,800	Catlin et al., 2013
Tonga	Whales	$5,000,000	Orams, 2013
Australia	Turtle	$742,144	Catlin et al., 2013
Caribbean	Sharks	$250,000	Catlin et al., 2013
Maldives	Sharks	$3,300	Catlin et al., 2013
Lovina, Bali	Dolphins	$4,100,000	Mustika et al., 2012
Palau	Sharks	$179,000	Vianna et al., 2012
Maldives	Manta rays	$8,100,000	Anderson et al., 2011
French Polynesia	Lemon sharks	$5,400,000	Clua et al., 2011
Australia	Humpback whales	$2,549,000	Knowles and Campbell, 2011
Western Australia	Whale sharks	$2,226,432 – $ 4,267,328	Catlin et al., 2010
Global	Cetacean	$2,000,000,000	Hoyt, 2001; O'Connor et al., 2009
Western Australia	Whales	$6,029,920 – $10,668,320	Stoeckl et al., 2005
Australia	Dolphin	$8,163,584	Stoeckl et al., 2005
Belize	Whale sharks	$34,906	Graham, 2004
Massachusetts	Whales	$440,000,000	Hoagland and Meeks, 2000
Hawaii	Humpback whales	$19,000,000 – $27,000,000	Utech, 2000
Hawaii	Humpback whales	$3,900,000	Forestell and Kaufman, 1990
BC, Canada	Whales	$3,645,312	Duffus and Dearden, 1990

**Foreign currency was converted to US dollars for comparison purposes using USD conversion rates 08/09/14.*

(PSRG) also recommended that the NOAA National Marine Fisheries Service reconsider plans to manage human interactions with spinner dolphins through restrictions based on time and area management for boaters and swimmers (National Oceanic Atmospheric Administration [NOAA], 2018). This approach provides the ability for enforcement and consistent protection.

The revenue generated through dolphin tourism could easily be used to contribute to better enforcement for the dolphins and community through a user tax or fee added to each boat ticket sold. Other instruments such as exit surveys could help provide better understanding of the participants and better ways for enforcement to address user interactions.

Global Implications

All marine tourism industries – not just dolphin-swims – create conflict due to lack of regulation and general oversight of the ecosystem. The popularity and revenues of these activities increase stress on the species involved, which leads to amplified conflict amongst the operators. Historical mistrust of both state and federal governments has made the implementation of regulations and reporting of revenues and numbers difficult despite the obvious commercial expansion. This baseline scenario analysis illustrates the under-valuation of the industry and can serve as a call for further research into the valuing, monitoring, and regulation of wildlife tourism in Hawaii and around the globe. Many islands and coastal communities with dolphin populations do not take part in dolphin-swim tourism, but have the potential to host such businesses. For example, Guam has a local spinner dolphin population, a dedicated tourism industry, and several dolphin-watching businesses that have contemplated moving toward an in-water swim model. Using the results presented here, other locations may be able to mitigate conflict and stress on local dolphin populations by implementing management from the beginning. As the number of boats offering dolphin-swims grows, a standardized training course for operators might ensure that the proper information is passed on to participants. Lavín et al. (2016) have shown that, by having been provided ecological information, informed tourists are more prone to select visiting options that reduce animal stress and support conservation mechanisms in areas with little enforcement. This will not only help to better integrate the businesses into the community, but also to provide a safer environment for both participants and the dolphins.

CAUSES AND CONSIDERATIONS

This paper does not attempt to provide a calculation of non-use or indirect costs associated with dolphin-swim tourism; while this is an important issue, the empirical data gathered from the operators do not lend for this type of examination. All efforts to ensure rigor were made and the data were assumed to be accurately reported; however, the results should still be considered interpretive.

The revenue estimates provided in this study only used market prices of commercial wild dolphin-swim/watch boats and do not constitute the entire dolphin tourism industry such as personal use stand-up paddleboards, kayaks, and shore swimmers. The number of users and revenue are estimates with the best available information as of 2013. There are new companies surfacing and ones operating illegally or on the side, so these numbers reflect an underestimation. Additionally, other islands (e.g., Maui and Kauai) which have recently reported new dolphin-swim tour companies have not been included. Operator costs were also not accounted for including fuel, equipment, employee wages, etc., an omission that represents a significant limitation to the research. Other considerations not included in this analysis are the impact of increasing boat traffic on the marine environment, use of local man-made and natural resources, and the rising human conflicts between user groups. The data provided represent an approximation of the dolphin-swim industry in Hawaii to give an idea of the participant numbers and revenue generated. Further research should explore the indirect costs and how much money is being funneled back to the communities surrounding dolphin-swim activities. Socioeconomic conditions vary for Hawaiian residents; for example, high poverty rates especially in the Waianae area can exceed 17%, more than 7% higher than the nationwide rate (Impact Assessment Inc., 2007).

CONCLUSION

As a whole, spinner dolphin tourism and marine tourism in Hawaii is severely under-studied and under-valued. This scenario analysis presents a first attempt at an accountability exercise based on a series of assumptions regarding demand of the Hawaiian dolphin tourism industry and its potential impact for the state. A better grasp on the broader economics of dolphin-swim tourism is necessary to gauge both direct and indirect effects which are not accounted for in this study. The estimates generated in this research provide a first and look at the potential revenue generated from an under-regulated and growing industry. The revenue potential identified in this research offers insight into the possible resources that could be made available for conservation and regulation enforcement, while still allowing for economic development. However, as the popularity and revenue growth increase, growing demand will be placed on the spinner dolphin population. Common-pool resources such as dolphins can easily become overly exploited through tourism if not managed appropriately (Heenehan et al., 2015). If growth continues without any additional protection or enforcement serious impacts will be placed on the dolphin population, leading to possible decline of the population or shift of habitat (Tyne et al., 2018; Kassamali-Fox et al., 2020). This would not only be a worst-case scenario for the genetically distinct Hawaiian spinner dolphin population, but would potentially crash the dolphin tourism industry as well, adding to the long list of species that have succumbed to the tragedy of the commons.

The benefit of providing a first analysis and estimate of the direct revenue associated with spinner dolphin-swim tourism is that it can offer resource managers a starting point for an assessment of a previously under-estimated component of the marine tourism industry in Hawaii. Resource managers should be working closely with the dolphin tourism stakeholders to better understand how conservation and regulation can be worked into local business models. There are large groups of stakeholders both commercially and in the community that interact with the spinner dolphins on a daily basis. They too could be collecting data on dolphin encounters to enhance the knowledge base and monitoring of the growing number of boats and people interacting with the dolphins in the water. Further understanding of the current practices and companies guiding dolphin tours is critical when reviewing and developing new laws and management of the dolphin-swim bays.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Office of Research Ethics at York University. Written informed consent to participate in this study was provided by the participants or their legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

CW conceptualized the idea for research, implemented the research, and wrote the manuscript. Co-authors provided the valuable input during research and in the drafting of the manuscript. All the authors contributed to the article and approved the submitted version.

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Whale Watching in the Pelagos Sanctuary: Status and Quality Assessment

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In 2001 Italy, France, and Principality of Monaco instituted a protected area for marine mammals in northwestern Mediterranean Sea, named the *Pelagos* Sanctuary. The agreement foresees the commitment by signing parties to manage human activities in the area, with a special mention to whale watching. Whale watching is a form of wildlife tourism which has considerably grown in the last decades. Understanding the profile of whale watchers and their satisfaction toward the activity, is the first step toward a sustainable and effective management of this touristic activity. In this work we provide the first analysis of the whale watching activity in the *Pelagos* Sanctuary, focusing on commercial whale watching tours departing from Italian harbors in Liguria. We provide a census of the activity and the results of close-ended questionnaires filled by whale watchers during trips in summer 2016 and 2017. The aim of the questionnaires was to understand the level of awareness of experienced and new whale watchers regarding the *Pelagos* Sanctuary and some conservation initiative going on in the area. Finally, we analyzed the satisfaction level, with the aim of evidencing weakness and strengths of the service offered. Our results evidence a growth in the activity in the last 15 years, with a wider differentiation of offers and impacting a larger area than previously found. Whale watchers in the area come from a variety of countries, demonstrating the importance of the Pelagos as a hot spot for this activity. A high level of satisfaction has been evidenced, with no difference among new and experienced whale watchers. At the same time, more effort is needed to increase awareness of Pelagos and its conservation initiative both at a national and international level. This study provides useful information for the start of an effective management of whale watching in this protected area.

Keywords: whale-watching, pelagos sanctuary, satisfaction analysis, cetaceans, tourism

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INTRODUCTION

Since the late 1990s, when whale-watching started in California, the whale watching industry has grown considerably worldwide (Hoyt and Parsons, 2012). From its expansion, whale watching has been reported to bring considerable economic benefits (Cisneros-Montemayor et al., 2010; Parsons and Brown, 2017). Whale-watching can also positively influence cetacean conservation (e.g., Jacobs and Harms, 2014), considering that it has replaced whaling in some countries (Cunningham et al., 2012; Vieira et al., 2018), and is considered to be an essential part of cetacean research

(Hauser et al., 2006; Higby et al., 2012; Tepsich et al., 2014; Alves et al., 2018; García et al., 2018). Together with the increase of whale watching popularity and the consequent proliferation of vessels and tours, the interest in understanding and measuring its impacts has grown (Parsons, 2012). The impact of whale watching is measured either by considering the potential negative impact on the exploited cetacean population, or by considering the positive impact on the tourism sector and, when sustainable managed, by considering the positive impact on the species in term of conservation (Sitar et al., 2017). Potential negative impacts of whale watching activities have been reported to be derived from disturbance reasons, with consequent stress index increases and behavioral changes (Magalhaes et al., 1999; Erbe, 2002; Lusseau, 2006; Richter et al., 2006; Visser et al., 2011; Parsons, 2012; New et al., 2015). At the same time, it has been demonstrated that whale-watching can be an effective tool to raise awareness about species conservation issues and to educate tourists on cetaceans' ecology and threats, especially when the tourist experience is enriched by good environmental education (Lien, 2001; Lück, 2003; Stamation et al., 2007; Wearing et al., 2014; García-Cegarra and Pacheco, 2017; La Manna et al., 2020).

The *Pelagos* Sanctuary (hereafter Pelagos) was established in 2001 in the northwestern Mediterranean sea (Notarbartolo-di-Sciara et al., 2008). Pelagos covers around 87,500 sq. km and it is subjected to an agreement between Italy, Monaco, and France for protection purposes of several species of cetaceans that inhabit the area. The *Pelagos* Sanctuary is characterized by the presence of various marine mammal species, being the habitat suitable to sustain their breeding and feeding needs. The species mostly found in the area are common bottlenose dolphins *Tursiops truncatus*, striped dolphins *Stenella coeruleoalba*, Risso's dolphins *Grampus griseus*, short-beaked common dolphins *Delphinus delphis*, sperm whales *Physeter macrocephalus*, fin whales *Balaenoptera physalus*, Cuvier's beaked whales *Ziphius cavirostris*, and long-finned pilot whales *Globicephala melas* (Notarbartolo-di-Sciara et al., 2008). Three different types of whale watching activities are known to occur in the area: true commercial activities (COM), characterized by daily trips of 4–8 h; Cetacean ecotourism (ECO), characterized by cruises lasting from weekends to weeks; and Research whale watching (RES), where eco-tourists are involved in research activities for funding reasons (Fortuna et al., 2004; Parsons et al., 2006). ECO and RES activities, organized and managed mainly by associations and NGOs involved in cetacean research and conservation, usually target a specialized type of public, where tourists are willing to spend several days aboard for training reasons, developing skills useful for cetacean research. On the other hand, COM whale watching targets more general tourists, attracted to tours by pure leisure reasons.

Despite the fact that the *Pelagos* agreement foresees a commitment by signing parties to manage whale watching activities in the Sanctuary (Art. 8), no official census or regimentation of whale-watching activities has been implemented so far by the signing countries. Two management actions regarding whale watching activity have been implemented by the *Pelagos* Secretariat and further enforced by the ACCOBAMS secretariat as well: The High Quality Whale Watching Label (HQWW®) (Ratel et al., 2016) and the Code of Good Conduct for whale watching in the Mediterranean Sea (ACCOBAMS, 2016). The HQWW® label is a quality certification that whale watching operators can request. The accreditation is on a voluntary basis and the process foresee several steps: crew members (biologists, captain, and mariners) must undertake a training program and at least one member of the crew who successfully attended the training must be onboard during the excursion; the operator must commit to conduct educational/awareness activities during the trips, to contribute to research by sharing sighting data and especially to comply with the Code of Good Conduct to approach cetaceans. Furthermore, some activities are identified as not compliant with the HQWW® certification, such as swimming with cetaceans; using airborne detection systems to locate cetaceans (e.g., planes or drones); combining any form of fishing with cetacean watching and feeding cetaceans. The Code of Good Conduct defines two areas when approaching cetaceans: the area of vigilance and the forbidden area. Particularly, the forbidden area, in which no boat is allowed to enter, includes the front, the back and a 100 m area around the animal; the vigilance area, in which the boat can enter at a reduced speed of five knots, is a 300 m sector around the animal (still excluding the front and the back). Considering the disturbance that a boat can cause also in the vigilance areas, maneuverings, number of boats, and other specific indications are also foreseen by the Code. In this work we aim to draw an updated picture of the status and quality of whale watching activities in the *Pelagos* Sanctuary area (**Figure 1**), specifically targeting Italian COM operators. First, a general census of whale watching operators along the Italian coasts of the *Pelagos* Sanctuary is provided. This census, together with available information from the French part of the sanctuary (Mayol et al., 2014), allowed us to build a comprehensive assessment of the status and development of the whale watching activity in this protected area. Then, a specific study on participants to COM whale watching tours in the central part of the Sanctuary (departing harbors located in Liguria-Italy) was carried out, with the support of the whale watching operating in the area. This study focused on:

1. Defining the profile of customers taking part in the whale watching activity in Pelagos, as no study has ever been conducted on whale watchers in the area;
2. Evaluating the customers' awareness about the existence of the *Pelagos* Sanctuary and the whale watching management activities associated with it (HQWW® and Code of Good Conduct), and test whether this depends on the experience and age, education level or origin of the whale-watching customers;
3. Analyzing the motivations and satisfaction of the whale-watching customers, in order to assess the success of this industry in the *Pelagos* Sanctuary and its value as a conservation/awareness activity;
4. Analyzing the factors mainly contributing to satisfaction, in order to evidence weaknesses and strengths of the service that could help in better addressing its further sustainable development.

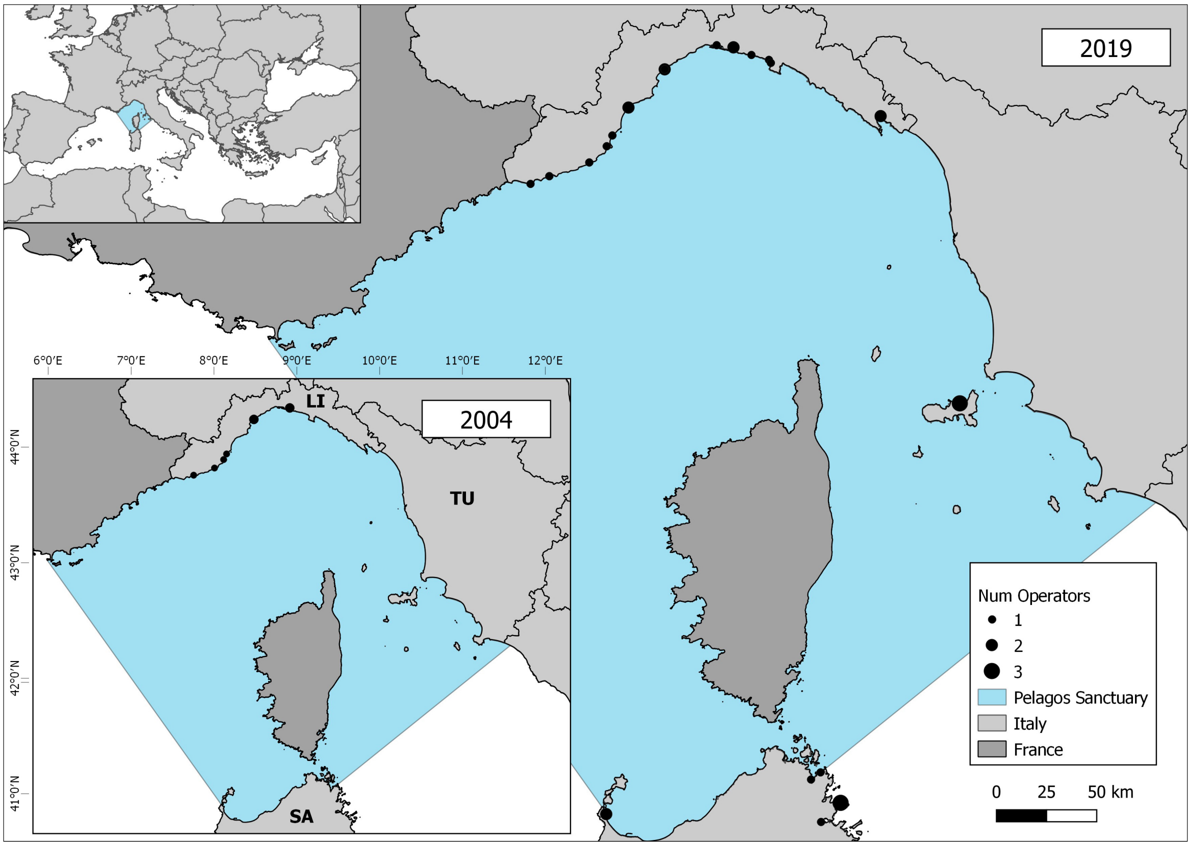

FIGURE 1 | Map of departing harbors of COM whale watching operating in the *Pelagos* Sanctuary, in 2004 and in 2019. Italian regions overlooking the *Pelagos* Sanctuary are Liguria (LI), Tuscany (TU), and Sardinia (SA).

MATERIALS AND METHODS

We started from the census by Fortuna et al. (2004), where three different categories of whale watching have been highlighted: true commercial (COM), Cetacean ECO, and RES (see Fortuna et al., 2004 for details on definition). A detailed survey based on the material available on the internet and on social networks, both in English and in Italian, has been conducted to identify the current state and amount of Italian Whale Watching operators in 2019. Data were then refined with information available through the research group involved with the application of HQWW® Certification in Italy. For this study we considered only operators organizing surveys in the *Pelagos* Sanctuary area or adjacent waters (within 25 km distance from borders of *Pelagos*). Information on all type of operators has been collected, but for the analysis we focused only on COM operators.

A closed-ended questionnaire was developed based on a literature review, and using the study of Bentz et al. (2016) as a benchmark. The questionnaire was then evaluated by three different researchers and finally it was validated by the crews of the whale watching companies (captains, mariners and biologists on board) to ensure avoiding confusing questions. The questionnaire was distributed during July–August 2016 and 2017 (covering the main touristic season) on board of whale watching vessels from two COM operators in Liguria (Italy). The involved operators were chosen as their activity is representative of the True Commercial whale watching definition: trip duration is about 4–6 h, organized weekly (up to 7 days a week in highest season), on board of big motorboats specifically aimed at encountering cetaceans (Parsons et al., 2006).

In order to enhance tourist involvement, the biologist on board presented to tourists both the researcher and the aim of the research, while the researcher was also available for questions and helping with the filling of the questionnaires. Questionnaires were conceived in order to provide information on socio-economic characteristics of whale-watchers, their motivation and expertise, their knowledge about the *Pelagos* Sanctuary and conservation actions carried out in the area and their expectation and satisfaction regarding the trip (Annex). Questionnaires were provided in Italian and English and distributed by the researchers onboard to participants who agreed to contribute to this study, at the end of the trip, during the way back to the harbor.

In order to evaluate the effect of experience, age, education level and origin of the participants' knowledge about the *Pelagos* Sanctuary and conservation measures related to whale watching

(HQWW®, Code of Good Conduct), whale watchers where divided first into 2 groups: *Experienced*, encompassing all whale watchers having already participated in at least one whale watching trip, and *New*, encompassing all customers in their first experience with whale watching. Secondly, each group was divided into subgroups, based on their age, education level or origin. Specifically, concerning the origin two subgroups were identified: *Pelagos,* coming from one of the regions overlooking Pelagos Sanctuary (Tuscany, Liguria, Sardinia, France or Principality of Monaco) and *ExtraPelagos*, not being from one of the regions overlooking the Pelagos Sanctuary. Chi-square tests were performed to explore differences among groups and subgroups. In case of significant difference between age and educational level subgroups, *post hoc* pairwise chi-square tests were applied in order to define which subgroups are significantly different from each other.

Tourists' satisfaction was examined in two different ways. First, a performance-only perspective was applied: participants were asked to rate their level of satisfaction regarding the excursion on a 10-point scale (1 = very unsatisfied; 10 = very satisfied). The Level of satisfaction was determined according to two different scale: Pearce (2006) and Hanan and Karp (1991). The Pearce scale considers the mean value obtained, indicating high satisfaction for mean scores greater than 7.8, moderate if between 7.1 and 7.8, and low if the mean score is smaller than 7.1. The Hanan and Karp scale, on the other hand, considers the percentage of the scores between 8 and 10 (values included). A high satisfaction level is indicated by 85–90% of scores between 8 and 10, a medium level when 70–80% of responses are 8, 9, or 10, while if less than 60% of customers rated the satisfaction between 8 and 10, the satisfaction level is considered low. Kurskall-Wallis test was used to inspect differences among the two groups (*Experienced* vs. *New*) and subgroups.

Several factors where then considered, grouped into three categories, distinguishing Trip related features (*"See at least one cetacean," "See several cetacean species," "See a fin whale or sperm whale," "See animals close to the boat," "See several marine species," "Absence of crowding by other boats during sightings"*), Conservation/Awareness related (*"See animals in a respectful manner," "Commitment to the environment by the operator," "Information on marine species provided on board," "Environmental education onboard," "Information on Pelagos Sanctuary provided on board," "Collaboration with scientific research"*) or Service related (*"Professionalism of the crew on board," "Good weather conditions," "Crowding on board," "Good photo opportunities," "Cost of the trip," "Boat type"*). For each factor, expectations and satisfaction were measured on a five-point Likert scales (between 1 = not at all important/very unsatisfied and 5 = very important/very satisfied). Spearman's correlation was then used to identify the category that most contributed to satisfaction, separately for the two groups of whale watchers, as well as to test the contribution of each factor separately.

Secondly, an Importance-Performance analysis (IPA) that compares expectations with satisfaction was performed. This technique was chosen considering its ability to highlighting strengths and weakness of the activity, thus potentially suggesting improvements (Bentz et al., 2016). A gap analysis of satisfaction median scores (S) and importance median scores (I) was performed both considering features grouped in the three categories both for each parameter, separately for the two considered groups of whale watchers.

The gap G, where

$$G = I - S$$

was then used to highlight category and features meeting or exceeding tourists' expectations ($G \leq 0$) or evidencing the need for improvement ($G > 0$).

RESULTS

Whale Watching Operators in the Italian Part of the Pelagos Sanctuary

Seventeen COM, four RES and eight ECO, for a total of 29 whale watching operators were found operating along the Italian coasts of the *Pelagos* Sanctuary and adjacent areas (see **Supplementary Material**).

Looking specifically at COM operators, while they were initially concentrated in the western coast of Liguria (**Figure 1**), nowadays, departing harbors are located along the eastern Ligurian coast, as well as in Tuscany and Sardinia. Generally, it is possible to identify two different types of offer: pre-planned surveys based on a fixed calendar (from 1 to 7 days a week), on big motorboats hosting 200–350 persons on board, or a "on request," where trips are organized only if a certain number of participants made a booking. These are generally organized onboard smaller motorboats, sailing boats, catamaran, or RHIBs.

The main operation period is summertime (June–September); an extension in spring and autumn is foreseen but only for few operators.

Sixty five percent of COM operators have a biologist or a specialized guide on board; 24% declare to be actively collaborating with research institutions.

Eleven out of 17 COM operators have received a whale watching quality certification (eight the HQWW® and three another international certification). All the certified COM operators follow a code of good conduct for approaching cetaceans at sea (as foreseen by the certification), while for operators not certified, no evidence of any code of conduct is present on their web sites.

Pelagos Whale-Watchers Profile

In total, 915 questionnaires were distributed to whale watchers on board two Italian COM operators in Liguria, during 85 different trips during summer 2016 and 2017. A high response rate was recorded, with 98% of the questionnaires filled at least partially, while 15 were left blank and consequently discarded from the study. As not all questionnaires were filled completely, results for each question will be presented as a proportion relative to the number of questionnaires in which the question was filled, indicating the total number of questionnaires in which the question was filled in brackets. The number in brackets then refers to the real sample size to which percentage should be referred to.

Sixty one percent of questionnaires were filled by females (n = 837 questionnaires); considering age, whale-watchers were mainly adults, within the age group 36–45 and 46–55, with 29 and 24%, respectively, followed by youngsters, within age groups < 25 and 26–35 recording 19 and 17%, respectively, and finally elderly (n = 711). Almost half questionnaires were filled by someone with a university education level (49%) or high school level (38%), while only 8 and 3%, respectively, were from secondary or elementary school level (n = 848).

More than half of the participants in the trips were families with kids (53%), 28% where couples and 13 % were group of friends. The remaining 6% was composed by single or organized groups (n = 882).

Concerning the whale-watchers' origin, 80% of questionnaires were filled by not-local tourists (not coming from the Liguria region), coming from 21 different countries (n = 893). The majority of tourists were spending long holidays in the Liguria region, with 34% declaring to stay from 8 to 15 days and 21% up to a month. Fourteen percent declared to have traveled to Liguria only for the whale watching excursion and consequently to spend only 1 day in the region, while the rest was staying for short term holidays (1 week maximum).

Eighty nine percent of whale watchers declared to be passionate about naturalistic excursion (n = 880) and 73% to be passionate about cetaceans (n = 868). Despite this, 71% were participating in a whale watching trip for the first time and were then considered as *New*. Among *Experienced* whale watchers, 42% already participated in a whale watching trip with the same operator at the time of the questionnaire.

Twenty three percent of the customers came from regions overlooking the *Pelagos* Sanctuary (Tuscany, Liguria, Sardinia, France, or Principality of Monaco). The percentage changes among *Experienced* or *New*, with 28% of *Experienced* whale watchers being from a region overlooking the *Pelagos* Sanctuary, and 21% of New being from Pelagos (**Figure 2**).

Pelagos Sanctuary, HQWW®, and Code of Good Conduct Awareness

Among all the participants, half of the customers stated that they were aware of the existence of the *Pelagos* Sanctuary (n = 881). *Experienced* whale watchers are more likely to be aware of the *Pelagos* Sanctuary existence (67% declaring to know about it), while this percentage is lower (44%) for *New* [$\chi^2_{\text{Pearson}}(1) = 37.77$, $p < 0.001$, $n = 839$] (**Table 1**). Looking at their origin, *Experienced_Pelagos* are more aware than *Experienced_ExtraPelagos* [$\chi^2_{\text{Pearson}}(1) = 10.41$, $p = 0.001$, $n = 244$]. Similarly for the *New* group, origin plays a significant role in the awareness about the existence of the Pelagos Sacntuary [$\chi^2_{\text{Pearson}}(1) = 28.34$, $p < 0.001$, $n = 591$] (**Table 2A**). Concerning age class, no difference was found amongst *New* (**Table 2B**), while an higher percentage of elderly ($>$ 55 years old) and youngers ($<$ 25 and 26–35 years old) were recorded amongst *Experienced* [$\chi^2_{\text{Pearson}}(4) = 16.16$, $p = 0.003$, $n = 209$]. Specifically, the elderly age class differed significatively from other classes (all *post hoc* tests elderly age class vs. other age classes: $p < 0.05$). No statistical difference was found comparing education level (**Table 2C**).

Concerning the code of conduct, 30% of whale watchers knew about the existence of a code of good conduct to approach cetaceans (n = 872), with a higher percentage in *Experienced* than in *New* [44 and 25%, respectively, $\chi^2_{\text{Pearson}}(1) = 31.30$, $p < 0.001$, $n = 832$] (**Table 1**). Nor origin, age or education level had an influence for both *Experienced* and *New* whale watchers (**Tables 2A–C**).

Regarding the HQWW® label, only 9% of the respondents were aware of the existence of this label (n = 875). Awareness of the label is higher in *Experienced* whale watchers [14 vs. 7% for *Experienced* and *New,* respectively, $\chi^2_{\text{Pearson}}(1) = 9.81$, $p = 0.002$, $n = 830$]. Origin has no role for *Experienced*, but a higher proportion of *New_Pelagos* is aware of its existence, compared to *New_ExtraPelagos* [$\chi^2_{\text{Pearson}}(1) = 4.60$, $p = 0.032$, $n = 585$] (**Table 2A**). No statistical difference was found among age classes for both groups, while regarding the education level, among *Experienced*, an higher percentage of whale watchers with primary or secondary education level were more aware of the existence of the label [$\chi^2_{\text{Pearson}}(3) = 9.61$, $p = 0.022$, $n = 230$]. *Post hoc* test nevertheless did not confirm a statistical significant difference among the four subgroups (all *post hoc* tests: $p > 0.05$).

Fifty nine percent of whale watchers declared that the presence of the label would affect the choice of a whale watching operator (n = 830), but no statistical difference was found among the two groups (**Table 1**) nor among the subgroups based on origin or age class (**Tables 2A,B**). Education level plays an important role among both groups, with significantly higher proportion of whale watchers with higher education level declaring being influenced by a quality label in the choice of an operator [$\chi^2_{\text{Pearson}}(3) = 13.14$, $p = 0.004$, $n = 220$ and $\chi^2_{\text{Pearson}}(3) = 12.95$, $p = 0.005$, $n = 527$ for *Experienced* and *New*, respectively] (**Table 2C**). This difference was also confirmed by the *post hoc* test for *Experienced* (*post hoc* test university education level vs. high school level: $p < 0.05$) but not for *New* whale watchers.

Satisfaction Analysis (Performance Only Approach)

Satisfaction was measured with a mean score of 8.24 and 77.2% of answers between 8 and 10 (n = 882). No differences were found among *Experienced* or *New* whale watchers (Kruskal-Wallis $\chi^2 = 3.05$, $p = 0.08$). Based on both scales, the overall satisfaction score for both *New* and *Experienced* whale watchers can be classified as medium-high (Hanan and Karp, 1991; Pearce, 2006; **Table 3**). Within each group, no statistical difference was found regarding age classes or education level (For *Experienced*: Kruskal-Wallis $\chi^2 = 4.771$, df = 4, p-value = 0.3116 and Kruskal-Wallis $\chi^2 = 1.5197$, df = 3, p-value = 0.6777 for age and education, respectively, for *New* Kruskal-Wallis $\chi^2 = 2.7814$, df = 4, p-value = 0.595 and Kruskal-Wallis $\chi^2 = 1.1356$, df = 3, p-value = 0.7685, for age and education).

All tested factors resulted as significantly ($p < 0.05$) and positively correlated to satisfaction, apart from "*Absence of crowding by other boats during sightings*." For both *Experienced*

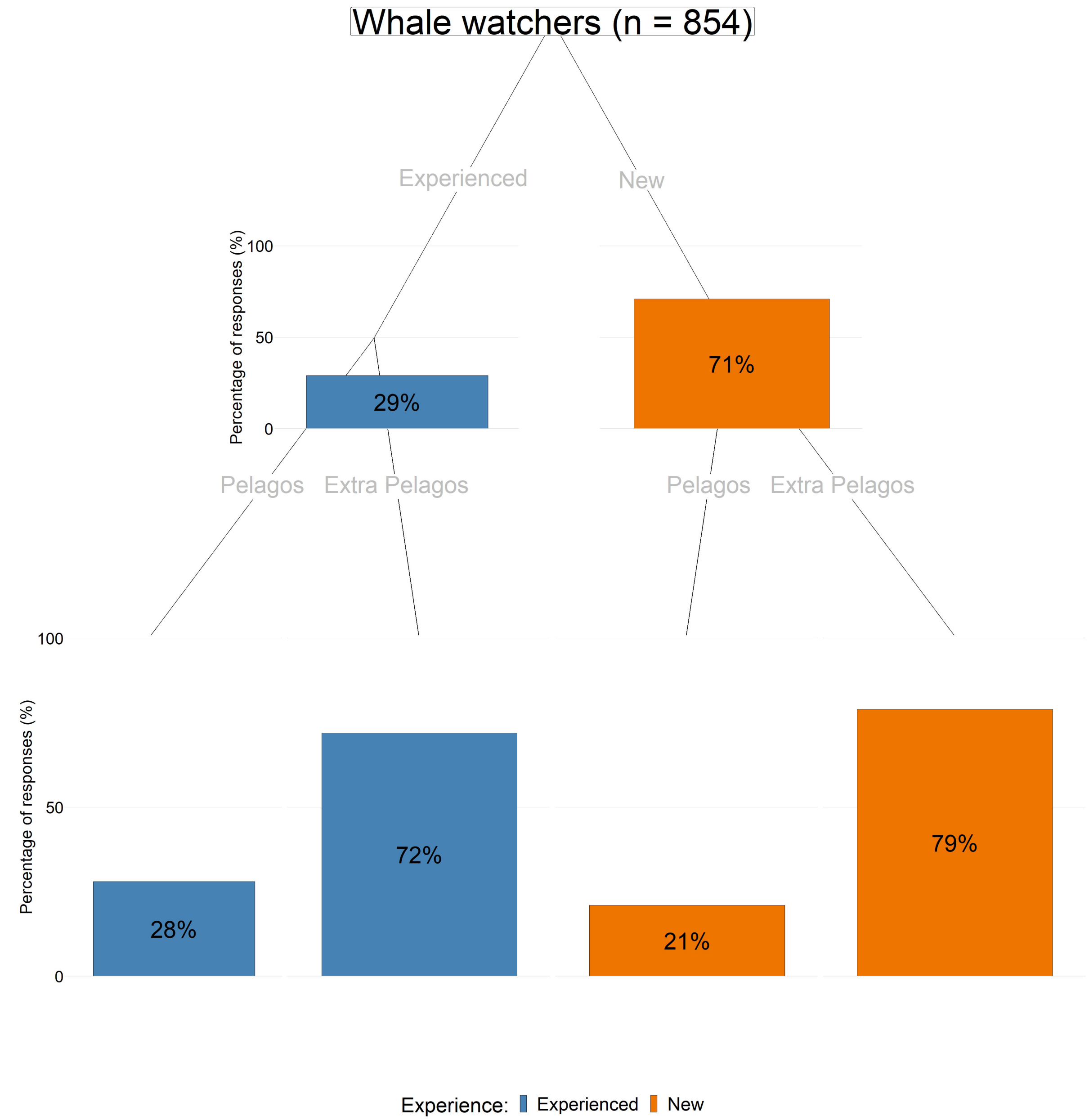

FIGURE 2 | Percentages of *Experienced* and *New* whale watchers, overall **(upper graph)** and considering the origin **(lower graph)**.

TABLE 1 | Awareness of the existence of Pelagos Sanctuary, Code of Good conduct for approaching cetaceans, HQWW®, and influence of the presence of a label in the choice of operator, for Experienced (blue) and New (orange) whale watchers.

	% of positive responses		Chi-square results			
	Experienced	**New**	χ^2_{Pearson}	**df**	***p***	***n***
Awareness of *Pelagos* sanctuary	67	44	37.76	1	< 0.001*	839
Awareness of code of conduct	44	25	31.30	1	< 0.001*	832
Awareness of HQWW	14	7	9.81	1	0.002*	830
Influence of a quality certification	60	58	0.30	1	0.585	788

*Chi-square results are also reported as well as the overall number of responses received (n). Statistically significative values (p < 0.05) are evidenced by *.*

TABLE 2 | Awareness of the existence of Pelagos Sanctuary, Code of Good conduct for approaching cetaceans, HQWW® and influence of the presence of a label in the choice of operator, separately for *Experienced* (blue) and *New* (orange) and for the sub-groups considering origin (A), age class (B), and education level (C).

(A)

Experienced whale watchers	% of positive responses		Chi-square results			
	Extra Pelagos	Pelagos	χ^2 Pearson	df	*p*	*n*
Awareness of *Pelagos* sanctuary	61	83	10.41	1	0.001*	244
Awareness of code of conduct	42	51	1.94	1	0.163	243
Awareness of HQWW	12	18	1.25	1	0.263	241
Influence of a quality certification	60	58	0.11	1	0.737	230
New whale watchers	**% of positive responses**		**Chi-square results**			
	Extra Pelagos	**Pelagos**	χ^2 **Pearson**	**df**	***p***	***n***
Awareness of *Pelagos* Sanctuary	38	65	28.34	1	< 0.001*	591
Awareness of code of conduct	24	27	0.29	1	0.593	585
Awareness of HQWW	6	11	4.60	1	0.032*	585
Influence of a quality certification	59	50	2.94	1	0.086	555

(B)

Experienced whale watchers	% of positive responses					Chi-square results			
	< 25	26–35	36–45	46–55	> 55	χ^2 Pearson	df	*p*	*n*
Awareness of *Pelagos* Sanctuary	62	71	59	59	97	16.16	4	0.003*	209
Awareness of code of conduct	39	32	43	45	58	4.57	4	0.334	207
Awareness of HQWW	16	13	14	12	14	0.28	4	0.991	207
Influence of a quality certification	48	57	62	74	58	6.13	4	0.189	196
New whale watchers	**% of positive responses**					**Chi-square results**			
	< 25	**26–35**	**36–45**	**46–55**	**> 55**	χ^2 **Pearson**	**df**	***p***	***n***
Awareness of *Pelagos* sanctuary	44	41	39	50	58	6.63	4	0.157	458
Awareness of code of conduct	25	22	20	29	30	3.66	4	0.454	453
Awareness of HQWW	9	6	7	6	2	2.66	4	0.616	456
Influence of a quality certification	53	57	59	62	46	3.64	4	0.457	436

(C)

Experienced whale watchers	% of positive responses				Chi-square results			
	Elementary school	Secondary school	High school	University	χ^2 Pearson	df	*p*	*n*
Awareness of *Pelagos* Sanctuary	75	67	67	67	0.22	3	0.975	234
Awareness of code of conduct	62	53	42	43	1.84	3	0.606	232
Awareness of HQWW	38	36	12	12	9.61	3	0.022*	230
Influence of a quality certification	25	50	49	69	13.14	3	0.004*	220
New whale watchers	**% of positive responses**				**Chi-square results**			
	Elementary school	**Secondary school**	**High school**	**University**	χ^2 **Pearson**	**df**	***p***	***n***
Awareness of *Pelagos* sanctuary	65	39	45	44	4.55	3	0.208	560
Awareness of code of conduct	36	31	28	21	6.01	3	0.111	554
Awareness of HQWW	9	8	9	4	4.74	3	0.192	554
Influence of a quality certification	32	45	54	63	12.95	3	0.005*	527

*For each tested parameter, percentage of positive responses is reported, separately for groups and sub-groups. Chi-square results are also reported as well as the overall number of responses received (n). Statistically significative values ($p < 0.05$) are evidenced by *.*

TABLE 3 | Overall satisfaction level of whale watchers and separately for the two groups.

Whale watchers	Pearce		HANAN-KRAP	
	Mean	**Class**	**%**	**Class**
Total	8.24	High	77.2	Medium
Experienced	8.34	High	77.5	Medium
New	8.22	High	78.1	Medium

and *New* whale-watchers, Trip Features had a major role in influencing final satisfaction. Least important category was Conservation/Awareness Features for *Experienced* and Service Features for *New* (**Table 4**). Looking at single factors within each category, the top two factors by importance among Trip features where "*See several cetacean species*" (ρ = 0.55 and ρ = 0.46 for *Experienced* and *New,* respectively) and "*See a fin whale or a sperm whale*" (ρ = 0.53 and ρ = 0.41, respectively) (**Table 4**). Strong difference among the two considered groups are found for the category Conservation/Awareness, as for *Experienced* whale watchers satisfaction toward "*Commitment to the environment by the operator*" had the stronger correlation with overall satisfaction (ρ = 0.42), followed by "*Collaboration with scientific research*" (ρ = 0.33), whereas "*See animals in a respectful manner*" was the least correlated factor (ρ = 0.27). For *New* whale watchers on the contrary this factor was among the two most correlated with satisfaction (ρ = 0.32), while "Information on Pelagos Sanctuary provided on board" was the least correlated (ρ = 0.24) (**Table 4**). Concerning Service features, for Experienced the more correlated were "Professionalism for the crew on board" (ρ = 0.40) and "Good photo opportunities" (ρ = 0.38), while "Boat type was the most correlated for New (ρ = 0.35). Good weather condition was the less correlated feature for both groups (ρ = 0.28 and ρ = 0.16 for *Experienced* and *New,* respectively)."

Figure 3 shows the importance of Trip (**Figures 3A,B**), Conservation/Awareness (**Figures 3C,D**) and Service (**Figures 3E,F**) related features based on the percentage of *Experienced* and *New* whale watchers that scored a feature as "important" (four in five-point Likert scale) or "very important" (five in five-point Likert scale). The highest expectations for the three categories were *"See at least one cetacean,"* "*See animals in respectful manner,"* and "*Professionalism of the crew on board,"* for both *Experienced* and *New* whale watchers.

Figure 4 illustrates the satisfaction for Trip (**Figures 4A,B**), Conservation/Awareness (**Figures 4C,D**), and Service (**Figures 4E,F**) related features based on the percentage of *Experienced* and *New* whale watchers that scored a feature as "satisfied" (four in five-point Likert scale) or "very satisfied" (five in five-point Likert scale). For both *New* and *Experienced* whale watchers the most satisfying features where "*See at least one cetacean*" and "*See animals in respectful manner,"* for the Trip and

TABLE 4 | Factors affecting satisfaction, separately for the two groups.

Experienced whale watchers		New whale watchers	
Factors satisfaction with	**Rhoρ**	**Factors satisfaction with**	**RHOρ**
Trip features	**0.41170**	**Trip features**	**0.32751**
See several cetacean species	0.54906	See several cetacean species	0.46575
See a fin whale or sperm whale	0.53496	See a fin whale or sperm whale	0.40951
See animals close to the boat	0.48815	See at least one cetacean	0.38740
See at least one cetacean	0.43866	See several marine species, even not cetaceans	0.38113
See several marine species, even not cetaceans	0.39384	See animals close to the boat	0.32968
Absence of crowding by other boats during sightings	0.13789	Absence of crowding by other boats during sightings	0.07767
Conservation/awareness features	**0.30959**	**Conservation/awareness features**	**0.30389**
Commitment to the environment by the operator	0.42577	Collaboration with scientific research	0.34569
Collaboration with scientific research	0.33168	See animals in respectful manner	0.32339
Environmental education on board	0.32128	Commitment to the environment by the operator	0.32336
Information of marine species provided on board	0.27682	Environmental education on board	0.32295
Information on *Pelagos* sanctuary provided on board	0.27337	Information of marine species provided on board	0.31858
See animals in respectful manner	0.26907	Information on *Pelagos* sanctuary provided on board	0.24348
Service features	**0.31025**	**Service features**	**0.25191**
Professionalism of the crew on board	0.40513	Boat type	0.35574
Good photo opportunities	0.38716	Professionalism of the crew on board	0.33465
Cost of the trip	0.36923	Good photo opportunities	0.31870
Crowding on board	0.31229	Cost of the trip	0.31446
Boat type	0.30200	Crowding on board	0.18793
Good weather conditions	0.28143	Good weather conditions	0.15908

Non-significant factors ($p > 0.05$) are indicated by the gray background. For all significant factors, significance was $p < 0.001$.

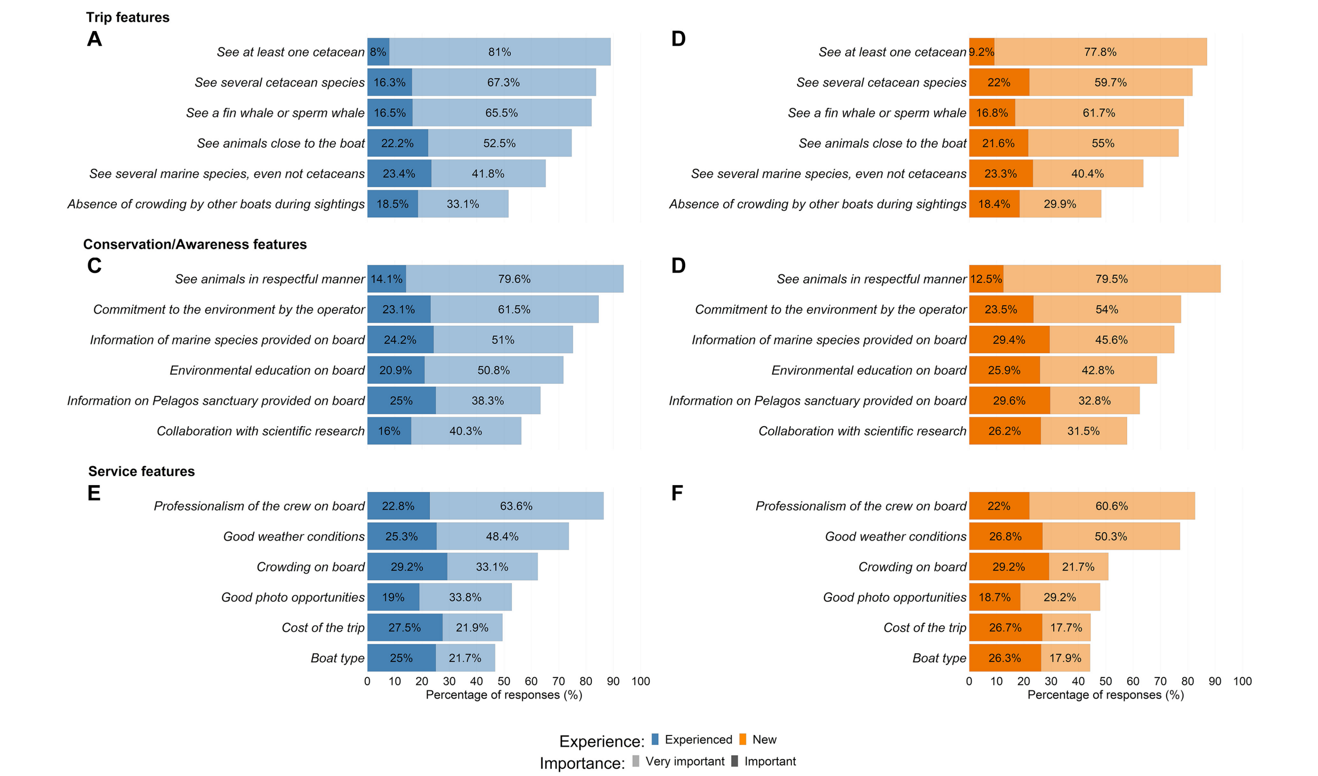

FIGURE 3 | Importance of trip **(A,B)**, conservation/awareness **(C,D)** and service **(E,F)** features for *Experienced* (blue) and *New* (orange) whale watchers.

Conservation/Awareness categories, respectively. For the Service features, *Experienced* whale watchers were very satisfied with "*Professionalism of the crew,*" while *New* whale watchers where more satisfied with "*Good weather conditions*." The features that were less satisfying for *Experienced* whale watchers were "*See several marine species, even not cetaceans,*" "*Collaboration with scientific research*" and "*Cost of the trip*." These last two satisfied less *New* whale watchers as well, while for Trip related features the less satisfying one was "*See a fin whale or a sperm whale*."

IP Analysis

Results of the IP Analysis for *Experienced* and *New* whale watchers are reported in **Table 5**. *Experienced* whale watchers rated important and satisfaction equally for the three categories (G = 0), while a higher satisfaction than expectation (G < 0) was reached in the Conservation/Awareness Category for *New*. Looking at single factors, four out of 18 factors for *Experienced*, and five factors for *New* were rated G < 0. Most of the positively evaluated factors were Service related. Specifically, "*boat type*" and "*cost of the trip*" were appreciated by both groups. *Experienced* positively evaluated "*weather conditions,*" while *New* appreciated "*good photo opportunities*." "*Absence of crowding by other boats*" was the only feature among Trip related that satisfied both groups. Satisfaction did not exceeded Importance for none of the Conservation/Awareness features for *Experienced*, while "*information on marine species provided on board*" was rated G < 0 for *New*. Regarding negative results (G > 0), "*environmental information provided onboard*" did not meet the *Experienced*'s expectations. *New* whale watchers were disappointed by the opportunity to "*see a fin whale or a sperm whale*" and to "*see several cetacean species*": for both these parameters the expectation value exceeded the satisfaction (G > 0) (**Table 5**).

Finally, 91% of whale watchers would go whale-watching again after this experience (n = 721). Among them, 70% declare to be choosing the same operator for the next whale watching trip (n = 659), while 28% declared having no intentions of going whale-watching again in Liguria.

DISCUSSION

Our assessment accounted for a total of 29 operators organizing whale watching tours in the Pelagos Sanctuary. The last available assessment in Italy counted 10 operators in total operating in Pelagos (four COM, four ECO, and two RES) (Fortuna et al., 2004). Along the French coasts, a total of 31 operators were counted, working almost only in the *Pelagos* Sanctuary area or adjacent waters (Mayol et al., 2014). Overall, at least 59 operators are currently organizing whale watching tours in Pelagos. Whale watching in the *Pelagos* Sanctuary has then increased in approximately 180% during the last 15 years. This growth regards particularly COM operators, whose number jumped from four to 17 within the considered period. COM

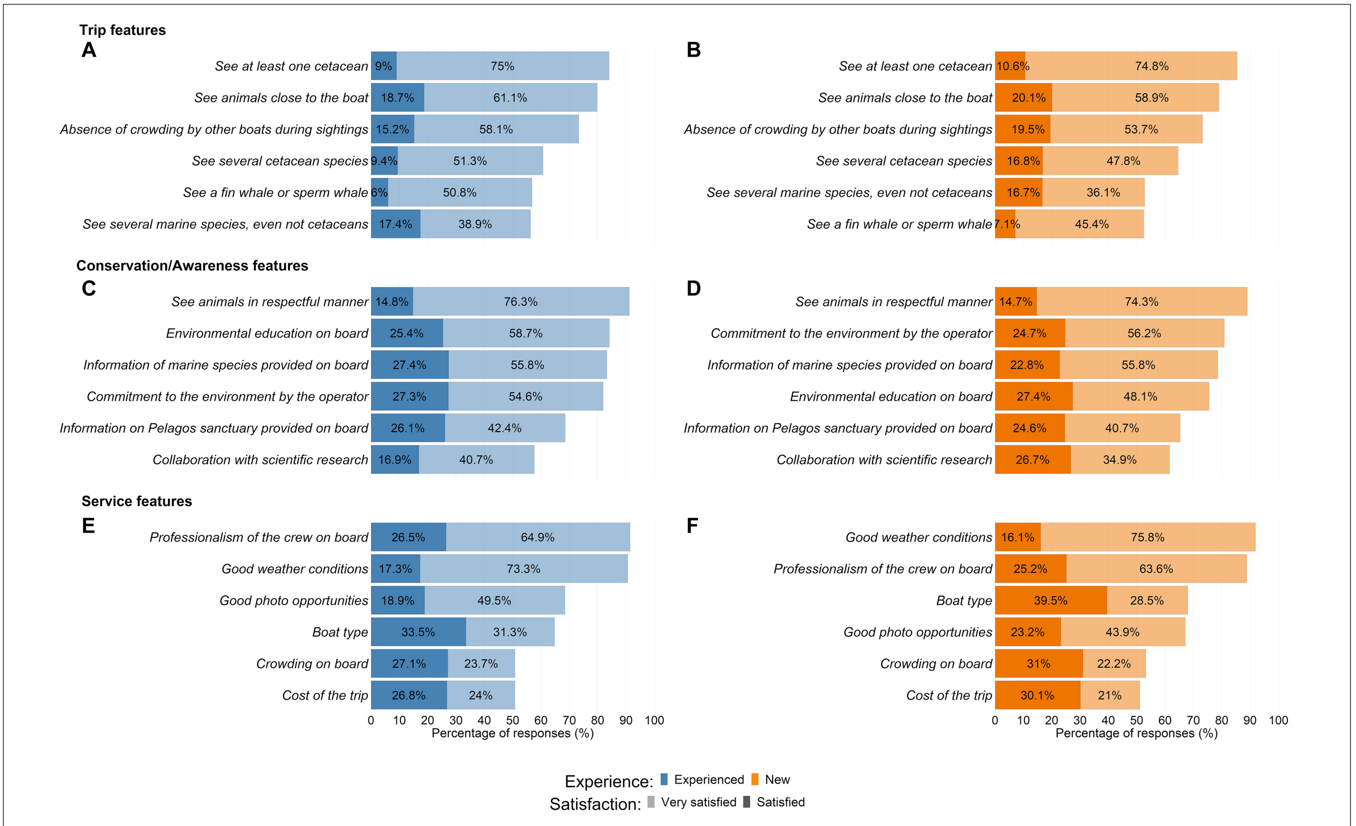

FIGURE 4 | Satisfaction for trip **(A,B)**, conservation/awareness **(C,D)** and service **(E,F)** features for *Experienced* (blue) and *New* (orange) whale watchers.

Whale watching has spread over other Italian regions of the *Pelagos* Sanctuary, while in 2004 it was concentrated only in one area (Fortuna et al., 2004). A similar growth and expansion has been observed in the French area, where an average yearly increase of 3.5% in the number of operators has been observed since late 1980–2014 (Mayol et al., 2014). The type and duration of trips has also changed over time. It is important to note that a high percentage of COM operators are nowadays offering on request-trips. While pre-planned trips allow for an overview of the potential impact of whale watching on cetacean populations, by allowing a prediction of the number and type of operators conducting trips in the area, on request trips cannot be monitored in advance, thus they can lead, during certain periods, to an over-exploitation of cetacean populations. The type of vessel used has also changed, as only big motorboats where used 15 years ago, while nowadays a variety of vessels can be chosen by whale watchers, including small motorboats, sailing vessels, catamarans and RHIBs. Results show that 65% of COM operators have a biologist or a specialized guide on board and 24% declare to be actively collaborating with research institutions. These percentages were higher in 2004, when 75% of COM operators did public awareness through biologists on board, and 50% where actively collaborating with research institutions. This could be the signal of the fact that the whale watching activity is becoming more appealing and while first the aid of researchers was considered as crucial for the activity, nowadays watching whales is becoming more and more a "solely leisure" activity.

Only 46% of COM operators have received a certification, declaring compliance with codes of conduct for approaching the animals. Compliance with code of conduct is foreseen as mandatory within the certification process, with periodical checks from the institutions in charge of the certification. For the non-certified operators, no real measurement of the level of compliance to the code of conduct has ever been made. It was not possible to check the activity of non-certified operators, but the absence of any mention to the application of a code of conduct on the web sites of operators could already indicate a lack of knowledge. These results should trigger more action from both international agreements both national authorities toward an effective control among all existing operators and to further enhance the certification process.

Despite the low rate of knowledge about the HQWW® label and of the Code of Good Conduct, "*See animals in respectful manner*" has been widely recognized as an important factor for whale watchers. It has already been demonstrated that customers play a crucial role in driving tour operators to comply with existing codes of conduct (Filby et al., 2015). As a consequence, awareness actions aimed to more widely advertise both the HQWW® and the Code of good conduct, could indirectly lead to a quality-check of the whale watching activity in the area. Moreover, this tourists-driven quality check could help filling the

TABLE 5 | IP analysis for *Experienced* and *New* whale watchers.

Tour features	Experienced whale watchers			New whale watchers		
	Importance of expectation	Satisfaction	Gap-value G	Importance of expectation	Satisfaction	Gap-value G
Trip features	**5**	**5**	**0**	**5**	**5**	**0**
See at least one cetacean	5	5	0	5	5	0
See a fin whale or sperm whale	5	5	0	5	4	1
See several cetacean species	5	5	0	5	4	1
See several marine species, even not cetaceans	4	4	0	4	4	0
See animals close to the boat	5	5	0	5	5	0
Absence of crowding by other boats during sightings	4	5	−1	3	5	−2
Conservation/awareness features	**5**	**5**	**0**	**4**	**5**	**−1**
See animals in respectful manner	5	5	0	5	5	0
Information of marine species provided on board	5	5	0	4	5	−1
Information on Pelagos sanctuary provided on board	4	4	0	4	4	0
Environmental education on board	5	4	1	4	4	0
Collaboration with scientific research	4	4	0	4	4	0
Commitment to the environment by the operator	5	5	0	5	5	0
Service features	**4**	**4**	**0**	**4**	**4**	**0**
Good photo opportunities	4	4	0	3	4	−1
Professionalism of the crew on board	5	5	0	5	5	0
Boat type	3	4	−1	3	4	−1
Good weather conditions	4	5	−1	5	5	0
Crowding on board	4	4	0	4	4	0
Cost of the trip	3	4	−1	3	4	−1

Strengths of service (G < 0) are indicated with gray background, while weakness (G > 0) are indicated by framed values.

gaps previously evidenced, both considering the low percentage of certified operators both the apparent lack of code of conduct among non-certified operators.

The role of whale watching operators in transmitting conservation messages to tourists has already been demonstrated (Lopez and Pearson, 2016; García-Cegarra and Pacheco, 2017; La Manna et al., 2020). Our results confirm this, as the *Experienced* group demonstrated to be more aware of conservation measures, such as the existence of the *Pelagos* Sanctuary, of the code of good conduct, and of the HQWW® label, compared to *New*. Considering that 63% of the *Experienced* had already gone whale watching in Liguria, the higher knowledge of the *Experienced* could also be related to the awareness message spread onboard COM whale watching vessels in the Sanctuary. It is interesting to note how among both *Experienced* and *New* whale watchers, being from a region overlooking Pelagos plays a crucial role in awareness, regarding both the existence of *Pelagos* Sanctuary and the HQWW® label. This result stresses the importance, on one hand, of regional initiatives and, on the other hand, of the need of more national and international initiatives in spreading this information. This is further stressed by the fact that less than 50% of *New* whale watchers and one third of the *Experienced* still did not know about the existence of the *Pelagos* Sanctuary, almost 20 years after its institution. Similarly, a very low percentage of whale watchers were aware of the existence of HQWW and Code of Good Conduct, regardless of age class or education level. More educated people would be more influenced in the choice of an operator by the presence of a quality label. Quality of whale watching in the *Pelagos* Sanctuary was medium-high, slightly lower than what observed by Bentz et al. (2016) in the Azores. Indeed, differences in geography, climate, and presence of marine megafauna between our study area and the Azores must be evidenced. These differences make it impossible to directly compare the obtained results. At the same time, Azores represent one of the world best known places for the whale watching activity and was used as a benchmark for our analysis. The beforehand mentioned differences where taken into account in the analysis of the questionnaires. As an example, authors in Bentz et al. (2016) indicated the high probability of seeing whales as the factor majorly contribution to high satisfaction level. Among the species regularly sighted in the area, fin whale, and sperm whale are the most charismatic, and their presence is one of the main factors contributing to satisfaction for both *Experienced* and *New*. The presence and distribution of fin whales and sperm whales in the area is known to vary annually (Azzellino et al., 2012; Morgado et al., 2017). For the whale watching trips considered in this study, sighting success for fin whale and sperm whale has been 20% (17 trips with at least one fin whale sighting out of 85) and 13% (11 trips with at least one sperm whale sightings out of 85), respectively. It is important to stress how despite this low sighting rates of the two main target species, averaged satisfaction level is medium-high for this area.

Origin, Age, and Education level had no influence on overall satisfaction. While tourists' satisfaction is usually used a measure of operators' performance, it can also be used as a key driver for the management and development of touristic activities. Specifically for wildlife tourism, measuring factors mainly affecting satisfaction can directly provide effective insights for a sustainable planning of the activities. Informing operators on which factors influences tourists' satisfaction could help diminishing the possible negative impact of the activity itself on the exploited natural resource.

IP Analysis evidenced that generally, both new and experienced whale watchers where satisfied with trip settings, being cost and boat type identified as strengths factors. For both groups, being in an area not crowded by other boats was indicated as a strength of the service offered. This is in contrast with what observed elsewhere, especially in famous whale watching destination, where crowding has a negative impact (Bentz et al., 2015). Respecting the indications gave by the Code of Good conduct, where a maximum of two vessel is allowed in the same area of the animals, and only one at a time in the vigilance area, can be seen as a strengthen factor from operators, rather than a limitation. At the same time, respecting this rule helps in diminish possible negative effect on cetaceans in the area. *Experienced* whale watchers do expect a better environmental message on board COM whale watching operators in the *Pelagos* Sanctuary, while *New* whale watchers were disappointed by the number of cetacean species observed and by the possibility to see fin whale or a sperm whale. Being *New* the highest proportion of whale watchers, whale watching operators should better advertise the offered tours, focusing on the overall ensemble of marine species that can be sighted (including marine birds and sea turtles as an example). Quality of the educational and awareness message spread on board can drive and adjust tourists expectations during wildlife tours (Orams, 2000; La Manna et al., 2020). Rising the quality of the information provided onboard is also one of the aims of the HQWW® label, which foreseen a specific training program for both guides and vessels crews. Ensuring the spreading of this label as well as tourists' awareness, can then directly help in booster a more sustainable attitude toward both tourists and operator. Similarly, proximity to the animals, while seen as an important factor, is also known to be potentially risky for animals. Our results demonstrate that respectful approach are as or even more important to tourists than proximity. This indication reinforces the need for responsible and environmentally sustainable whale-watching practice (Cornejo-Ortega et al., 2018). Further analysis then will be needed for effectively check operators compliance with the Code of Good Conduct. With this research, we aimed at providing a baseline for a future comparisons of tourist satisfactions including different operators (RES and ECO) as well as expanding the analysis to other regions. Specifically considering the *Pelagos* Sanctuary area, it would be important to assess intra-national as well as inter-national differences among signing regions and countries, in order to assess a benchmark level that could then be exported also outside the protected area. As a matter of fact, our results suggest the whale-watching sector has the potential to further grow over the next years, not only in the *Pelagos* Sanctuary region but also spreading into other regions, has already evidenced by our census (see **Supplementary Material**). Monitoring the whale watching activity and its potential impact on the cetacean population is then becoming crucial, especially looking at the lower involvement of research activities measured in 2019, compared with the past. This need is further enhanced by the change in the type of offer, as on-request trips could make it difficult to assess effective presence of boats in the same area. Moreover, some whale-watching activities are focused primarily on bottlenose dolphin population (La Manna et al., 2020), a species listed as "Vulnerable" and needing conservation actions in the Mediterranean (Bearzi et al., 2008, 2012).

The analysis of the whale watching activity in the *Pelagos* Sanctuary, being the first available for this protected area, can be considered as the base for developing and reinforce better management strategy that would support the economic benefits, improving the service satisfaction, and at the same time minimizing negative impacts and enhance the positive impact of this activity on cetacean populations in the area.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

PT, MZ, and AM conceived the study and prepared the questionnaires. MZ was responsible for the data collection on board. PT and MZ were responsible for building the final database and for the data entry. PT and AB conducted the analysis. MR and AM supervised the overall work. All authors contributed in the writing of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.596848/full#supplementary-material

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Impacts of Whale Watching on the Behavior of Humpback Whales (*Megaptera novaeangliae*) in the Coast of Panama

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Ecotourism focused on whales and dolphins has become a popular activity and an important source of revenue for many countries. Whale watching is vital to supporting conservation efforts and provides numerous benefits to local communities including educational opportunities and job creation. However, the sustainability of whale-based ecotourism depends on the behavior and health of whale populations and it is crucial that ecotourism industries consider the impact of their activities on whale behavior. To address this statement, we collected behavioral data (e.g., change in swimming direction, frequency of breaching, slap behaviors, diving, and spy hops) from humpback whales (*Megaptera novaeangliae*) in the marine protected area of Las Perlas Archipelago off the Pacific coast of Panama. The goal was to determine if tourist vessel presence had an influence on whale behaviors. We conducted this study during the humpback whale breeding season from August through September 2019. Based on 47 behavioral observations, we found that higher boat density corresponded with humpback whales' frequency of direction changes, which based on previous literature is believed to be a sign of disturbance. Alternatively, no changes in behavior were observed with varying boat density. This result is important given Panamanian regulations first implemented in 2007 by Resolution AMD/ARAP No. 01, 2007 prohibit whale-based tourism from disturbing whales, which is explicitly measured by changes in whale behavior. Because there is no systematic monitoring of whale watching activity to enforce the regulations, there is currently little compliance from tour operators and tourists. The integration of animal behavior research into management planning should result in more effective regulation and compliance of such conservation policies.

Keywords: ecotourism, *Megaptera novaeangliae*, disturbance, stress, behavioral ecology, animal welfare, wildlife-ecotourism

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INTRODUCTION

Wildlife-based ecotourism, which includes whale watching, is identified as, "tourism based on encounters with non-domesticated animals…[which] can occur in either an animal's natural environment or in captivity" (Higginbottom, 2004). It provides economic benefits to many countries around the world (Hoyt, 2001; O'Connor et al., 2009; Guidino et al., 2020;

Wiener et al., 2020) and has increased drastically in popularity over the past 50 years. Globally, over 13 million tourists take trips to view cetaceans each year, generating over $2 billion US dollars in revenue across 119 countries (Hoyt and Hvenegaard, 2002; O'Connor et al., 2009; Stoeckl et al., 2010; Guidino et al., 2020; Wiener et al., 2020). Whale watching industries are rapidly growing in developing countries such as Cambodia, Laos, Nicaragua, and Panama (Hoyt, 2001; O'Connor et al., 2009). While ecotourism activities have many economical, educational, and ecological benefits relating to conservation, there have been many published studies that conversely question the benefits of this form of ecotourism, proposing that these activities may be harming the wildlife involved (Parsons, 2012; Leslie et al., 2015; Larson et al., 2016). Therefore, these activities deserve a higher level of scrutiny and monitoring to ensure their ongoing sustainability and economic, community, educational, etc., contributions (Stamation et al., 2007; The International Ecotourism Society, 2015).

The main contribution of whale watching is that it provides a stable financial alternative to the traditionally consumptive use of whales through hunting or "whaling." The growing influx of tourists coming to watch whales provides the revenue required to support local communities and cultures while simultaneously supporting whale conservation efforts (Wearing et al., 2014). Whale watching focused on humpback whales (*Megaptera novaeangliae*) was also found to be effective in encouraging natural resource protection and patronization of local businesses, especially when tour guides take care to disseminate conservation messages to tourists (Peake et al., 2009). In addition, through specific platforms such as whale watching, the public has the opportunity to come in contact with often endangered or threatened wildlife and learn about conservation efforts (García-Cegarra and Pacheco, 2017). This practice falls under "responsible" whale watching guidelines, which is defined as an environmental and economical use of whales that is sustainable, promotes whale conservation, and education while simultaneously supporting local communities (O'Connor et al., 2009). This is especially relevant given that the rapid urbanization of society is prompting people to desire opportunities to "reconnect" themselves with nature (Curtin and Kragh, 2014).

The growing popularity of this industry also has drawbacks especially in developing countries, where regulatory frameworks are often lacking leading to a higher likelihood that animal welfare and safety regulations will be ignored (Sitar et al., 2016; Kassamali-Fox et al., 2020). Tour boat operators may intentionally or inadvertently utilize locations that experience little enforcement or actively violate the rules of responsible whale watching in the desire to attract more clients, ultimately leading to detrimental impacts on whale welfare (Corbelli, 2006; Parsons, 2012; Kessler and Harcourt, 2013; Sitar et al., 2016). Accordingly, the International Whaling Commission (IWC) established measures to protect whales and published guidelines for responsible whale watching in 1997 (International Whaling Commission, 1997). Unfortunately, with little enforcement in some countries, there are still high levels of detrimental whale interactions with non-consumptive whale-watching vessels (Parsons, 2012).

During encounters when high numbers of vessels are present, whales will often exhibit a high frequency of behavioral shifts, such as direction changes, which are reflective of avoidance tactics employed when whales encounter predators (Frid and Dill, 2002; Williams et al., 2002). These behaviors, combined with the high-speeds and unpredictable approach angles often displayed by vessels, greatly increase the risk of collision (Guzman et al., 2013). In addition, whales must expend extra energy to avoid boats, while decreasing the occurrence of necessary survival activities (e.g., nursing, foraging, and reproduction; Morete et al., 2007; Stamation et al., 2010; Schaffar et al., 2013; Fournet et al., 2018; Fiori et al., 2019). This is especially true in breeding areas that are primarily frequented by mother and calf groups because they are more susceptible to whale watching disturbances (Morete et al., 2007; García-Cegarra et al., 2019). One study suggested that long-term disruption of routine behaviors caused by high levels of negative boat and whale interactions could have lasting reproductive impacts on humpback whale populations (Braithwaite et al., 2015), while others highlight potential impacts due to the inability for whales to effectively communicate due to "acoustic masking" from loud boat sounds (Rossi-Santos, 2016; Erbe et al., 2018, p. 290). This could result in reduced success when finding a mate in breeding areas, locating food in feeding areas, and further expended energy to increase call volume or duration (Foote et al., 2004; Fournet et al., 2018; Putland et al., 2018).

Given these issues and mediating factors, the marine and coastal areas of Panama are ideal locations for observing the whale–vessel interactions and potential repercussions. Panama is a popular tourist destination due to the presence of the Panama Canal, which only serves to increase daily levels of vessel traffic through its service as an important commercial trade route. Humpback whales from the southeast Pacific population migrate from their feeding grounds in Chile and Antarctica to the tropical areas along the Pacific coasts of Central America for the breeding season (Rasmussen et al., 2007; Acevedo et al., 2017). The season extends from June to October, and sometimes December, with peaks in August and September (Guzman et al., 2015). The humpback whale population of this archipelago is estimated to be around 1,000 individuals, with about 25–50 calves born annually (Guzman et al., 2015). This population of humpback whales is identified as Breeding Stock G (International Whaling Commission, 1998), which is one of the seven "stocks" inhabiting oceans in the southern hemisphere. This specific population undertakes one of the longest migration distances (Stone et al., 1990; Acevedo et al., 2017) of more than 16,000 km roundtrip from the feeding grounds to the breeding grounds (Rasmussen et al., 2007; Félix and Guzmán, 2014; De Weerdt et al., 2020), with the entire stock swimming along 9,000 km of coastline (Félix et al., 2011). Female and calf pairs tend to remain closer to shore (Glockner and Venus, 1983; Bruce et al., 2014; Oña et al., 2017) while adults prefer more direct routes in deeper waters (Félix and Haase, 2005; Rasmussen et al., 2012; Félix and Guzmán, 2014; Guzman and Félix, 2017). Mother–calf pair preference for coastal waters poses higher risks of vessel collision and entanglement in gillnets, as fishermen and commercial ships share these waters (Félix and Guzmán, 2014). Although whales are migratory for the majority of the year, they congregate in waters less than 200 m deep for their annual breeding season. Hence, the shallow waters of the Pacific of Panama are ideal for mother humpback whales giving birth, due to the lack of competitive males pursuing the females, ocean turbulence, and predators (Flórez-González et al., 1994; Corkeron and Connor, 1999; Darling and Nicklin, 2002; Cartwright and Sullivan, 2009; Craig et al., 2014; Pitman et al., 2015). The objective of this study is to determine if tour boat number and mode of approach to whales elicit changes in their behavior frequencies in the Las Perlas Archipelago in Panama. We hypothesize that whales will decrease the frequency of certain behaviors as indicators of disturbance when boat presence increases and when boat captains are not complying with regulations.

MATERIALS AND METHODS

Study Site

This study was conducted in the Las Perlas Archipelago (8.41°N, 79.02°W) in the Gulf of Panama, which lies about 60 km southeast of Panama City (**Figure 1**). The archipelago comprises 250 basaltic rock islands and islets spread over 1,688 km, making it the fourth-largest coastal marine protected area of Panama (ADM/ARAP No. 1 from 13 February 2007; Guzman et al., 2008). We recorded behavioral responses of humpback whales in the Las Perlas Archipelago between 18 August and 6 September 2019, with observational sessions consisting of both land-based and boat-based visual behavioral studies, from a lookout point on Contadora Island (the largest inhabited island) and a ∼9.75 m whale-watching vessel, respectively. 720 total minutes were recorded, with 135 min from land-based surveys and 585 min from boat-based surveys, throughout the 16 days of research. Our boat, unlike other boats, took extreme precautions to minimize our potential disturbance to the whales by following the mandated regulations such as keeping a 250 m distance, having a certified boat operator with a permit for commercial operations, and limiting observation times to 30 min per group.

Data were collected using a whale group-follow protocol, as the presence of competitive groups (i.e., a female surrounded by one or several males displaying active behaviors, such as breaching, striking, charging, and trumpeting), made it difficult to follow specific individuals (Mann, 1999). Therefore, a focal follow method was used. Variables in the data included four group types (e.g., competitive, mother–calf pair and escort, pair, and lone whale), group size, behaviors (see **Table 1**), Global Positioning System (GPS) coordinates, whale direction changes, and the number of boats within approximately 300 m of the whales. The distance was visually measured for both boat and land surveys by the researcher using Chapera island as a referential point. We then estimated how far the whale was between the boat or Contadora (the lookout point) and Chapera. Diving behavior was measured by the number of fluke dives that occurred within 15 min by a focal whale (including adults and calves). Other recorded variables were measured to characterize the environmental conditions during the survey which included the Beaufort wind scale and cloud cover (Spencer et al., 2006).

Description of Group Types

A mother and calf pair consisted of a large whale (assumed to be the mother) together with a small individual one-third the length of the adult, the calf (Chittleborough, 1958; Cartwright and Sullivan, 2009). A lone whale was a single individual traveling without any other individuals observed within 50 m, while pairs contained two adult whales traveling in the same direction. Meanwhile, whales were considered a group (or "pod") if three or more individuals were moving in the same direction and less than 50 m from each other. These groups were considered competitive if three or more adult humpback whales were within 50 m of each other, exhibiting high energy behavior. The composition of these groups usually consisted of a single female (with or without calf), with one or more males that are showing a high frequency of surface behavior and physical contact with each other (Herman et al., 2007).

Behavior Frequency

During boat-based surveys, observation began once humpback whales were spotted within 300 m of the research vessel, which gave a clear view for researchers to collect data. Land-based study sessions began once a whale was spotted within approximately 3 miles (4.8 km) of the lookout point given the increased visibility and the use of Outland X 10x42 binoculars. For both land and boat surveys, once whales were spotted, one researcher tracked the GPS coordination and direction change of humpback whales. The GPS coordinates were subjectively estimated by the researcher judging the whale's distance between the two islands of Contadora (the lookout point) and the island of Chapera in viewpoint of the land-based studies. Researchers pinpointed the estimated location of the whale on the device's map using a mobile device's GPS application and recorded the coordinates. A change in direction was visually measured by considering the location and forward positioning of whales when surfacing. If the whale group surfaced in a different location and in a different facing direction than their original position, it indicated a direction change. The second researcher tracked all 15 behaviors from **Table 1** as well as group type, group size, Beaufort wind scale, number of boats, and cloud cover. If more than one group was spotted during a study session, the group closest to the observer was tracked. Studies occurred in good weather conditions (Beaufort wind scale < 5) but were obstructed in severe weather conditions (Beaufort scale > 5; Cloud cover = 100%), if whale sightings were lost, or if the whale group split during the observation session. If a whale or pod were spotted, then every 15 min, observations of weather conditions, and a scan of behaviors (e.g., scan sample) were conducted and then recorded. We did not record the frequency of behaviors that occurred continuously over 15 min.

While counting the number of vessels, boats were only included in a session if it was observed to be clearly following the humpback whale group and if they were within 300 m of the whale. Observation sessions that included zero boats present were considered controls. Since the lack of boat presence served as the control variable, these observations could only be conducted during land-based studies to avoid inadvertent

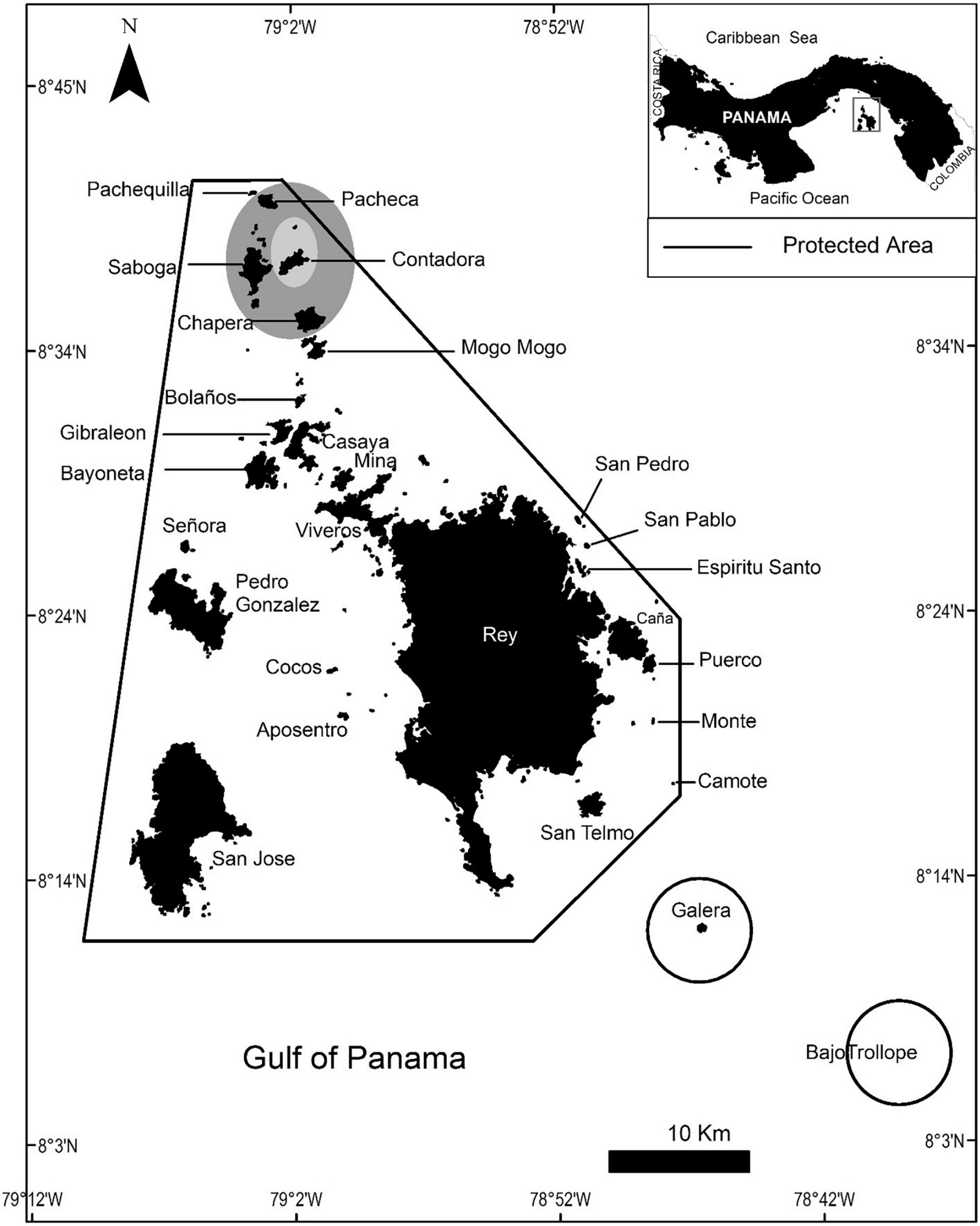

FIGURE 1 | Map showing the study area in Las Perlas archipelago in Panama. The solid lines indicate the limits of the protected area. The shaded area is the core of the fieldwork and data collection, but qualitative observations extended to the outer areas.

TABLE 1 | Description of behavior categories for humpback whale behaviors (based on descriptions by: Glockner-Ferrari and Ferrari (1984) and Gabriele (1992) (adapted from Bauer, 1986; Helweg, 1989; Corkeron, 1995; Darling and Nicklin, 2002).

Behavior name	Description
Breach	Whale leaps out of the water, spinning in the air before re-entering
*Tail-Up Dive	Whale lifts tail out of the water and attains a vertical angle for deep dives
Peduncle Arch	Whale arches its back showing the dorsal fin that usually occurs after they surface to breathe
Head Raise/Spy Hop	Raises head vertically out of the water while stationary, flippers outstretched
*Pectoral Fin Slap	Slaps flipper down onto the surface of the water
*Tail Slap	Raises flukes out of the water and slaps them on the surface
*Side Fluke	Swimming on one side with one fluke extending above the surface
*Head Slap	Jumps out of the water and hits the ventral side of head forcefully on surface
*Chase/Charge	Lunges at another whale, often bubble-streaming
*Strike	Intentionally hits another whale with fluke extending above the surface
Collide	Whales collide, appears to be intentional
Trumpet	Extended low-trumpet or "foghorn-like" sound from the blowhole
Singing	An extended high-pitched sound made by male humpback whales
Resting	Motionless movement in which whale stays in one place
*Avoidance	The rapid change in direction to avoid a potential threat

** indicates behaviors which are characteristic of avoidance or stress.*

effects from the research vessel. Many behavioral events, such as singing, trumpeting, side flukes, and colliding, were omitted from the study given their low or absent sample sizes. Others were combined into a single category because of low individual incidence. For example, head slaps, tail slaps, and pectoral fin slaps were all combined into "slap behaviors."

Statistical Analysis

We used a Chi-squared goodness of fit test to measure the influence of boat density on whale behavior. We used this method due to its established ability to test the relationship between behaviors and boat presence (Bagdonavicius and Nikulin, 2011). To normalize the data, we proportionally measured the behavioral observations using a linear regression hypothesis test. Individual whales may express different behavioral responses when faced with a disturbance. Thus, to determine if group type was a significant predictor of a whale's behavior, we applied a Kruskal–Wallis and a *post hoc* pairwise Wilcoxon test to assess which sets of groups had a significantly different number of direction changes from each other (Pohlert, 2014). Results are reported as mean ± standard error followed by the *p*-value. Finally, we used a regression model featuring a Pearson's product-moment test to test the strength or weakness between the relationship between direction changes and the number of vessels. Such a test is essential for drawing a best-fit line through the two variables (direction change and vessel numbers) and examining how far off the variables are from the regression line (Benesty et al., 2009). Both boat and land-based studies were included in every analytical test. We performed all statistical analyses in R version 3.6.0 (R Core Team, 2017) and Microsoft Excel (2003).

RESULTS

Between August and September 2019, we recorded 47 behavioral sessions. Groups with mother and calf pairs and mother–calf and escort groups were pooled for analysis due to the low sample size of mother–calf and escort groups (three groups total). These 47 samples consisted of 24 mother and calf pairs and escort sightings (51%), 11 competitive group sightings (23%), seven lone whale sightings (15%), and five paired adult sightings (11%). The average number of individuals in a pod was 2.57 with a range of one individual to a maximum of eight individual whales in the study. Thereafter, we compared the explanatory variable (number of boats) and two dependent variables (direction change and behavior). Mother–calf and escort pods made up 50% of the samples involving boats but were rarely observed during controlled samples, making up only 14% of the data, respectively.

Behavior State Transitions

We collected behavioral observations in both the absence and presence of vessels. Overall, the Chi-squared goodness of fit test indicated a significant difference among all behaviors ($X^2 = 57.1147$, $p < 0.001$). In the presence of vessels, breaching gradually increased as boat numbers grew, then significantly declined with more than three boats present (2%; **Figure 2**). This decline in breaching often occurred when boats were chasing whales. Humpback whales were most often seen executing slap behaviors (e.g., pectoral fin slaps, tail slaps, and head slaps) during sampling with zero boats present (55%). Alternatively, the frequency of diving behavior (e.g., tail up-dives) varied widely among different levels of boat presence (36% of dives occurred in sessions with two boats, 29% with four or more boats, 28% with zero boats, 5% with one boat, and 2% with three boats), but there was no discernable pattern related to the number of vessels. While spy hops/head rises were rarely seen, they only occurred during situations when boats were present.

More than 62% of behaviors were observed in eleven competitive groups ranging from three to eight individuals within each pod. Mother–calf and escort groups provided 20% of the behavioral data samples, five pair groups provided 16%, and seven lone whale samples accounted for only 2% of the behavioral data. Breaching was the only behavior that was not predominately expressed by competitive whale groups. Competitive groups made up 23% of the breaching while other non-competitive groups made up the other 77%. This occurred primarily with paired groups (40%), followed by mother–calf and escort pods (36%) and lone whales (<2%). In addition, a linear regression model (**Figure 3**) capturing the proportion of behavioral transitions presented no clear indication of significance of change

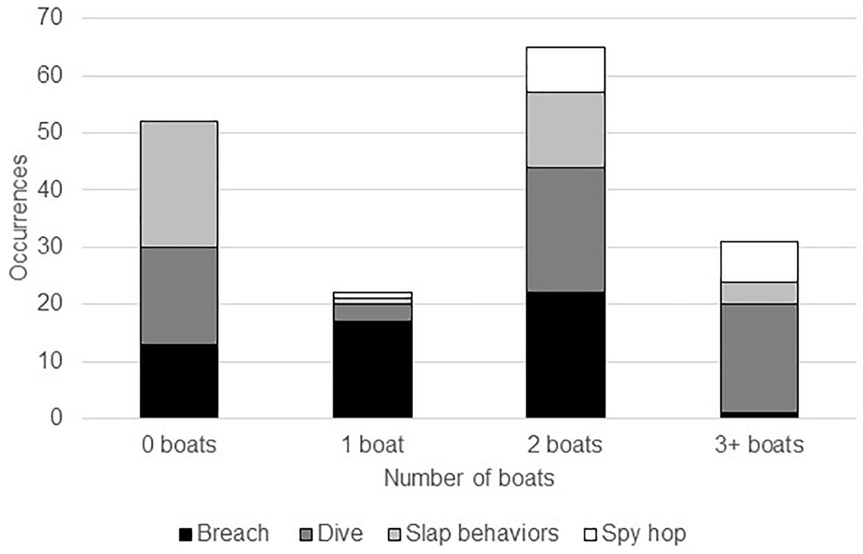

FIGURE 2 | *Megaptera novaeangliae.* Total number of categorized whale behavior occurrences observed during varying boat presence while conducting group-follow behavioral samples.

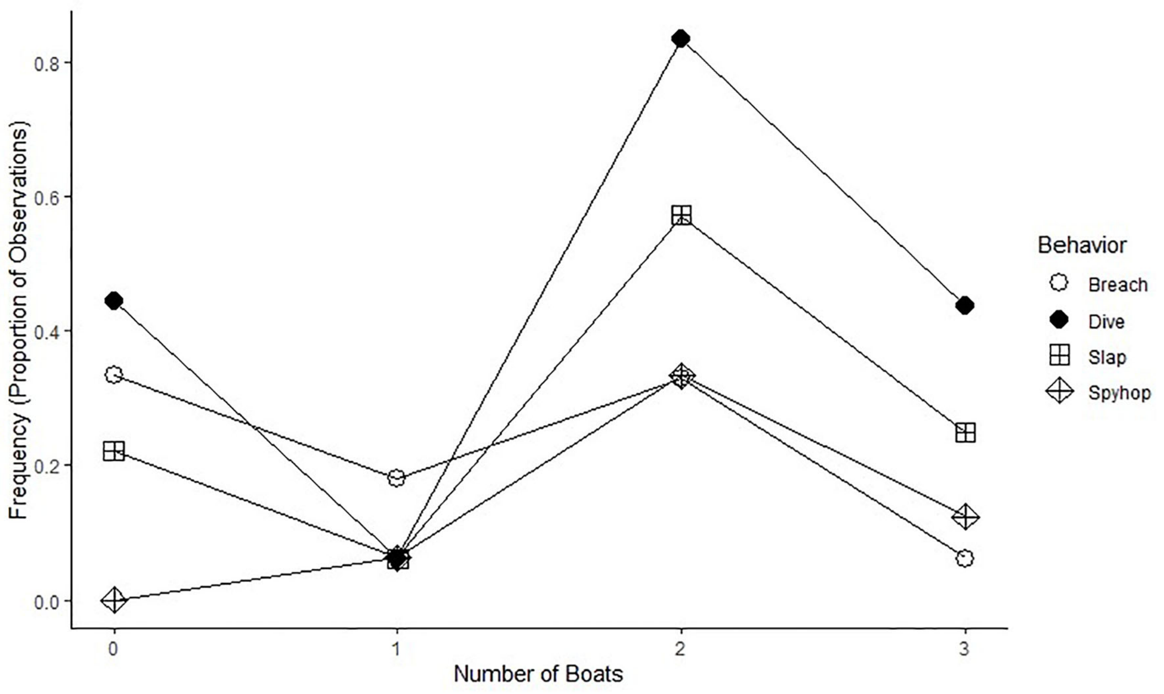

FIGURE 3 | The frequency of behavioral observations as a proportion of the total numbers of observations for each boat type.

with varying boat numbers (Breach: $R^2 = 0.42$, $p > 0.05$; Dive: $R^2 = 0.09$, $p > 0.05$; Slap: $R^2 = 0.13$, $p > 0.05$; Spy hop: $R^2 = 0.34$, $p > 0.05$).

Direction Change and Group Type

We conducted a *post hoc* pairwise Wilcoxon test (**Figure 4**) to assess which group types exhibited a significantly different number of direction changes from each other. Of the comparisons across all whale group types, the pair versus competitive group type and pair versus calf group type were the only pairwise comparisons rejected ($Z = 1.68$, 16 ± 0.474, $p < 0.05$; $Z = 1.68$, 29 ± 0.486, $p < 0.05$, respectively). The rest of the pair-wise comparisons, therefore, supported the null hypothesis, which assumes little to no

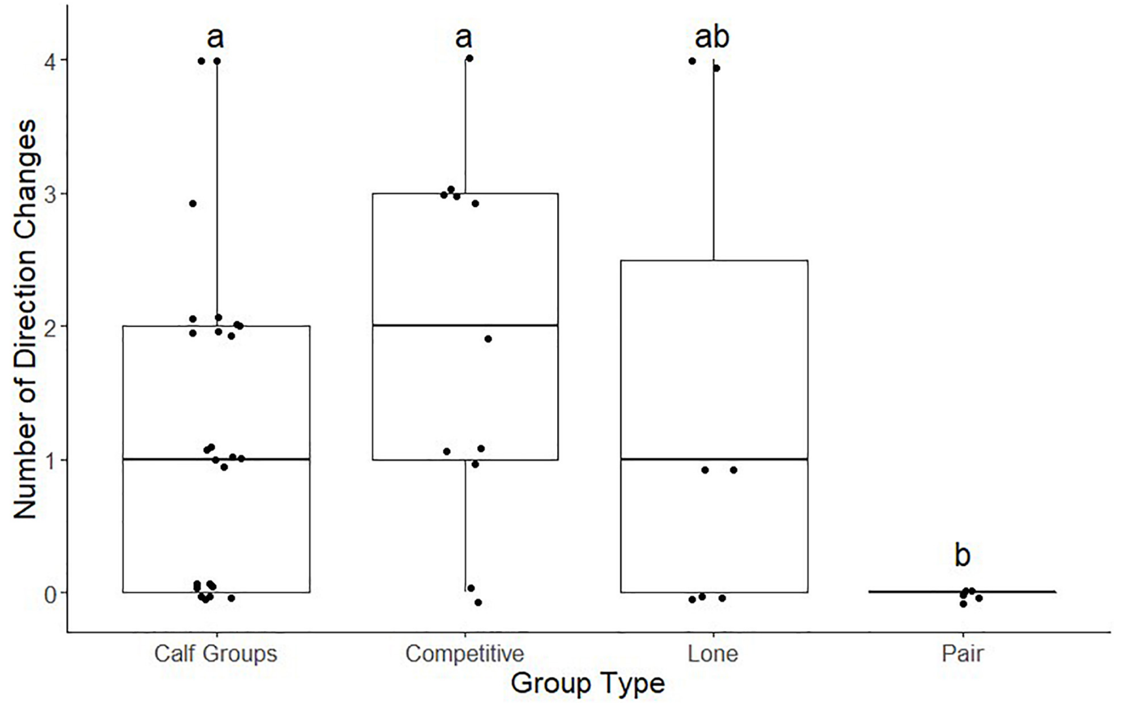

FIGURE 4 | *Megaptera novaeangliae.* Box plot comparing the number of direction changes of four different whale group types (competitive groups, lone groups, calf groups, and pairs). Groups with shared letters are not significantly different.

difference occurred among the number of direction changes for each group type.

Relationship of Direction Change to Number of Vessels

As the number of vessels during an observational session increased, the number of whale direction changes increased. Using a linear regression model, direction change, and the number of vessels also produced a positive relationship ($R^2 = 0.38$, $p < 0.001$; **Figure 5**). Few direction changes occurred when zero boats were present, with only one competitive group changing direction (once) during a controlled observation. However, the number of observations within each treatment was unequal. Observation sessions with one boat occurred most frequently (34%) followed by four or more boats (22%), zero boats (20%), two boats (15%), and three boats (9%). Mother–calf and escort groups had the most amount of direction changes, with 26 total direction alterations (see **Figure 5**). This result may be attributed to calf-mother-escort groups being the most observed group type (51% of samples).

DISCUSSION

Behavior Frequency

The number of boats present had varying effects on the four behavior events measured during our study: breaching, diving, slap behaviors, and spy hop. It is theorized that breaching represents a communicative tactic caused by whales slapping their bodies on the surface when vocalization is obstructed (Whitehead, 1985; Dunlop et al., 2010; Kavanagh et al., 2017). While numerous factors can hinder vocalization such as high wind speeds, rain, and vessel noise, whale communication in this environment could have been blocked by higher levels of vessel noise, leading to an increase in the observed breaching behavior (Whitehead, 1985; Richardson et al., 1995; Moore et al., 2012; Cholewiak et al., 2018; Gabriele et al., 2018).

This is reflected in the results as the increase in vessel number appeared to be associated with higher incidences of breaching.

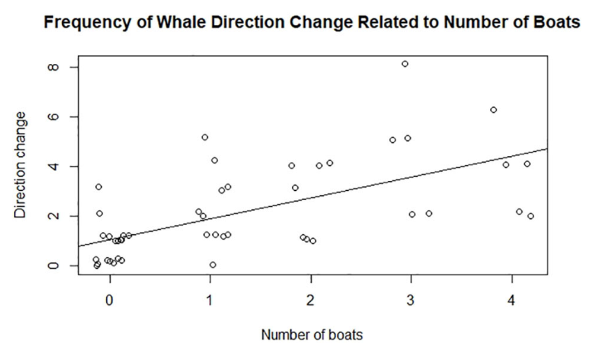

FIGURE 5 | *Megaptera novaeangliae.* Observed correlation between the number of boats and the total number of direction changes while conducting group-follow behavioral samples.

However, the breaching frequency decreased once vessel numbers exceeded two boats. It is also possible that crowding from multiple boats limited surface area, restricting available space for whales to breach. Whale breaching has also been theorized to be a form of play, especially when exhibited by calves (Whitehead, 1985), which could explain the relatively high involvement of calf pairs in breaching. Alternatively, breaching may also be a tactic for male humpback whales to display their physical abilities when seeking a mate, which explains the high breach count that also occurred in pairs and competitive groups (Whitehead, 1985; Darling and Nicklin, 2002; Pacheco et al., 2013). Unfortunately, due to boats being more inclined to violate the existing whale-watching regulations, the high levels of whale-chasing exhibited by vessels could negatively influence the stress level of the whales, reducing their breaching. These behaviors could eventually be replaced with an increase in avoidance behaviors, such as direction change and longer dive times (Stamation et al., 2010).

The number of slap behaviors increased when the number of boats declined. This observation supports the theory that if a whale is close to another group, they will communicate through slapping behavior (Shapiro, 2008). Whales of both sexes slap their fins to communicate or gain attention when seeking a mate. Females specifically use this slapping tactic since they do not sing (Deakos, 2002; Herman et al., 2007). This behavior was especially evident in this study as Panama is a hotspot for breeding humpback whales, with increased competitive behaviors exhibited between males and females.

Competitive groups had the highest incidences for three of the four observed behaviors: slap behaviors, spy hopping, and diving. However, these results may differ from other studies conducted at different times of the year because whale behavior changes dramatically during breeding seasons (Corkeron, 1995; Stamation et al., 2010; Schaffar et al., 2013).

Tail slaps are the most common surface behavior observed, most likely because they are not associated with high energetic costs (Noren et al., 2009; Segre et al., 2020). Therefore, humpback whales may only resort to breaching when noise pollution (such as that caused by high vessel presence) increases, as the sound of breaching travels much farther than the noise of a tail or pectoral fin slap. Schuler et al. (2019) attribute the change in surface behavior to the disparity between the weight and surface area of a whale's tail versus that of their body. Researchers of previous studies also found an increase in vessel number to cause humpback whales exhibiting surface behaviors to switch from surface activity to traveling. This may have long-term effects on individuals and groups because of the high energy expenditure of reacting to the boats (Schuler et al., 2019; **Table 2**).

Spy hops or head raises occurred less frequently than the other documented behaviors, but more occurred during sessions of high boat presence. This could suggest that spy hops ensue when whales wish to view activities above the surface (Galvin, 2006). In this study, as spy-hopping only occurred when vessels were present, the whales were most likely curious about the vessels following them, thereby supporting this hypothesis.

The linear regression model displayed no clear indication of different behavior event frequencies when correlated with varying vessel numbers. This result could be an indication of habituation to anthropogenic presence and noise, which poses additional risks (Richardson et al., 1995; Stone and Yoshinaga, 2000), as well as the range of different types of vessels which vary in their acoustic volume. With Panama being one of the central ports in the global cargo-shipping network, higher levels of vessel traffic will likely only increase the risk of whale-vessel collision (Kaluza et al., 2010; Guzman et al., 2013). While the risk of collision with larger ships has been reduced due to the passage of the Gulf of Panama Traffic Separation Scheme in 2014 (CITE), the lack of regulation enforcement among non-commercial ships means potentially hazardous collisions between cetaceans and vessels (Panama Maritime Authority, 2014).

TABLE 2 | Categories of behaviors used in this study from prior studies on the impacts of whale watching on orcas and humpback whale behavior.

Behaviors studied	Findings	References
Avoidance behaviors	Cetaceans increased their path sinuosity but decreased the linearity of their path with vessels present.	Senigaglia et al., 2016
Avoidance behaviors	Humpback whales showed avoidance behaviors 84% of the time, increasing the sinuosity of path and change in direction with increased vessel approach.	Schaffar et al., 2013
Group type and behavior	Humpback whale calf pods were much more reactive to vessels than non-calf pods and displayed more avoidance behaviors when vessels came within 100 meters of the whale.	Stamation et al., 2010
Behavior	Humpback whales that engaged in surface activity were likely to switch behavior when vessel presence increased. Long-term effects are associated with the loss of energy when whales react to boats.	Schuler et al., 2019
Behavior	Blue whales showed fewer foraging behaviors the closer vessels approached them, leading to a reduction in energy for foraging which could have long-term effects on Blue whales.	Guilpin et al., 2020
Behavior	Humpback whales exhibited more surface behaviors with increased vessel exposure, which could lead to energetic consequences.	Di Clemente et al., 2018

This is an observational study and we did not experimentally manipulate boat numbers. Thus, the number of samples differs between boat numbers. Further studies are required to confirm if humpback whales in the Las Perlas Archipelago display the same behavioral responses that whale groups exhibit in published studies (Darling and Nicklin, 2002; Williams et al., 2002; Lusseau and Bejder, 2007; Morete et al., 2007; Stamation et al., 2010; Schaffar et al., 2013; Fiori et al., 2019; Schuler et al., 2019).

Direction Change and Group Type

We suggest that the whale group type was not a significant predictor of the number of direction changes exhibited. The significant difference between pairs versus competitive groups and pairs versus groups found in Las Perlas Archipelago may be the result of competitive groups being in a setting where they must be vigilant and always watching their competitors; however, this attentive attribute may cause them to exhibit stress-based behaviors to avoid boats. The concern of energy costs is especially relevant with regard to calf groups since it seems whale watching vessels prefer following calf groups due to their playful behavior. As calves may feel more threatened by boats than other group types, Panamanian regulations have extra laws to protect calves, given their vulnerable state. We saw a significant difference even with a small sample size, but a greater number of samples would clarify the extent of the relationship. Nevertheless, these results support findings from previous whale behavioral reports. In one study, group type was included as an explanatory variable to predict dive time, swim speed, and directness index and found the relationship between group type and the other variables had no significance and did not lead to a better fitting model (Schaffar et al., 2013). Unfortunately, we were unable to measure changes in swim speed in this study. Another study found pods with calves exhibit higher levels of activity compared to non-calf pods (Stamation et al., 2010). This supports the results of our study, which showed groups with calves executing the largest number of direction changes. However, due to the small sample size of this study, no other conclusions can be confidently derived regarding whether whale behavior can be predicted by the whale group type.

Relationship of Direction Change to Number of Vessels

The results of this study displayed a positive correlation between the direction change and the number of vessels present, with most of these changes being exhibited by pod groups containing calves (**Figure 5**). Calves are especially vulnerable to increased vessel presence due to the higher likelihood of vessel collision, less knowledge of vessel movement, and decreased ability to partake in essential behaviors such as feeding, nursing, and learning how to care for themselves (Scheidat et al., 2004; Stamation et al., 2010). This may explain why calf groups had the highest sum of direction changes compared to all other whale pod types since vessels had a higher preference for chasing whale groups with calves. Results from this study show clear indications of behavioral change being a consequence of increased vessel presence, violating Panama's regulation that prohibits vessels from "chang[ing] the behavior of cetaceans" (*sensu* Carlson, 2010).

Previous research suggests that the proximity of boats is a robust predictor of the number of directional changes a whale might exhibit (Schaffar et al., 2013). As direction change is a tactic humpback whales use to avoid predators, this avoidance behavior may also be utilized when faced with a boat, which could be viewed as a perceived threat (Schaffar et al., 2013; **Table 2**). Several researchers suggest direction changes are also related to stress and could indicate an increased level of physiological disturbance (Kruse, 1991; Beale, 2007; Schaffar et al., 2013; Schuler et al., 2019; see **Table 2**). Thus, while avoidance behavior may ensure self and group preservation, it also comes at a physiological cost to the organism. Not only can increased levels of stress negatively impact an organism's health, but it can also inhibit normal whale behavior and interactions, which can disrupt social interactions (mother–calf pair in particular), mating, and foraging (Beale, 2007; Lusseau et al., 2009).

Regulatory Implications and Compliance

Due to concerns about whale interactions with vessels, Panama initially passed Resolution Decree ADM/ARAP No. 1 on 13 February 2007, to control the level of vessel disturbance on cetaceans to conserve their populations. Regulations from this decree require operators to have a permit for commercial operations, have a maximum of two whale-watching vessels per group, take extra care when calves are present, maintain a 250 m distance from the whales, and limited observation times to 30 min per group or no more than 15 min when calves are involved, and obey the restriction of individuals from entering the water with whales, to prevent altering the behaviors of cetaceans (*sensu* Carlson, 2010).

Lack of enforcement from the Panamanian government has elicited the reiteration and repeated implementation of these policies every year. While boat operators may be aware of the policies currently in place, there is little structural enforcement to ensure regulatory compliance. Better enforcement protocols must, therefore, be enacted to better ensure vessels are abiding by Panama's regulations. To reduce vessels from violating whale watching regulations, a satellite-based monitoring system should be implemented to track the activities of these vessels. This technology has already been shown to be successful in fisheries management plans and has alleviated illegal, unreported, and unregulated (IUU) fishing (Schmidt, 2005). Alternatively, lack of compliance may also be the result of poor communication from the government concerning the regulations, leaving local whale watching companies and boat operators with a lack of knowledge about the existence of these laws (Sitar et al., 2016, 2017).

In summary, Panama has strict whale watching operation regulations that are not being followed or enforced in the Las Perlas Archipelago. At multiple times throughout this study, we observed all laws pertaining to vessel regulations being broken at least once by boats. The on-going lack of regulation enforcement may result in more audacious decisions from boat operators in the future, leading to harmful or even lethal collisions with adult whales and calves. At the very least, these results show increased changes in whale behavior when vessels are present, which is illegal according to Panamanian protocols (*sensu* Carlson, 2010). Thus, it is highly recommended that both boat operators and tourists be educated about regulations and the importance of abiding by the law. While the purpose of this study was not to propose the eradication of whale watching, it was to highlight the potential harm being done due to the lack of compliance with responsible whale watching protocols. Responsible whale watching develops an interdependent relationship between people and whales: people gain from the ecosystem services provided by whales and economic income from this tourism industry, while whales benefit from less stress from vessels and indirectly from tour guides expanding environmental awareness and enlightening tourists about environmental or conservation issues. Continued whale research, monitoring, and modeling efforts in Panama must be implemented to better inform management decisions regarding stricter regulatory and enforcement protocols that are vital to minimize disturbance on this vulnerable population of humpback whales.

Conclusion and Future Research Recommendations

Although our study is limited to the short-term impacts of boat vessel presence on humpback whale behavior, long-term changes in behavior may indirectly lower reproduction rates (Lusseau and Bejder, 2007). This can occur through drowned out vocalizations and a reduction in the success of whales finding mates due to vessels altering whale group dynamics and travel direction (Weilgart, 2013). Additionally, whale health can be negatively affected due to chronic levels of stress, increases in energy expenditures, and discontinuation of essential behaviors such as feeding, resting, nursing, etc. (Parsons, 2012). Constant changes in behavior and less concentration on survival activities could result in eventual population declines over time, as groups with calves are the most vulnerable, especially as whale watching vessels prefer following calf groups for their charismatic physical characteristics and playful behaviors. Due to this increased vulnerability, Panamanian regulations need to contain extra provisions to ensure the protection of whale calves (*sensu* Carlson, 2010).

However, behavior and stress may not necessarily be coupled in a way that can be easily observed. This was evident in this study when some whales did not appear to change their behaviors despite increased levels of vessel interaction. It has been proven that animals may not exhibit avoidance behaviors, but nevertheless experience high levels of stress hormones (Schuler et al., 2019). For this reason, additional physiological studies are recommended. Previous studies have shown that biopsy samples of cortisol found within blubber samples can provide measurements of stress levels over several weeks to a month, which would provide insight into how stress levels may fluctuate throughout an entire whale watching season as the number of tourist boats changes (Noren and Mocklin, 2012; Teerlink et al., 2018). Alternative cortisol collection methods including fecal (Wasser et al., 2000; Rolland et al., 2005; Hunt et al., 2006; Burgess et al., 2013) and blowhole spray have also been shown to provide more acute measurements of stress related to vessel presence.

Future behavioral research should also include the use of more accurate measuring methods and tools. For example, the use of a theodolite tool would produce accurate distance measurements between vessels and whales, which is essential for understanding if distance impacts whale behaviors. Unmanned aerial systems (UAS) (drones) would allow for the collection of more accurate behavioral samples via less invasive observational methods (Torres et al., 2018). Visual observations could also be maintained more consistently by drones due to optimal viewing angles, as traditional vessel-based observations can only be made while the whale is surfacing. Additional social surveys should be collected from tourists, local communities, and boat operators to help us understand their impression of the whale watching industry and whether whale watching is, generally, of value.

In Las Perlas Archipelago, whale watching generates income for local communities. It also creates employment opportunities and provides ecosystem services to tourists, residents, and boat operators. However, if disturbances to these whales continue unabated, it may lead to the eventual abandonment of the Archipelago by the population, as has occurred in other popular whale-watching locations elsewhere in the world (Dean et al., 1985). The satisfaction of tourists is vital to the ongoing sustainability of the Panamanian ecotourism industry, as a report by the World Bank in 2005 found that two-thirds of all visitors to Panama were motivated to visit the country due to environmental or ecotourism reasons and income from international tourists totaled 7% of the GDP (World Bank, 2005, p. 9). Decreases in tourist motivation to partake in ecotourism activities such as whale watching potentially cause the industry to suffer, thereby affecting the Panamanian economy. This is already somewhat evidenced by the drastic decrease in tourism caused by the COVID-19 pandemic. Understanding the dynamic changes in human well-being and animal population viability are critical for establishing effective wildlife conservation strategies. Variations in socioeconomic factors that benefit the local communities can motivate more people to protect and care about whales. It is therefore important to consider the coupled nature of ecological and socio-economic systems to understand the impacts of wildlife tourism on both humans and nature.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The animal study was reviewed and approved by Smithsonian Tropical Research Institute and the Institutional Animal Care and Use Committee.

AUTHOR CONTRIBUTIONS

AA is the primary author and this research is a component of her M.S. thesis paper. HG, BP, KS, and LG contributed to the overall idea, writing, research, data collection, and analysis of this paper. All authors contributed to the article and approved the submitted version.

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Energetic Effects of Whale-Watching Boats on Humpback Whales on a Breeding Ground

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Interactions between whale-watching boats and cetaceans can lead to changes in their behavior. From a management perspective, it is important to understand how this type of disturbance can be translated into physiological effects, such as changes in their energetic metabolism. Humpback whales (*Megaptera novaeangliae*) typically do not feed while in breeding grounds, thus they depend on finite energy reserves. The effect of whale-watching boats on the energetic metabolism of humpback whales, in the breeding ground of northern Peru (4°10′35″S, 81°08′03″W) was evaluated. Groups of humpback whales were tracked from land, under the following scenarios: with, without, and before-during-after the presence of whale-watching boats. Mass-specific cost of transport (COT) was used as a proxy of energetic efficiency and calculated from swimming speed and breath frequency estimations. No differences were detected in breath frequency, swimming speed, and COT when comparing whales with and without boats. However, in the presence of boats, swim speed increased, and COT decreased as the number of boats increased. Exponential increment in breathing frequency at higher swimming speed was not detected. The absence of swimming speeds beyond the assumed optimal range suggested no shifts into metabolic inefficiency. Our results suggest optimal swimming speed between 2 and 4.05 m/s, representing COT values between 0.020 and 0.041 J × (kg × m)$^{-1}$. In light of our results, we encourage the implementation of regulations of the activity, particularly limiting the number of boats interacting with the same group of humpback whales.

Keywords: mass-specific cost of transport, optimal swimming speed, efficiency of transport, anthropogenic perturbation, energy consumption, baleen whale

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INTRODUCTION

Whale watching, the observation of dolphins and whales in nature, is a growing economic activity in oceanic and coastal waters in many regions of the world. As whale watching grows, several studies have demonstrated the negative consequences of this activity on the behavior of cetacean species (reviewed in Senigaglia et al., 2016). Effects have been reported for small and large cetacean species including alterations in swimming speed, direction, breathing frequency, and overall behavior (e.g., Noren et al., 2009; Christiansen et al., 2010; Stamation et al., 2010; Senigaglia et al., 2016; García-Cegarra et al., 2019). Studies have linked those behavioral changes into effects on energy budget and metabolism of the species (e.g., Williams et al., 2006; Christiansen et al., 2013, 2014a). Physiological responses are essential for a better understanding of organismal and population consequences of the disturbance caused by whale-watching boats (Costa, 2012; New et al., 2015; Pirotta et al., 2018).

Mating, breeding, and migration are highly energy-demanding activities for cetacean species. Southern right whales (*Eubalaena australis*) lose on average of 25% of their body volume during the breeding season (Christiansen et al., 2018). To minimize the rate of decline in body condition and optimizing calf growth during migration to their feeding ground, lactating humpback whale females reduce their metabolic rate to half that of adults in foraging grounds (Bejder et al., 2019; Nielsen et al., 2019). During breeding, fin whales (*Balaenoptera physalus*) consume between 19 and 26% of their energy reserves (Lockyer, 1981, 1984). Significant reductions in net energy intake and/or increases in energy expenditure can lead to changes in body condition (Frid and Dill, 2002). Fetal growth (Christiansen et al., 2014b) and calf body condition (Christiansen et al., 2016, 2018) of mysticeti whales is significantly determined by the body condition of the maternal female. Energetic consequences of behavioral changes could lead to long-term reductions in body condition, reproductive success (fitness), leading to negative population consequences (Pirotta et al., 2018). Whale watching can disturb critical behaviors such as lactation thus, reducing the energy transfer from the mother to the calf, affecting growth rates, which can have consequences in migratory timing and heat loss. Overall, these effects may lead to negative consequences for the long-term individual survival, reproduction success, and recruitment into the population (Bejder, 2005; Lusseau, 2006; Nowacek et al., 2016).

Studying the physiology of large sized, free-ranging cetaceans is difficult due to the methodological and logistical constraints. However, based on indirect estimations several studies have showed how behavioral changes can translate into physiological variability (Christiansen and Lusseau, 2015; Pirotta et al., 2018). For example, a 23.2% increase in energy expenditure was detected for traveling minke whales (*Balaenoptera acutorostrata*) due to increasing breath frequencies during interactions with whale-watching boats (Christiansen et al., 2014a). Energy intake of minke whales and killer whales (*Orcinus orca*) was reduced by 42 and 18% because approaching whale-watching boats induced a reduction of feeding times (Williams et al., 2006; Christiansen et al., 2013). So far, no changes have been reported in the energetic budget of humpback whales (*Megaptera novaeangliae*) in feeding grounds during whale watching (Di Clemente et al., 2018). Understanding behavior variability and underlying changes in physiology can provide knowledge to establish links between short and long-term consequences of disturbance on species of cetaceans (New et al., 2015; Pirotta et al., 2018).

The humpback whale is one of the most popular species for whale watching (O'Connor et al., 2009). A suite of negative effects in response to whale-watching boats, such as the alteration of surfacing and diving behavior, aerial activity, acoustic behavior, and swimming speed (e.g., Corkeron, 1995; Scheidat et al., 2004; Sousa-Lima and Clark, 2008; Stamation et al., 2010; García-Cegarra et al., 2019) have been documented on the species. Humpback whales migrate from polar and temperate feeding grounds to tropical and subtropical breeding grounds (Dawbin, 1966). In the latter, humpbacks whales typically do not feed (Chittleborough, 1965), and depend on the energetic reserves stored in the blubber layer, muscles, visceral organs, and bones (Nordøy et al., 1995; Gunnlaugsson et al., 2020) acquired during the feeding season. Although feeding events have been observed in breeding and migratory routes (Stamation et al., 2007; Frisch-Jordán et al., 2019; De Weerdt and Ramos, 2020), energy intake is limited or absent during the breeding season.

Here, we investigated the effect of whale-watching boats on the energy consumption and efficiency of humpback whales in the coast of northern Peru, Southeast Pacific. This population is also known as stock G (IWC, 1998), and its breeding ground ranges from northern Peru to Costa Rica (Scheidat et al., 2000; Acevedo et al., 2017; Valdivia et al., 2017) and possibly up to Nicaragua (De Weerdt et al., 2020). Respiratory rates have been used to estimate the mass-specific cost of transport (COT), for large animals under undisturbed and disturbed conditions (Williams and Noren, 2009; Langman et al., 2012; Christiansen et al., 2014a; Maresh et al., 2014). This metric includes the mass and transport as a relative measure of the metabolic rate. COT can provide insights about the overall energy expenditure during movements, and how efficiently the energy is used relative to the distance traveled (Tucker, 1970). An optimal range of transport can then be estimated based on the range of swimming speeds where the COT is reduced to its minimum. Thus, variation in COT could be a useful proxy to understand the physiological effects of whale watching on cetaceans. We predicted that approaching whale-watching boats to whales would lead to an increase in energy consumption by increasing swimming speeds and breath frequencies.

MATERIALS AND METHODS

Study Area

Daily land-based surveys were performed from a rocky cliff named "Cerro La Mesa" at 31 m above the sea level. From this position, we covered a panoramic view of 7 km of radius (153km^2 of area) of the coastal area between El Ñuro (4°13′01″S, 81°10′35″W) and Máncora (4°06′26″S, 81°02′50″W), where whale-watching activities are conducted (**Figure 1**). Observation of whales and boats were performed daily, between 07:00 and 10:00 from July 17th to August 29th and from September 5th to October 15th in 2016. During the study period, weather conditions were favorable during 95% of the survey days with visibility of 6 to10 km. Sea conditions allowed the tracking of whales throughout the study period with Beaufort states between 0 (34%) and 1 (66%). The area has been described as the Southern limit of the breeding ground of Stock G with the season ranging from mid-July to the end of October (Pacheco et al., 2009; Guidino et al., 2014).

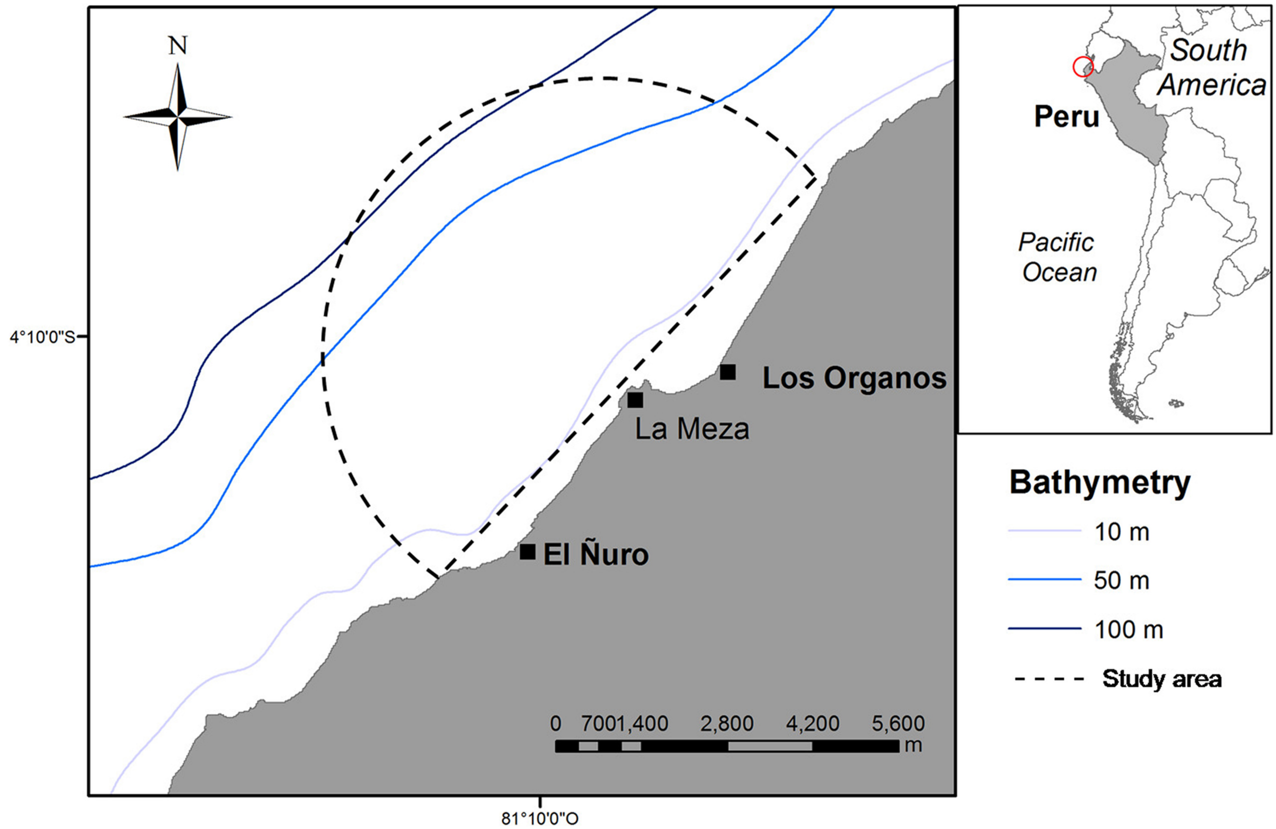

FIGURE 1 | Location of the studied area. Semi-circle represents the 7 km vision range from the observation point at "Cerro la Meza."

Sampling Methods

Groups of humpback whales were recorded by continuous focal group follows (Altmann, 1974) using a digital theodolite (Nikon NPL-322, Nikon Trimble, Tokyo, Japan) and 15×50 Nikon binoculars. A group was defined as individuals of whales within 100 m distance of each other, moving in the same direction and displaying almost synchronized diving and movement patterns (Whitehead, 1983; Mobley and Herman, 1985). Calves were identified as whales with sizes ranging from one to two-thirds of the size to their accompanying adult, assumed to be the mother (Herman and Antinoja, 1977; Mobley and Herman, 1985). Groups of humpback whales were classified into two main categories: groups with calves and groups without calves. Mother-calf and mother-calf with one or more escorts were considered as groups with calves, while groups including only adults or sub-adults were considered as groups without calves (**Supplementary Table 1** provides a description of all group categories). Tracking of focal groups started when both observers (DV and AGC) spotted humpback whales with binoculars. Once the group was spotted and followed unequivocally for more than 10 min, the group was chosen as a focal group for tracking. The type of group and number of individuals was defined at the initial sighting and confirmed during the tracking. If the focal group splitted, one of the groups was chosen to continue tracking. When groups merged, the tracking continued for the focal group. However, this type of variability in the dynamics of the groups was not included in the analysis of this study.

Horizontal and vertical angles were recorded, based on a georeferenced reference point, for each emergence of the focal group using the digital theodolite. Using the sinus theorem, elevation, and coordinates of the reference point, the angles were converted into geographic coordinates and geographic tracks for each focal group. The specific details of the methodology are provided in García-Cegarra et al. (2019) including the geographic position of the tracks. A preliminary analysis of track accuracy was carried out by tracking a moving boat and recording its position every 5 min. A measurement error of 35 m for distances >4.5 km was estimated (Romero, 2015) and used to correct all geographic calculations. For groups with more than one adult, the first adult emerging to the surface was considered as reference for the overall group movement. The total distance traveled by each group was calculated as the sum of distances between each recorded surfacing location. Simultaneously, the number of breaths of each whale, the number of boats (when present), and the time surfacing of the whale group were recorded.

The distance between focal groups and whale-watching boats was measured using the digital theodolite, following the same method as for the focal groups. We considered an interaction threshold of 400 m distance between whales and boats following Baker and Herman (1989). However, behavioral changes can occur before boats enter this threshold distance (e.g., Watkins, 1986; Baker and Herman, 1989; Sprogis et al., 2020a). Sprogis et al. (2020b) demonstrated that vessel noise drives the behavioral response of humpback whales to boats. Although, we recorded the number of boats and their timing with the whales, the limitations imposed by the distance of the land-based survey, precluded us to unravel the role of noise of the boats on the behavior of the whales.

To measure the swimming speed and breath frequency of whales in the presence and absence of whale-watching boats, a minimum of 10 min of interaction was determined as lower time threshold. This value was determined to increase the precision of the measurements and to reduce the amount of interaction events inadequate for estimations. For example, for whales emerging every 8–9 min, the presence of a whale-watching boat for less than 10 min would only allow to register one emergence. This would only provide one record of breath thus traveled distance, and swimming speed cannot be estimated. Even though, whale responses to approaching boats may occur in a shorter period of time (<10 min), we assumed that these short burst events are unlikely to have an important impact on the overall energy efficiency. To avoid underestimation and bias in traveled distance, swimming speed and breath frequency estimations, only relative linear tracks were used in the analysis (Christiansen et al., 2014a). Tracks with whales logging at the surface were also removed from the analysis. Based on the presence and absence of whale-watching boats, focal groups were divided into three independent scenarios: before, during, and after the presence of whale-watching boats. Data from groups tracked before-during, during-after or before-during-after the presence of boats were divided into two and/or three dependent observations, respectively. For example, a before-during track was divided into two data observations, one going to the before scenario and the other to the during scenario. Tracks with the boat always present or absent provided one measurement each, while tracks before-during; during-after or before-during-after, provided 2 or 3 measurements, respectively.

The average swimming speed (S) of the focal groups was calculated by dividing the sum of the distances traveled between all emergence positions by the total time of the track. Breath frequencies (f) of humpback whales was calculated by dividing the total number of breaths per individual by the total time of the track. For groups with two or more adult whales, the total number of breaths was recorded for the group and finally divided by the number of adults to obtain the individual breath frequency. For groups with calves, breath frequencies and swimming speeds were calculated based only on the adult's behavior. This study was carried out under the approval of the Comité de Ética de Investigación Científica de la Universidad de Antofagasta, Chile (CEIC REV N° 039/2017 and 7298/2015).

Data Analysis

Mass-Specific Cost of Transport Estimation

The calculated swimming speed and breath frequency were used to calculate the mass-specific cost of transport (COT) following the methodology described in Christiansen et al. (2014a). **Supplementary Table 2** shows a summary of the parameters, equations, theoretical values, and references used for the estimation of COT in humpback whales.

The respiratory volume per minute, V_{min} ($l \times min^{-1}$, the volume of air breathed per minute) was calculated from the measured breath frequency, f ($breaths \times min^{-1}$) and the tidal volume, V_t ($l \times breath^{-1}$, volume of air inhaled per respiratory cycle.

$$V_{\mathrm{min}} = V_{\mathrm{t}} \times f$$

The tidal volume for humpback whale was assumed to be 60% of the volume or lung capacity, V_c (Wahrenbrock et al., 1974; Blix and Folkow, 1995).

$$V_t = 0.6 \times V_{\mathrm{c}}$$

The lung capacity (V_c) was estimated from the body mass of the humpback whale (Dolphin, 1987).

$$V_c = 53.5 \times W^{1.06}$$

The body mass, W (kg), was estimated from the average length (Lockyer, 1976). L refers to the length of the whale in meters. The average size (12.2 m) for both sexes based on humpback whale catch data of Peru, between 1961 and 1966, (Ramírez, 1988) was used for this purpose, resulting in average weight for individuals of both sexes of 25 317 kg.

$$W = 15.8 \times L^{2.95}$$

The oxygen consumption rate, V_{O2} ($l\ O2 \times min^{-1}$, volume of oxygen consumed per minute) was estimated from the respiratory volume per minute (V_t), the oxygen concentration in the air, P_{O2} (0.21, ratio of O_2 in the inspired air) and the oxygen extraction rate, E_{O2} (Blix and Folkow, 1995). The oxygen extraction rate from the air in the lungs during a respiratory cycle was established at a value of 45% (Wahrenbrock et al., 1974; Blix and Folkow, 1995).

$$V_{O2} = V_{\mathrm{min}} \times E_{O_2} \times P_{O_2}$$

The metabolic rate, MR ($J \times min^{-1}$), energy consumed per minute, was estimated by transforming the oxygen consumption rate V_{O2}, into energy units using the conversion factor 20.1 $kJ \times l_{O2}{}^{-1}$ (Blix and Folkow, 1995).

$$MR = (20.1 \times V_{O2})$$

Finally, the Mass-Specific Cost of Transport (COT; $J \times [kg \times m]^{-1}$), energy consumed per kilogram of body weight and per meter displaced, was calculated based on the metabolic rate, MR ($J \times min^{-1}$), swimming speed, S ($m \times s^{-1}$) and body mass of humpback whales, W (kg) (Sumich, 1983; Culik et al., 1994; Williams and Noren, 2009).

$$COT = MR \times [S \times W]^{-1}$$

Only adult whales were used in the analyses, to avoid confounding effects of growth on the metabolic rates. COT for calf groups was estimated from the breath frequency and

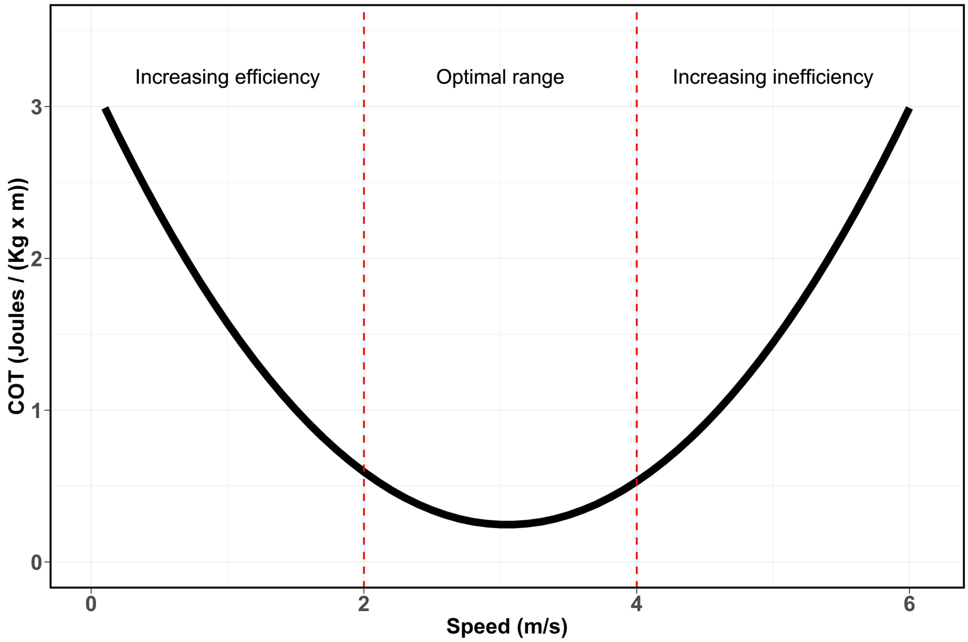

FIGURE 2 | U-shaped curve (Schmidt-Nielsen, 1972) showing the relationship between speed and cost of transport based on energetic efficiency. Red dashed lines represent the theoretic division of the curve based on metabolic efficiency. Increasing swimming speed, increase the energetic efficiency by reducing the COT. This reduction continues until the optimal range of transport, where the maximum efficiency and minimum COT are reached. Finally, when speeds continue to increase, COT increases rapidly leading to an increasing energetic inefficiency.

swimming speed of the adult individual in each group (e.g., the mother). Even though this data would not reflect newborn metabolism, we assumed that the changes in behavior and metabolism of the adult/s in a group with calves could be an indirect proxy of the stress that the calf faces during whale watching.

Statistical Analysis

Effect of Whale-Watching Boats

We hypothesized that breath frequency and swimming speed will increase while COT decreases between before and during scenarios and return to normal conditions after the boats have left. Higher number of boats and longer times spent with the whale groups will increase the mentioned effect in the three variables during the activity. To test the differences in the breath frequency, swimming speed and mass-specific cost of transport, three regression models were developed using an estimation procedure based on generalizing estimating equations for the generalized linear models (glm) and for the normal model. Normality of the variables was obtained after a log transformation for breath frequency and swimming speed and a logit transformation for COT. Observations of the same groups of whales (e.g., Before-During) were not independent, thus an exchangeable correlation structure was used for these observations. Each model tested the effects of the scenario (before, during, after) and calf presence on the breath frequency, swimming speed and COT. We analyzed the effect of the presence of calf on each of the models as several studies have already reported significant differences in behavior between groups with and without calves (Corkeron, 1995; Stamation et al., 2010; Craig et al., 2014; Sprogis et al., 2020a). The effect of the number of boats and time spent with the group of whales in the three variables was tested for the during and after scenarios. The estimations were performed using the geepack (Højsgaard et al., 2006) package in R (R Core Team, 2020) version 4.0.2.

Energy Efficiency

Non-linear regressions were performed between COT and swimming speeds values to determine whether these variables follow a U-shaped curvilinear relationship (Schmidt-Nielsen, 1972) as it has been documented for other marine mammals species (**Figure 2**, e.g., Williams et al., 1993; Otani et al., 2001; Rosen and Trites, 2002; Williams and Noren, 2009). The curve indicates that optimal speed ranges of transport can be detected when COT reaches its minimum values due to higher efficiency in the consumption of energy for displacement. However, when swimming speed increase beyond this range, the breath frequency increases disproportionally due to an increasing oxygen demand. This drastically reduces the energetic metabolism efficiency during transport and can be observed as an inflection point followed by an exponential increase of the COT values. Similarly, when analyzing the link between swimming speed and breath frequency, the onset of energetic inefficiency can be observed by an exponential increase of the breath frequency when speed exceed its optimal range (Williams et al., 1993; Yazdi et al., 1999). Linear regressions between swimming speed and breath frequency were performed to determine the relationship between the two variables. All tests and statistical analyses were performed using R version 4.0.2.

RESULTS

A total of 167.4 h of survey were completed. 132 h were used to visually follow focal groups; 39% (51.5 h) without and 61% (80.5 h) with whale-watching boats. A total of 412 humpback whales were followed in 173 focal groups: 91 groups without calves and 82 groups with calves (**Table 1**). From the 173 focal groups, 67 and 48 whale groups were tracked with boats always absent and absent, respectively. Also, 29, 20, and 9 groups were tracked before and during; during and after; and before, during, and after the presence of boats, respectively. Dividing groups into their respective encounter scenarios and adding the tracks where boats were always present (during) or absent (before), a total of 105, 106, and 29 breath frequency, swimming speed and COT measurements were, respectively, obtained for the encounter scenarios before, during, and after (**Table 1**). A mean of 3.13 (SD = 1.52; range: 1–9) and a maximum of 9 whale-watching boats were observed with the focal groups. On average boats followed groups of whales during 48.32 min (SD = 25.15 min, range: 13–125 min) and keeping an average minimum distance of 39.26 m (SD = 47.21 m, range: 6–125 m).

Significant differences between groups with calves and without calves were found for breath frequency and swimming speed. Based on significant coefficients, groups without calves registered breath frequencies and swimming speeds 18.43 and 25.78% higher, respectively, than groups with calves (**Tables 2**, **3**). Groups without calves breathed and swam at median values of 0.67 (IQR = 0.45) breaths $\times$ min^{-1} and 1.68 (IQR = 0.76) m $\times$ s^{-1}, while groups with calves breathed and swam at median values of 0.561 (IQR = 0.34) breaths $\times$ min^{-1} and 1.3 (IQR = 0.82) m $\times$ s^{-1}, respectively. No significant differences were found for the mass-specific cost of transport [$COT_{withoutcalf}$ = 0.045 (IQR = 0.04); $COT_{withcalf}$ 0.047 (IQR = 0.041) J $\times$ $[kg \times m]^{-1}$] between the these groups (**Tables 3**, **4**).

Effects of Whale-Watching Boats

Breath frequency, swimming speed, and COT, did not change significantly between before and during the presence of whale-watching boats. Likewise, no significant differences in breath frequency, swimming speed and COT were found between before and after, or between during and after (**Table 3**). The number of boats present, and the duration of interactions had a significant effect on breath frequency, swim speed and COT. Each additional boat with the whale group (e.g., from 2 to 3 boats) led to a 7% increase of the median swimming speed and a 10% reduction of the median COT. Furthermore, boats spending more time with a whale group led to a reduction of the speed of the groups, as each additional minute spent with the whale groups represented a significant 0.5% decrease in the median of swimming speed. This effect was present even after the boat left, as each additional minute spent with the whale group lead to a significant 0.4% in the median of swimming speed (**Tables 2**, **3**).

TABLE 1 | Summary of the number of tracks registered per scenario and type of group (with/without calf).

Presence of boat	Encounter scenarios			Type of group	
	Before	During	After	With calf	Without calf
Absence only	67	–	–	22	45
Presence only	–	48	–	26	23
Before-During	29	29	–	16	13
During-After	–	20	20	13	8
Before-During-After	9	9	9	5	4
Total	105	106	29	82	91

TABLE 2 | Estimated coefficients and standard error (S.E.), for each of the parameters of the models developed for breath frequency (*f*), swimming speed (S), and mass-specific cost of transport (COT).

Parameter	*Y* = log(f)		*Y* = log(S)		*Y* = logit(COT)	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Before	−0.396	0.0511	0.3918	0.0447	−2.9115	0.0680
During	0.0577	0.1138	0.1827	0.1128	−0.1410	0.1680
After	−0.1600	0.1745	0.0710	0.1667	−0.2273	0.3050
Calf	−0.1823	0.0601	−0.2578	0.0605	0.0794	0.0918
During boat presence						
Number of Boats	−0.0274	0.0302	0.0717	0.0336	−0.1056	0.0478
Time	0.0003	0.0016	−0.0061	0.0025	0.0069	0.0036
After boat presence						
Number of Boats	0.0020	0.0432	0.0418	0.0469	−0.0455	0.0793
Time	0.0037	0.0024	−0.0043	0.0020	0.0087	0.0044

TABLE 3 | Wald-test and *p*-values for each the hypothesis tested for the models developed for breath frequency (*f*), swimming speed (S), and mass-specific cost of transport (COT).

Hypothesis tested	*Y* = log(f)		*Y* = log(S)		*Y* = logit(COT)	
	W-test	*p*-value	W-test	*p*-value	W-test	*p*-value
Before vs. During	0.26	0.6101	2.62	0.1055	0.7	0.4028
Before vs. After	1.23	0.2674	0.35	0.5541	0.07	0.7913
During vs. After	0.84	0.3594	0.18	0.6714	0.56	0.4543
With Calf vs. Without calf	9.41	0.0022	18.13	<0.0001	0.75	0.3865
During boats presence						
Number of Boats	0.83	0.3623	4.55	0.0329	4.88	0.0272
Time	0.02	0.8875	6.18	0.0129	3.69	0.0547
After boats presence						
Number of Boats	<0.001	>0.9999	0.8	0.3711	0.33	0.5657
Time	2.47	0.116	4.48	0.0343	3.86	0.0495

Energetic Efficiency

Groups with and without calves showed the same pattern; high COT values at low swim speeds (**Figure 3**). Increasing swimming speeds led to a significant decrease in the COT, following a power function in groups with calves (**Figure 3A**, COT = 0.069 $\times$ $S^{-0.95}$, pseudoR^2 = 0.63) and without calves (**Figure 3B**, COT = 0.085 $\times$ $S^{-1.05}$, pseudoR^2 = 0.53). Changes in

TABLE 4 | Median (Interquartile range) values for groups with and without calves of humpback whales. *n* = number of observations.

Variable	Groups with calves (*n* = 121)	Groups without calves (*n* = 119)
Breath frequency	0.561 (0.34)	0.67 (0.45)
Swimming speed	1.30 (0.82)	1.68 (0.76)
COT	0.047 (0.041)	0.045 (0.04)

swimming speed explained between 53 and 63% of the variation of the COT values. Minimum COT was registered between 2 and 3.2 m × s^{-1} for groups with calves and between 2 and 4.05 m × s^{-1} for groups without calves, determining mass-specific costs of transport between 0.023–0.036 and 0.020–0.041 J × $[kg \times m]^{-1}$, respectively. However, the true minimum COT values remain unknown as no inflection point, where COT is excepted to increase, was detected during the movement of groups with and without calves.

While the presence of whale-watching boats did not lead to significant increases in the breath frequency of humpback whales, breath frequency increased linearly with swimming speed (**Figure 4** f= 0.57+0.07 × S; R^2 = 0.018; F-stat = 2.17; *p*-value = 0.03), at a rate of 0.07 breaths × min^{-1} for every m × s^{-1} increase in swim speed. However, breath frequency in humpback whale groups might be influenced by other factors, as only 1.8% (R^2: 0.018) of its variability was explained by changes in swimming speed.

DISCUSSION

Behavioral responses to whale-watching boats can potentially lead to an increase in the metabolic rate in cetaceans due to an increase in breath frequency and swimming speed (e.g., Christiansen et al., 2014a). Our results suggest that the mere presence of whale-watching boats does not lead to significant behavioral changes, but as the number of boats increased, so did the breath frequency and swim speed of the whales. Energy expenditure during transport remains near optimal values. No increments in mass-specific cost of transport were recorded and breath frequencies continued to increase linearly within the range of measured swimming speed.

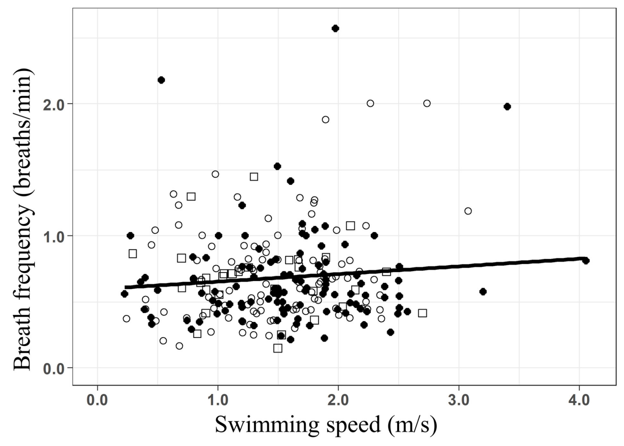

FIGURE 4 | Linear regression of the breath frequency (breaths/min) as a function of the swimming speed (m/s) for all groups of whales (*f*= 0.57+0.07 × S; R^2 = 0.018; F-stat = 2.17; *p*-value = 0.03). Data from before (◯), during (•), and after (☐) the presence of the whale-watching boats.

When assessing the impact of whale-watching boats on humpback whales, typically breath frequencies, and swimming speeds have been estimated (e.g., Scheidat et al., 2004; Morete et al., 2007; Stamation et al., 2010). Both slower swimming speed and lower breath frequencies have been often reported for

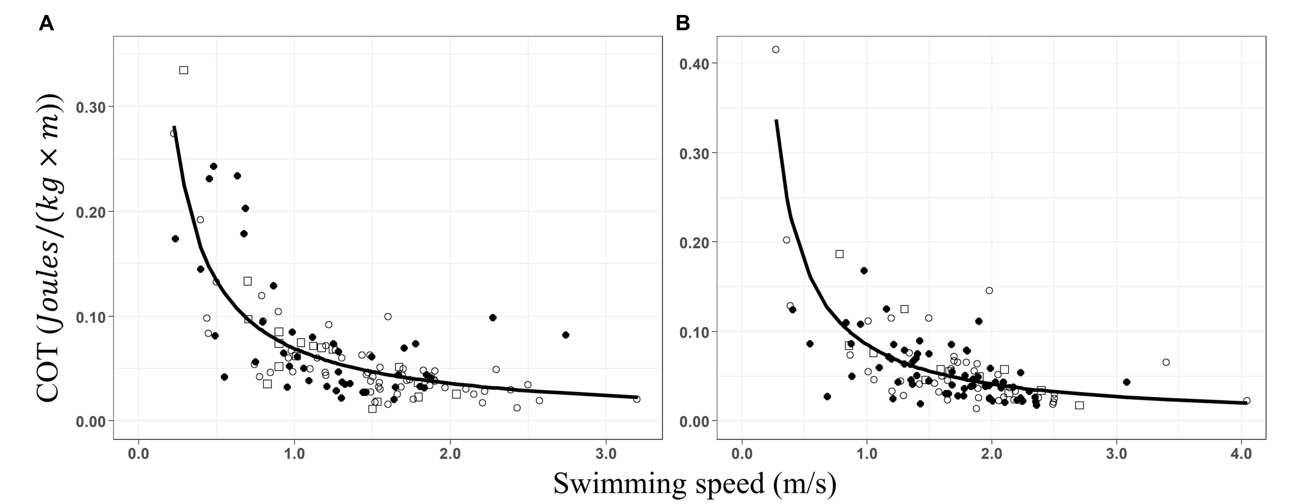

FIGURE 3 | Non-linear regressions of the mass-specific cost of transport (COT; J × $[kg \times m]^{-1}$) as a function of the swimming speed (m/s) for **(A)** groups of whales with calves (COT = 0.069 × $S^{-0.95}$, R^2 = 0.63) and **(B)** groups without calves (COT = 0.085 × $S^{-1.05}$, R^2 = 0.53). Data from before (◯), during (•), and after (☐) the presence of the whale-watching boats.

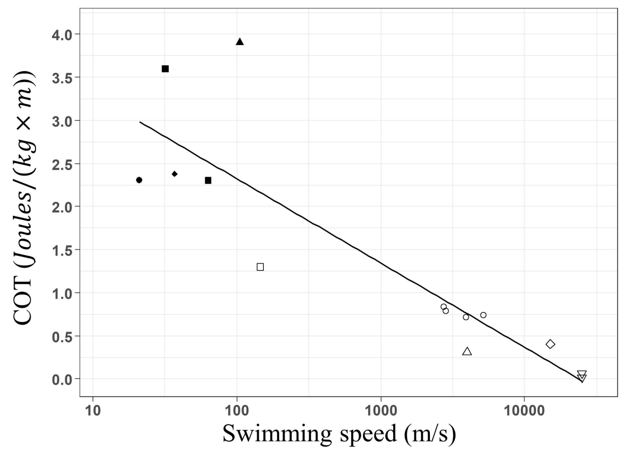

FIGURE 5 | Linear regression between the estimated optimal mass-specific cost of transport and mass of cetacean species. California sea lion *Zalophus californianus* (●: Fedak and Seeherman, 1979; Williams et al., 1991; Williams, 1999), Harbor seal *Phoca vitulina* (■: Davis et al., 1985; Williams et al., 1991), Harbor porpoise *Phocoena phocoena* (♦: Otani et al., 2001), gray seal *Halichoerus grypus* (▲: Fedak and Seeherman, 1979), Bottlenose dolphin *Tursiops truncatus* (□; Williams et al., 1993), Killer whale *Orcinus orca* (○: Kriete, 1995; Williams and Noren, 2009), Minke whale *Balaenoptera acutorostrata* (△: Blix and Folkow, 1995; Christiansen et al., 2014a), Gray whale *Eschrichtius robustus* (◇: Sumich, 1983) and Humpback whale *Megaptera novaeangliae* (▽: present study). Minimum COT decreases linearly with weight of marine mammal species following the function: COT = 4.14–0.420 × log(W), R^2 = 0.75, F-stat = 40.35, p = 3.653e^{-5}. Fitted values of the linear model are presented by the black line.

groups with calves (Carvalho-Gonçalves et al., 2018; Bejder et al., 2019). Mother and calf groups face physical and physiological challenges, because calves are learning social skills, have less muscle strength, and lung size compared to adults. This reduces their escape response capacity (e.g., fast swimming) when facing natural predators such as killer whales, harassment of competing adult males or whale-watching disturbance. In breeding grounds, calf groups inhabit shallow and calm waters to reduce disturbance by competitive adults (Smultea, 1994) and optimizes the energy transfer from the mother to the new-born during nursing (Cartwright and Sullivan, 2009; Sullivan and Cartwright, 2009; Videsen et al., 2017). Our minimal COT estimations for a 25,317 kg adult humpback whale, ranges around 0.023 J × [kg × m]$^{-1}$ for groups with calves and 0.02 J × [kg × m]$^{-1}$ for groups without calves. We developed a log-linear regression between body mass and COT values, using published values for other marine mammals including our results. Our estimates fitted into this regression (**Figure 5**, COT = 4.14–0.420 × log(W), R^2 = 0.75, F-stat = 40.35, p = 3.653e^{-5}), confirming that they occur within the expected range for an animal of 25,000 kg.

The Effects of Whale-Watching Boats

In contrast with results elsewhere (e.g., Corkeron, 1995; Scheidat et al., 2004; Schaffar et al., 2010; Stamation et al., 2010), the sole presence of whale-watching boats did not trigger changes in the behavior of humpback whales. However, each additional boat led to a significant 7% increase of the swimming speed, and consequently a 10% COT reduction. Similarly, a high number of whale-watching boats at less than 400 m induced killer whales to follow a more sinuous swimming path (Williams et al., 2002; Williams and Ashe, 2007) together with an increase in their swimming speed (Williams et al., 2002). Arguably a higher number of boats could result in a higher noise level. Higher noise levels can induce strong behavioral changes in humpback whales (Sprogis et al., 2020b). This can explain the differences in response of humpback in function of the numbers of boats observed in our study. Also, a high number of boats may lead to a lower degree of compliance with the voluntary guidelines for whale watching proposed for this region (Pacheco et al., 2011). Boats positioning themselves closer to the whales presumably to ensure the satisfaction of the tourist (García-Cegarra and Pacheco, 2017). Although this study did not gather information on specific features of the boats such as the type of engines, we recognize that different boat-engine configurations can lead to different noise levels, which may finally translate into different levels of disturbance. The time that boats spent with whales led to significant decreases in the swimming speed of groups of whales during and after the presence of the boat. The latter effect may be related to whale-watching boats performance. Groups of whales swimming at high speed will usually be sighted by boats for less time because they are more difficult to follow from a tour boat.

The data presented here fitted the first half of the typical U-shaped relationship between COT and swimming speeds. Increasing swimming speed, implies a reduction of breaths per kilometer traveled, hence reducing COT values and reaching a minimum when reaching the optimal range of transport. The second half of the U-shaped curve was not observed, as the recorded maximum swimming speeds (4.05 m × s^{-1}) did not exceed the optimal range. Similarly, studies on harbor porpoises (*Phocoena phocoena*) (Otani et al., 2001), killer whales (Williams and Noren, 2009), and minke whales (Christiansen et al., 2014a) did not register the second half of the U-shaped curve. Conversely, Williams et al. (1993) and Yazdi et al. (1999) described the complete curve for bottlenose dolphins (*Tursiops truncatus*), showing that COT increases when reaching speeds beyond the optimal range. Both studies were performed by dolphins trained to reach specific speeds, in confined (e.g., dolphinarium) and open water (e.g., following boats). Our results suggest that such speeds may not be reached in natural conditions and individuals will tend to maintain energy efficiency during travel even when facing disturbance.

The optimal swimming speed estimated for humpback whales ranged between ca. 2 and the maximum speed recorded in our study, 4.05 m × s^{-1}, generating minimum COT values between 0.020 and 0.041 J × [kg × m]$^{-1}$. As no inflection point and subsequent increase of the COT were recorded, energetic efficiency was maintained during tracking. However, since the second half of the U-shaped curve was not detected, the upper limit of the optimal swimming speed range cannot be determined with accuracy. Records of humpback whales swimming at more than 4.05 m × s^{-1} would be needed to determine if the optimal range continues beyond our estimated range. Additionally, breath frequencies increased linearly with

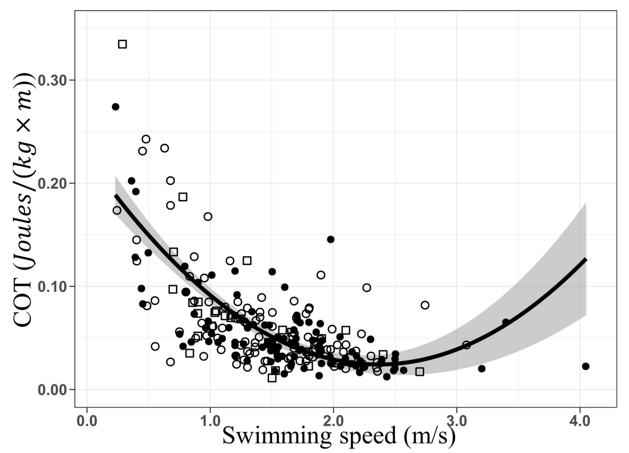

FIGURE 6 | Quadratic regressions of the mass-specific cost of transport (COT; J × [kg × m]$^{-1}$) as a function of the swimming speed (m/s). COT = 0.22–0.17 × S+0.03 × S^2, R^2 = 0.46, F-stat = 103.8, p = 2.2e^{-16}. Data from before (◯), during (•), and after (☐) the presence of the whale-watching boats. Gray area represents the standard error.

increasing swimming speed, confirming persistence of energetic efficiency (Williams et al., 1993) over the range of swimming speeds recorded. Similar results have been described for killer (Williams and Noren, 2009) and minke whales (Christiansen et al., 2014a). Performing a quadratic regression, a possible inflection and increase of COT was explored (**Figure 6**). An inflection point can be noted between 2.3 and 2.4 m × s^{-1} and an optimal swimming speed range between 2 and 2.6 m/s. However, the low number of groups of whales swimming at speeds exceeding this range (S>2.6 m/s), increases notably the standard error reducing prediction accuracy. The optimal range could extend further, or on the contrary higher swimming speed could directly lead to energetic inefficiency. Experiments carried in controlled conditions and with small cetaceans (Williams et al., 1993; Yazdi et al., 1999), allowed to exceed their optimal range. This performance is unlikely to occur in large cetaceans like the humpback whale in nature.

Cetaceans may respond to human disturbance as they do against natural predators (e.g., killer whales) (Christiansen and Lusseau, 2012). Some species of baleen whales maintain high and sustained speeds to avoid killer whale attacks (Ford et al., 2005; Ford and Reeves, 2008). When chased by orcas, minke whales can keep high velocities for several hours (ca. 8.5 h) over large distances (ca. 18 km) (Ford et al., 2005). Humpback whales may physical defense themselves when confronting predators. Mothers would defend their calf when facing attacks from killer whales (Pitman et al., 2017). Species of cetacean that fight predators, tend to be less hydrodynamic but with a better ability to maneuver and with robust bodies with callosities that could be used as weapons or amour (Ford and Reeves, 2008). However, they can also sustain high speed when fleeing from predators. In humpback whales, the presence of a single boat may not trigger an escape response, however, several boats may elicit a fast response.

Humpback whales of Breeding Stock G face other anthropogenic stressors such as entanglement with fishing gears, shipping noise, and vessel collision, throughout their breeding and feeding grounds (O'Connor et al., 2009). The effect of whale-watching interaction cannot be considered only as a punctual and occasional event, because such repeated anthropogenic stressor events may occur for the same individual or group in addition to natural events (e.g., escape from predation, intraspecific competition). Vulnerable groups, such as mother and calf groups (Stamation et al., 2010; García-Cegarra et al., 2019) move slowly and are usually found closer to the coast, being easily approached by several whale-watching boats (García-Cegarra et al., 2019). Whale watching is a growing industry in Peru (Guidino et al., 2020) but is not regulated yet (Pacheco et al., 2011). We urge the establishment of regulations particularly measurements that controls the time and number of boats per group of whales especially in mother and calf groups (García-Cegarra et al., 2019).

DATA AVAILABILITY STATEMENT

The minimum data to reproduce the analysis supporting the conclusions of this article is available in the **Supplementary Table 3**. Further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The animal study was reviewed and approved by the Comité de Ética de Investigación Científica de la Universidad de Antofagasta, Chile (CEIC REV N° 039/2017 and 7298/2015).

AUTHOR CONTRIBUTIONS

DV and AP conceived the manuscript. AG-C provided most of the funds during the field works. DV and AG-C collected the data with the advice and guidance of AP. DV analyzed and interpreted the data and results of the study. DV led the preparation of the manuscript with the guidance of AP and AG-C. All authors edited the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.600508/full#supplementary-material

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Effects of Vessel Distance and Sex on the Behavior of Endangered Killer Whales

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Accurate knowledge of behavior is necessary to effectively manage the effects of human activities on wildlife, including vessel-based whale-watching. Yet, the wholly aquatic nature of cetaceans makes understanding their basic behavioral ecology quite challenging. An endangered population of killer whales faces several identified threats including prey availability and disturbance from vessels and sound. We used bio-logging tags that were temporally attached to individuals of the endangered Southern Resident killer whale population to more fully understand their subsurface behavior and to investigate vessel effects on behavior, including foraging behavior involving prey capture. We collected tag data over three field seasons in the waters surrounding the San Juan Islands, WA, United States, corresponding to the core summer area of the critical habitat of the population. Here, we used hidden Markov models to identify latent behavioral states that include characterization of different foraging states from sound and movement variables recorded by the multi-sensor tags. We tested a number of vessel variables (e.g., vessel counts, distance, and speed) on state transition probabilities, state occurrence and time spent within each behavioral state. Whales made fewer dives involving prey capture and spent less time in these dives when vessels had an average distance less than 400 yd (366 m). Additionally, we found both a sex and vessel distance effect on the state transition probabilities, suggesting that females and males respond differently to nearby vessels. Specifically, females were more likely to transition to a non-foraging state when vessels had an average distance less than 400 yd (366 m). A female's decision to forego foraging states due to the close proximity of vessels could have cascading effects on the ability to meet energetic requirements to support reproductive efforts. This is particularly concerning in an endangered population that is in decline. Our findings, suggesting that female killer whales are at greater risk to close approaches by vessels, highlight the importance of understanding sex-specific responses to disturbance. These findings can inform future management decisions seeking to preserve foraging opportunities and enhance recovery efforts relevant to many cetacean species, including vulnerable and endangered populations.

Keywords: Killer whale (*Orcinus orca*), behavior, foraging, vessel effects, whale-watching, hidden Markov model

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INTRODUCTION

Nature-based tourism, including the viewing of free-ranging and often charismatic wildlife, is a well-established industry in many parts of the world. Human activity, however, can have negative consequences on animals, including subsequent effects on the behavior of individuals, social groups and populations, which is especially concerning for vulnerable or endangered species. Knowledge of the basic aspects of animal behavior can lead to the success or failure of wildlife management programs (Knight, 2001; Coleman et al., 2013; Berger-Tal and Saltz, 2016). For example, cetaceans rely on sound for basic life functions and odontocetes (dolphins, porpoises, and toothed whales) use echolocation for navigation and foraging. Vessel-based whale-watching often introduces noise from motor-based propulsion in addition to obstacles at the surface to these air-breathing mammals (Senigaglia et al., 2016). Furthermore, vessel traffic from other activities (e.g., commercial shipping) is common in well-populated coastal corridors and many vessels emit sonar signals to aid in navigation or fishing (e.g., depth sounders and fish finders). Yet, we know little about how introduced signals might affect the use of sound and behavior in these aquatically obligate marine mammals, particular for species that rely on sound at similar frequencies for biosonar-based foraging. Given their cryptic nature, which imparts considerable challenges in quantifying anthropogenic effects, only a limited number of studies have been able to investigate behavioral effects of anthropogenic disturbance in odontocetes, particularly whether all individuals are equally affected, given contextually dependent responses to disturbance (Ellison et al., 2012). Recent technological advances have enabled the use of smaller bio-logging instruments that are temporally attached to cetaceans, allowing researchers to better understand their subsurface behavior and investigate relevant anthropogenic effects (Johnson and Tyack, 2003; Quick et al., 2016; DeRuiter et al., 2017).

Killer whales (*Orcinus orca*) are the largest delphinid species. North Pacific ecotypes are differentiated by genetics, foraging ecology, physical appearance, and acoustic behavior (Ford et al., 2000, 2011). The fish-eating "resident" ecotype consists of large matrilineal groups that heavily rely on echolocation for foraging (Barrett-Lennard et al., 1996; Au et al., 2004). Individuals produce slow repetition clicks while searching for prey, click faster during initial pursuit of individual prey, and produce buzzes (very rapid bout of clicks) immediately prior to prey capture attempts (Holt et al., 2019; Tennessen et al., 2019a). In the eastern North Pacific, Southern Resident killer whales are listed as Endangered in the United States and Canada (National Marine Fisheries Service [NMFS], 2016; Department of Fisheries Oceans Canada [DFO], 2017). They prefer salmonids, especially Chinook salmon (*Oncorhynchus tshawytscha*), but many stocks they rely on are also listed as endangered, threatened, or depleted (Ford and Ellis, 2006; Hanson et al., 2010; Ford et al., 2016). In addition, vessel traffic and associated noise from commercial shipping, whale-watching, fishing, and recreational activities, is pervasive in the core summer habitat that the whales use for feeding (Holt et al., 2009; Veirs et al., 2016; Cominelli et al., 2018). Both prey availability and disturbance from vessels and noise are identified risk factors to the Southern Resident population that has shown little recovery since ESA listing (National Marine Fisheries Service [NMFS], 2016; Center for Whale Research[1], accessed 30 March 2020).

Given the recognized risk factors and documented effects, vessel regulations have restricted viewing distance of killer whales to varying degrees[2]. United States vessel regulations, effective May 2011, make it unlawful for vessels to approach within 200 yd (183 m) from most directions and 400 yd (366 m) of a killer whale's path (National Oceanic Atmospheric Administration [NOAA], 2011). A state law (RCW 77.15.740), implemented in May 2019, prohibits approach within 300 yd (274 m) to the side and 400 yd in front/behind any Southern Resident killer whale, and vessel speed must be ≤ seven knots within one-half nautical mile (926 m[3]). An interim order, effective June 2019, prohibits all vessels from approaching any killer whale within a 400 m distance and vessel speed must be ≤ seven knots within 1 km in Canadian waters[4]. Empirical evaluation of the effectiveness of these unaligned regulations are needed to inform future decision making within an adaptive management framework.

Earlier studies documented effects of vessels and noise on resident killer whales, including changes in surface active and vocal behavior, diving and movement parameters, and behavioral activity states (Williams et al., 2006, 2009; Holt et al., 2009; Lusseau et al., 2009; Noren et al., 2009). A concerning finding of previous land-based observational studies was the reduction in time spent foraging in the presence of vessels (Williams et al., 2006; Lusseau et al., 2009). Indeed, a meta-analysis of several cetacean studies found disruptions of activity budget, in which individuals were less likely to rest and forage, to be one of the most consistent responses to whale-watching vessels (Senigaglia et al., 2016). Reduced foraging effort can have cascading effects on an individual's ability to meet energetic requirements to support growth, survival and reproduction, and is especially concerning in vulnerable populations (Farmer et al., 2018; Pirotta et al., 2018). Yet, many earlier findings rely on observations of behavior at the surface that can introduce bias (Tuyttens et al., 2014). Additionally, accurately identifying different phases of biosonar-based foraging are challenging without assessment of both the acoustic and movement behavior of the whales (Holt et al., 2019; Tennessen et al., 2019a,b). In this study, we utilized multi-sensor tags to test different vessel effects on the subsurface behavior of killer whales, including acoustic behavior and foraging outcomes, to inform future management actions. Effects on behavior that we tested include vessel count, distance and speed related to current regulations, and echosounder signal presence, tested alone or in combination with one another and other effects. Specifically, we implemented hidden Markov models (HMM) to identify unobservable behavioral states from the variables obtained by the tags that were temporally attached to Southern Resident killer whales. We then examined a number of vessel effects on the state

[1] https://www.whaleresearch.com/orca-population

[2] www.bewhalewise.org

[3] https://app.leg.wa.gov

[4] www.pac.dfo-mpo.gc.ca/whales-baleines/srkw-measures-mesures-ers-eng.html

transition probabilities and on the occurrence and time spent in each behavioral state.

MATERIALS AND METHODS

Study Location and Data Collection

Data collection took place in the transboundary waters surrounding the San Juan Islands, WA, United States (approximate range: 48.2° to 49.0° N, 122.7° to 123.6° W, **Supplementary Figure 1**) during daylight hours in September 2010, 2012, and 2014. The study location is part of the population's critical habitat in both the United States and Canada, including their core summer habitat (National Oceanic Atmospheric Administration [NOAA], 2006). The area and season of data collection was chosen to reflect whale-watching activity by both commercial and private vessels. Twenty-three digital acoustic recording tags (Dtags) were temporarily attached to individually identified whales from photo-ID records (Center for Whale Research) using a pole from an inflatable research vessel. The Dtag is a suction cup-attached multi-sensor, bio-logging instrument containing two hydrophones, temperature, pressure and triaxial accelerometer and magnetometer sensors (Johnson and Tyack, 2003). Of the twenty-three tags deployed, we excluded data from 10 deployments in the analysis because of limited audio data quality, mainly due to high flow noise and/or suboptimal tag placement. All individuals were tagged only once, except for two individuals (K33 and L91) that were tagged twice but in separate years; thus, all deployment time series were considered independent of each other (**Table 1**).

We used the larger version 2 tag in 2010 and 2014 which sampled audio data at 192 kHz and non-audio data at 50 Hz, and the smaller version 3 tag in 2012 which sampled audio data at 240 kHz and non-audio data at 200 Hz. During Dtag deployments, we conducted focal follows on the (1) tagged whale, collecting geo-referenced data during surfacing and (2) all vessels, including the research vessel, within 1.5 km of the focal whale until the tag released from programming or fell off on its own (Holt et al., 2017). As conditions allowed, we recorded focal follow data using two integrated equipment packages, each consisting of a GPS/data collector, a laser range finder, and compass (Giles, 2014). One unit recorded whale data, the other recorded vessel data. Attribute data recorded for each vessel included a date and time stamp, its latitude and longitude position, vessel name and class (commercial whale-watching, private, research, enforcement, etc.) and estimated speed (sensu Holt et al., 2017). We recorded vessel data in concentric rings starting with those closest to the focal whale at least every 5 min. During focal follows, the research vessel operated at distances and speeds consistent with vessels engaged in whale-watching.

Data Processing and Calculation of Variables

We used the Dtag Toolbox[5], along with custom-written routines in Matlab 2017a (Mathworks, Natick, MA, United States), to download, calibrate, and process tag data following established protocols (e.g., Holt et al., 2017; Tennessen et al., 2019a).

The unit of analysis was a dive derived from depth data down-sampled to 5 Hz. We calculated the start and end times of each dive using an automated detector that identified excursions from the surface ($\leq$0.5 m) to depths $\geq$ 1 m that were checked for error and corrected accordingly. Individual reactions to tagging ranged from none to moderate, the latter which included flinching upon tag contact or diving and remaining submerged for a few minutes, but for all deployments individuals returned to pre-tagging surfacing behavior within 5 min of tagging. We therefore excluded dives during the first 5 min of each deployment time series to address any potential short-term behavioral responses to tagging (sensu Tennessen et al., 2019a,b). We used other non-audio tag data sampled at 50 Hz for analyses. For each dive, we populated six response variables described in Tennessen et al. (2019b), which were informed by previous studies (Holt et al., 2019; Tennessen et al., 2019a). These variables were (1) maximum depth, (2) jerk peak (3) median absolute roll (4) circular variance in heading (5) presence of echolocation clicks (slow/regular) (6) presence of buzzes. These variables were chosen to capture the different phases of foraging (including search and capture of prey) along with other behaviors. Only clicks and buzzes assigned to the tagged whale were included in the analysis (Holt et al., 2019). We calculated vessel variables from focal follow data as in Holt et al. (2017) using the midpoint in time of each dive to temporally align vessel ($\pm$ 5 min) and dive data. If multiple observations of the same vessel occurred within the interval, we only used the observation closest in time to the dive midpoint. The horizontal distance from whale to each unique vessel was estimated from the latitude/longitude positions of the vessel relative to the whale's latitude/longitude that was closest in time to the dive midpoint. We also scored the presence of echosounder signals, i.e., sonar signals emitted by vessels to aid in navigation and fishing, received by the tag (both transmitted and reflected signals) for each dive (Holt et al., 2017).

Statistical Analysis

We used HMMs as a multivariate framework to categorize the subsurface behavior of killer whales. This statistical approach has been widely applied in studies that investigate movement and behavior using animal-borne tags that yield time series data, including those on cetaceans (Quick et al., 2016; DeRuiter et al., 2017). HMMs identify the most likely unobservable (hidden) state from observable behavior in sequences that follow a first order Markov process. The number of latent or hidden states, N, is specified *a priori* and the HMM approach estimates a time series of estimated states (allowing animals to transition between states at each time step) conditioned on the observed data. HMMs are flexible and allow for the inclusion of covariates, on both the intercept parameters ("state dependent distributions") and on the transition probability matrices. Our objective was to test vessel effects on killer whale behavior, using the six response variables described above. This approach consisted of (1) fitting several HMMs with different single covariates on the state transition probability matrix to determine the appropriate number of hidden states, (2) fitting additional models with up to

[5]www.soundtags.org

TABLE 1 | Summary of analyzed Dtag deployments.

Year	Deploy. ID	Whale ID	Sex	Tag duration (h)	No. dives analyzed	No. dives per state			
						1	2	3	4
2010	oo10_261m	L72	F	0.53	32	12	0	7	13
2010	oo10_264m	L83	F	2.53	216	89	0	100	27
2010	oo10_265m	K33	M	6.18	517	286	21	102	108
2012	oo12_251m	K33	M	1.56	149	52	6	48	43
2012	oo12_254m	L95	M	6.13	522	160	8	256	98
2012	oo12_261m	L84	M	2.11	176	74	2	41	59
2012	oo12_266m	L91	F	2.46	205	46	9	96	54
2012	oo12_266n	L47	F	0.51	56	26	1	7	22
2012	oo12_267m	J28	F	1.63	159	99	0	22	38
2014	oo14_249m	L113	F	5.51	572	155	10	304	103
2014	oo14_263m	L85	M	6.24	484	197	6	162	119
2014	oo14_264m	L91	F	0.68	59	18	4	11	26
2014	oo14_266m	K35	M	4.43	462	138	10	215	99

two covariates on the state transition probabilities and comparing these with the original models to investigate vessel effects on killer whale likelihood of transitioning between behavioral states, and (3) investigating effects of vessel distance on state occurrence and time spent in each state.

We used the depmixS4 package (Visser and Speekenbrink, 2010) in R v.3.3.3 (R Core Team) to fit several candidate models. Here, the specified number of states and response variables were informed by and described in detail in Tennessen et al. (2019b). Briefly, we explored 3–5 state models using the six response variables with individual sex as a covariate on the state dependent distributions, and different single covariates on the transition probabilities among states (unconstrained). Depth, jerk, roll and heading variance were natural log transformed and modeled using a Gaussian distribution while clicking and buzz presence were modeled using a binomial distribution. For simplicity, we did not consider random effects potentially associated with the individual or environmental context (but see DeRuiter et al., 2017). Covariates populated for each dive included vessel counts, mean distance of all vessels within 1.5 km, distance of closest vessel, and median speed of all vessels within 1.5 km of the tagged whale (as in Holt et al., 2017), presence/absence of echosounder signals, year and individual sex. Sex was included based on previous results (Tennessen et al., 2019b) and year was included to address potential inter-annual variability (Holt et al., 2017). Vessel count, speed and distance were binary categorical variables (high/low or close/far) using different breakpoints to define levels among competing models according to sample size, distribution of covariates and implications for management (**Table 2**). For example, vessel distance was split into close/far categories by 200 (183 m) and 400 yd (366 m) to inform management actions related to vessel regulations. We attempted to populate received noise levels for each dive to investigate noise effects (Holt et al., 2017). However, tag-related flow noise contamination resulted in considerable missing noise data and thus, hindered the preservation of dive-by-dive time series required for the assumptions of HMMs.

Because estimation of HMMs may be sensitive to starting values, we re-fit each candidate model 200 times using random initial parameters, and we retained the one with lowest AIC score as the best across the 200 iterations (see Tennessen et al., 2019b). We first ran candidate models with 3 to 5 states, each with only one covariate on the state transition probabilities and used the lowest AIC score along with the ability to biologically interpret results as criteria for selecting the top-ranked models following Tennessen et al. (2019b). A challenge in working with HMMs is that increasing the number of states generally improves model performance metrics, such as AIC with an incurred trade-off of reduced biological interpretability of the resulting state-dependent distributions (Quick et al., 2016, 2017; DeRuiter et al., 2017; Tennessen et al., 2019b). We found the same to be true here: all 5-state models had lower AIC scores than 4-state models, which had lower AIC scores than 3-state models. However, in contrast to Tennessen et al. (2019b), 5-state models were unusually complex with the available data and the state-dependent distributions were not easily interpretable in contrast to 4-state models. Thus, we took the top-ranked 4-state models (delta AIC $\leq$ 30, **Table 3**) and then combined up to two covariates on the transition probabilities and re-ran 4-state model fitting to see if model ranking improved with combined covariates (**Table 4**).

Using output from the HMMs, we used multinomial logistic regression models to ask whether vessel distance or sex affected state occurrence. We treated the estimated state assignment, based on the most likely (Viterbi) state sequence of the best model, as the response variable, and used vessel distance (2-level fixed effect) and deployment number (random effect) as predictors. All multinomial logistic regression models were fit using the brms package (Bürkner, 2017) in R. We ran these models using four MCMC (Markov chain Monte Carlo) chains, a burn-in period of 2000 samples, and retained another 1000 samples (Rhat values of all parameters were 1.0, supporting model convergence). We also explored the effect of sex on state occurrence (Tennessen et al., 2019b) by running models with

TABLE 2 | Definitions of single covariates on the state transition probability matrix of candidate models.

TPM Covariate	Form (level)	Details	Comment
count1	Factor (2)	<11 vessels ≥11 vessels	Approximate equal split based on range (1–21 vessels)
count2	Factor (2)	<6 vessels ≥6 vessels	Equivalent decibel level split if all vessels radiate equal noise levels
count3	Factor (2)	<8 vessels ≥8 vessels	Split in between count1 and 2
speed1	Factor (2)	median speed < 5 kn median speed ≥ 5 kn	See Holt et al., 2017 for details
speed2	Factor (2)	median speed < 3 kn median speed ≥ 3 kn	See Holt et al., 2017 for details
dis1	Factor (2)	mean distance < 200 yd mean distance ≥ 200 yd	Considers average compliance with United States. federal vessel regulations in most directions
dis2	Factor (2)	mean distance < 400 yd mean distance ≥ 400 yd	Considers average compliance with United States. federal vessel regulations in the path of whales
closDis1	Factor (2)	closest distance < 200 yd closest distance ≥ 200 yd	Considers full compliance with United States federal vessel regulations in most directions
closDis2	Factor (2)	closest distance < 400 yd closest distance ≥ 400 yd	Considers full compliance with United States federal vessel regulations in the path of whales
echosounder	Factor (2)	presence absence	
sex	Factor (2)	female (F) male (M)	
year	Factor (3)	2010 2012 2014	

and without a sex predictor and comparing posterior estimates of the coefficient using 10-fold cross-validation (k = 10) and information criterion scores (R loo package, Vehtari et al., 2019). Estimates of 10-fold expected log posterior density with and without sex were qualitatively similar (differing by < 7 units) with overlapping standard errors (33 and 31.1), suggesting no strong effect of including sex.

To investigate differences in time spent in each state, we treated dives as the sampling unit. We generated 1000 posterior samples, in which each vector of state assignments corresponded to the number of dives (n = 3609). For each posterior sample, we summarized the time spent in each state using the known duration (in minutes) of each dive and stratified this calculation by sex and vessel distance. To evaluate the effects of vessel distance, we calculated the difference between the amount of time spent in each state when vessels were close versus far for males and females separately and summarized the 95% credible intervals on the distribution of the difference.

TABLE 3 | AIC, log-likelihood and delta AIC values for 4-state models that include a single covariate on the state transition probability matrix.

TPM Covariate	AIC	loglik	Delta AIC
dis1	30895.54	−15356.8	0
sex	30915.83	−15366.9	20.2888
count2	30922.02	−15370	26.48312
count1	30923.24	−15370.6	27.7007
dis2	30923.76	−15370.9	28.22143
closDis2	30935.13	−15376.6	39.58817
speed1	30935.19	−15376.6	39.65505
speed2	30935.73	−15376.9	40.19547
echosounder	30938.55	−15378.3	43.00837
year	30969.16	−15381.6	73.62215
1 (null)	30985.42	−15413.7	89.88741
count3	31006.46	−15412.2	110.9274
closDis1	31007.15	−15412.6	111.609

TABLE 4 | Definitions of combined covariates on the state transition probability matrix for candidate models.

TPM Covariate	Form (level)	Details
dis1sex	Factor (4)	mean distance < 200 yd & F mean distance ≥ 200 yd & F mean distance < 200 yd & M mean distance ≥ 200 yd &M
dis2sex	Factor (4)	mean distance < 400 yd & F mean distance ≥ 400 yd & F mean distance < 400 yd & M mean distance ≥ 400 yd &M
dis1count1	Factor (4)	mean distance < 200 yd & < 11 vessels mean distance ≥ 200 yd & ≥ 11 vessels mean distance < 200 yd & ≥ 11 vessels mean distance ≥ 200 yd & < 11 vessels
dis1count2	Factor (4)	mean distance < 200 yd & < 6 vessels mean distance ≥ 200 yd & ≥ 6 vessels mean distance < 200 yd & ≥ 6 vessels mean distance ≥ 200 yd & < 6 vessels
dis2count1	Factor (4)	mean distance < 400 yd & < 11 vessels mean distance ≥ 400 yd & ≥ 11 vessels mean distance < 400 yd & ≥ 11 vessels mean distance ≥ 400 yd & < 11 vessels
dis2count2	Factor (4)	mean distance < 400 yd & < 6 vessels mean distance ≥ 400 yd & ≥ 6 vessels mean distance < 400 yd & ≥ 6 vessels mean distance ≥ 400 yd & < 6 vessels
count1Sex	Factor (4)	< 11 vessels & F ≥ 11 vessels & F < 11 vessels & M ≥ 11 vessels & M
count2Sex	Factor (4)	< 6 vessels & F ≥ 6 vessels & F < 6 vessels & M ≥ 6 vessels & M

RESULTS

Summary of Deployments and HMM Runs

We analyzed 13 tag deployments (7 female, 6 male) that totaled 40.5 h of on-animal time (**Table 1**). The mean duration per deployment was 3.1 h (range = 0.5–6.2 h). From these deployments, we analyzed a total of 3609 dives (1299 dives of females, 2310 dives of males). The mean number of analyzed dives per deployment was 278 (range = 32–572). The mean number of vessels populated per dive was 4 (range 1–21) and most were commercial whale-watching or private vessels. Private vessels included those that appeared to be viewing whales, engaged in recreational fishing, or transiting the area.

Compared to the null model, model fit was significantly improved by including sex, year, vessel covariates or a combination of covariates on the transition probabilities (**Tables 3**, **5**). The 4-state model with the lowest AIC values included the combined transition probability covariate of sex and mean vessel distance split into close and far categories by a 400 yd (366 m) threshold. The next best model included a single transition probability covariate of mean vessel distance split by a 200 yd (183 m) threshold with a delta AIC score of 6, followed by the third ranked model which included the combined transition probability covariate of sex and mean vessel distance split by a 200 yd (183 m) threshold (delta AIC = 8.5). The other models had delta AIC scores > 25 relative to the top-ranked model (**Table 5**).

State Classification

The state-dependent distributions of the top-ranked model (**Figure 1**) were as follows: (1) State 1 dives were the shallowest with smallest values of heading variance, roll, and jerk, with little clicking and no buzzing, (2) State 2 dives were deepest with the largest values of heading variance, roll, and jerk, and with clicking in almost all dives and common buzzing, (3) State 3 dives were shallow with slightly less variance in depth than State 1 and small values of heading variance, roll, and jerk, and abundant clicking in males and some clicking in females but no buzzing for either sex, and (4) State 4 dives were shallow to intermediate with small-to-moderate values of heading variance, roll, and jerk, with some clicking and virtually no buzzing.

TABLE 5 | AIC, log-likelihood and delta AIC values for all 4-state models.

TPM Covariate	AIC	loglik	Delta AIC
dis2Sex	30889.30	−15329.7	0
dis1	30895.54	−15356.8	6.23
dis1Sex	30897.78	−15333.9	8.48
sex	30915.83	−15366.9	26.52
count2	30922.02	−15370.0	32.72
count1	30923.24	−15370.6	33.93
dis2	30923.76	−15370.9	34.45
closDis2	30935.13	−15376.6	45.82
speed1	30935.19	−15376.6	45.89
speed2	30935.73	−15376.9	46.43
echosounder	30938.55	−15378.3	49.24
dis1Count2	30955.54	−15374.8	66.24
count2Sex	30958.16	−15364.1	68.86
year	30969.16	−15381.6	79.86
count1Sex	30970.94	−15370.5	81.64
1 (null)	30985.42	−15413.7	96.12
dis1Count1	30995.87	−15394.9	106.56
dis2Count1	31002.10	−15398.1	112.80
count3	31006.46	−15412.2	117.16
dis2Count2	31006.79	−15388.4	117.49
closDis1	31007.14	−15412.6	117.84

Transition Probabilities Among States

Whether the mean distance of vessels was < 400 yd (herein "close") or ≥ 400 yd (herein "far"), persistence was especially high in state 1 and 3 and to a lesser extent in State 4 for both sexes, illustrating the behavior assigned to three of the four states was clustered in time. In contrast, it was unlikely that whales persisted in state 2 (made back-to-back state 2 dives), especially for females (**Figure 2** and **Supplementary Table 1**). The effect of vessel distance on state transition probabilities differed between the sexes. Males were more likely to switch from state 2 to state 1 and to a lesser extent state 3 with far vessels whereas they were more likely to switch from state 2 to state 4 with close vessels. Moreover, it was extremely unlikely that males would switch from state 2 to state 3 with close vessels (**Figure 2** and **Supplementary Table 1**). Females were more likely to switch from state 2 to state 3 or 4 as well as persist in state 4 with far vessels whereas they were more likely to switch from state 2 to state 1, and switch from state 4 to state 1 with close vessels (**Figure 2** and **Supplementary Table 1**).

State Allocation by Dives

Figure 3 illustrates state allocation on a dive-by-dive basis for each tag deployment (summary across deployments provided in **Supplementary Table 2**). Results of the multinomial logistic regression supported differences in state occurrence (**Supplementary Table 3**). The negative log odds ratio (with state 1 as the reference baseline) indicated that whales were less likely to be in states 2, 3 or 4 than in state 1. Additionally, the positive log odds ratio for far vessels supported an effect of vessel distance on state allocation and was most different for state 2 (estimate = 0.74, s.e. = 0.35), followed by state 4. That is, state 2 occurrence was higher when vessels were farther away.

Both females and males spent substantially more time in state 2 when vessels were far compared to when vessels were close (**Figure 4**, note in the case of females with close vessels, error bars are not visible because dives assigned to state 2 had very little uncertainty in assignment resulting in very small error bars). In contrast, whales spent less time in state 3 and 4 when vessels were far (**Figure 4**). For both sexes, the 95% credible interval of the difference in time spent for each state was different from zero in all cases except state 1 (**Figure 4**).

DISCUSSION

In the current study, we used hidden Markov modeling of six observed sound and movement variables recorded from

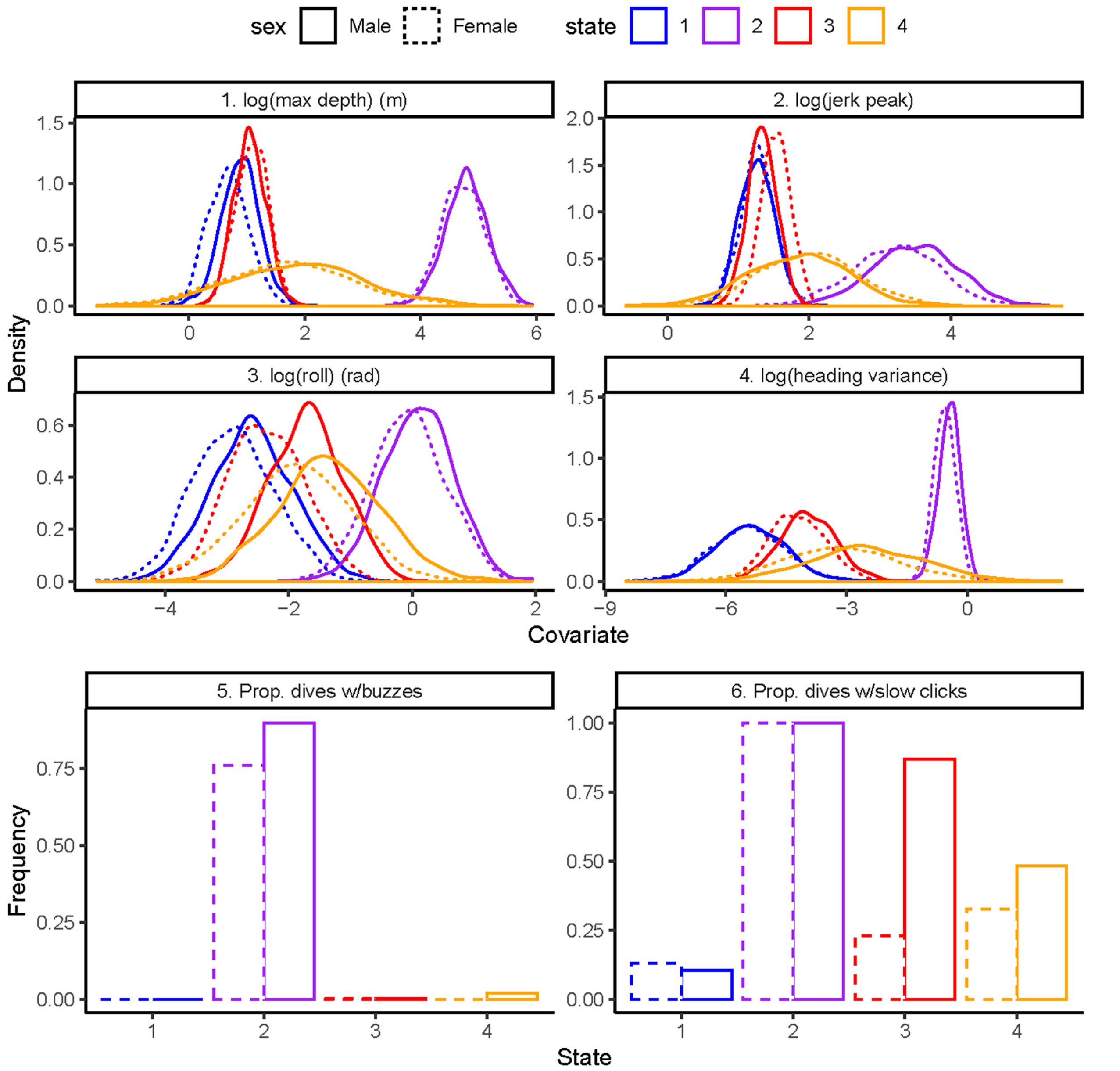

FIGURE 1 | State-dependent distributions of the best model by sex: 1. Log maximum depth in meters (top left), 2. Log standardized jerk peak (top right), 3. Log absolute roll in radians (middle left), 4. Log heading variance (middle right), 5. Proportion of dives with buzzes (bottom left), 6. Proportion of dives with slow clicks (bottom right).

suction-cup tags attached to fish-eating killer whales, along with vessel data, to (1) characterize unobservable killer whale behavioral states and (2) identify vessel effects on foraging behavior. We found that females and males differed in their state transition probabilities depending on whether vessels were close (average vessel distance < 400 yd) or far (average vessel distance ≥ 400 yd). State frequency and cumulative time spent in these states also differed depending on vessel distance.

State 1 dives were characterized by the shallowest depth, with smallest values of heading variance, roll, and jerk, with very little clicking and no buzzing (**Figure 1**). State 1 involves traveling/respiratory dives given that persistence in state 1 was high for both males and females regardless of whether vessels were close or far. In contrast, state 2 was characterized by the deepest dives with the largest values of heading variance, roll, and jerk, with ubiquitous clicking and the greatest levels of buzzing. State 2 dives involve close pursuit, attempt to capture and successful capture of salmonid prey given the repeated direction changes in heading and rapid changes in acceleration (jerk) (Tennessen et al., 2019b). Indeed, the vast majority of

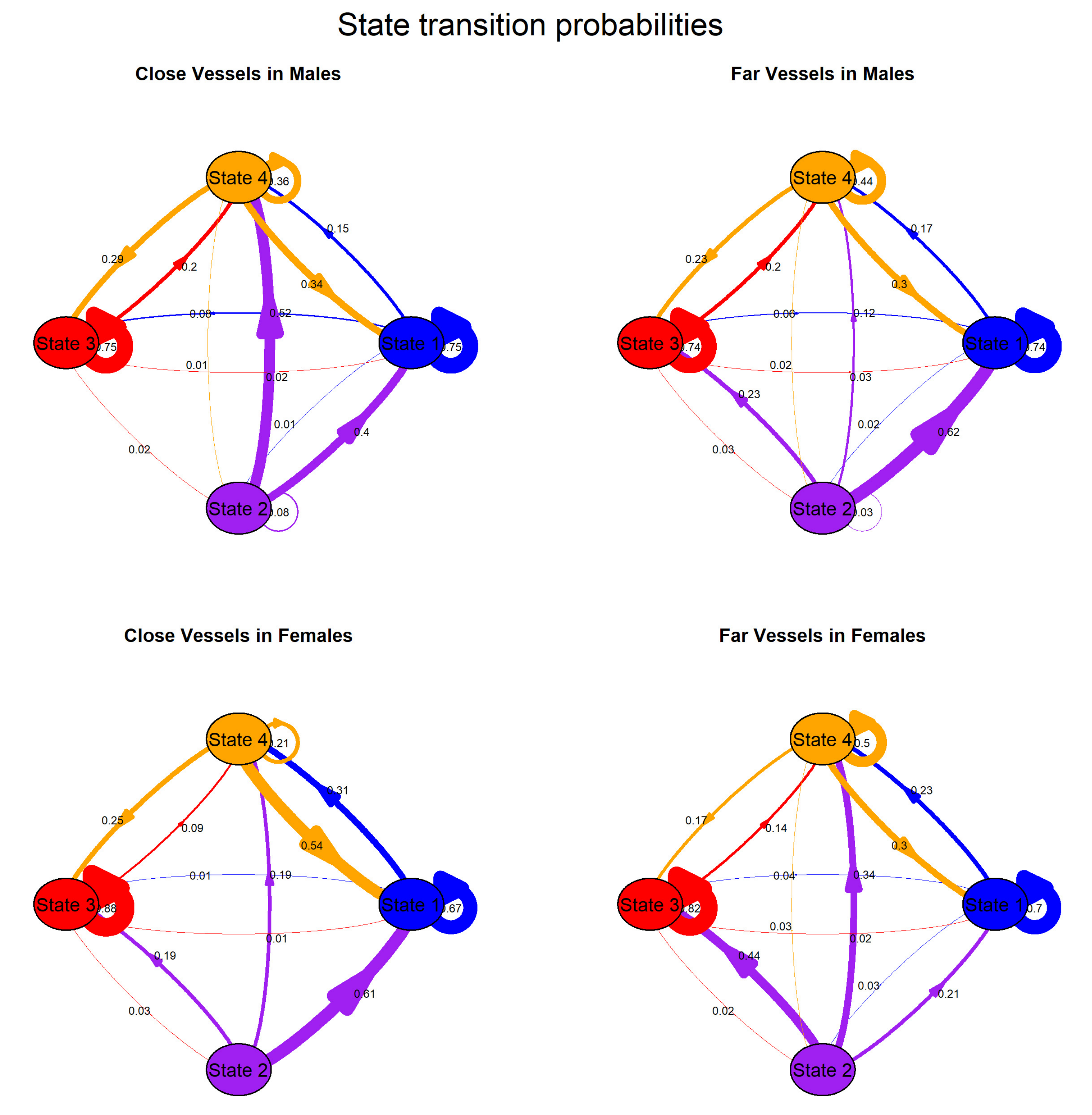

FIGURE 2 | Transition probabilities among states for males (top plots) and females (bottom plots) by close (left plots, mean vessel distance < 400 yd) and far (right plots, mean vessel distance ≥ 400 yd) vessels. Arrows indicate direction of transitions from state of origin, arrow thickness scales with probability. See **Supplementary Table 1** for details.

state 2 dives mapped directly to predicted prey capture dives based on kinematic signatures, which were validated with direct observations of predation (Tennessen et al., 2019a).

Similar to state 1, state 3 was characterized by shallow depth, with small values of jerk and no buzzing. Average values of heading variance and roll were slightly greater in state 3 compared to state 1, especially in males (**Figure 1**), but there was considerable overlap in the two distributions. In contrast to state 1, state 3 dives had abundant clicking in males and higher values of clicking in females. High persistence in state 3 indicated that these dives reflect searching for prey whereby individuals produce echolocation click trains on repeated shallow dives to acoustically scan an area for prey targets (Holt et al., 2019; Tennessen et al., 2019b).

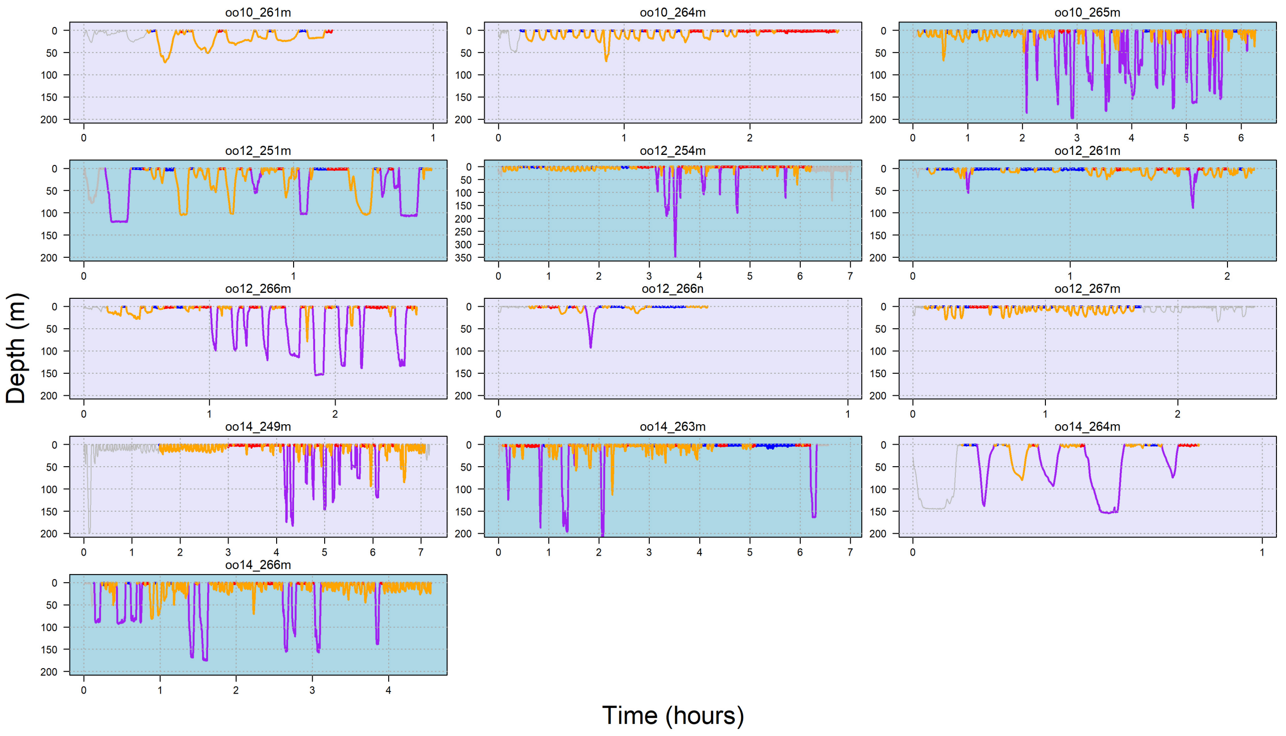

FIGURE 3 | Dive profile by behavioral state for each deployments over time. Note the difference in both *x*- and *y*-axis scale among plots. Female = lavender box, male = light blue box, state 1 = dark blue, state 2 = purple, state 3 = red, state 4 = orange. Gray dives indicate omitted 5-min interval at start of deployment and periods which vessel data were not available.

Lastly, state 4 was characterized by dives with intermediate values of depth, heading variance, roll, jerk, and clicking and almost no buzzing. Persistence in state 4 was moderate relative to state 1 and 3. These response variable distributions suggest that state 4 is associated with several behaviors including searching for prey at deeper depths than in state 3 and initiating pursuit of prey that, given the absence of buzzes, does not involve close pursuit/capture attempts or prey capture (Holt et al., 2019). State 4 dives might also involve socializing and/or prey-sharing among group members (Ford and Ellis, 2006; Wright et al., 2016).

States 1 (traveling/respiratory) and 3 (acoustic search) and, to a lesser extent, state 4 (intermediate dives) were characterized by state persistence, demonstrating that most behaviors occurred in bouts as in other cetacean studies (**Figures 2, 3**; DeRuiter et al., 2017; Quick et al., 2017; Tennessen et al., 2019b). In contrast, persistence in state 2 (deep forage) was rare in males and virtually absent in females, likely because lengthy prey chases at depth can incur significant energetic costs that require recovery periods. Furthermore, state 2 dives resulting in prey capture are often followed by prey-handling and sharing events (Holt et al., 2019; Tennessen et al., 2019b).

In the current study, 5-state models were unusually complex with the available data and the state-dependent distributions were not biologically interpretable. In contrast, 4-state models adequately characterized the behavior of fish-eating killer whales, including different phases of foraging that we expected (Holt et al., 2019). Three of the four states (**Figure 1**) were similar to three of the five states reported by Tennessen et al. (2019b). The three similar states from the present study were the deep forage, acoustic search, and intermediate states; the difference was that state 1 of the current study is likely a combination of travel and respiratory dives that are differentiated into two separate states in the previous study (Tennessen et al., 2019b). Given the different focus of the current study, namely to test effects of vessel covariates on foraging behavior, these 4-state models captured the most important structure in the data that was biologically informative to address our scientific objectives.

Vessel distance and sex significantly affected state transition probabilities (**Figure 2** and **Supplementary Table 1**), with close vessels reducing the likelihood of foraging-related behaviors. In particular, females were more likely to switch from state 2 (deep forage) to state 3 (acoustic search) or state 4 (intermediate dives) as well as persist in state 4 with far vessels whereas they were more likely to switch from state 2 (deep forage) to state 1 (travel/respiratory), and switch from state 4 (intermediate dives) to state 1 (travel/respiratory) with close vessels. Furthermore, males were more likely to switch from state 2 (deep forage) to state 1 (travel/respiratory) and to a lesser extent, to state 3 (acoustic search) with far vessels whereas they were more likely to switch from state 2 (deep forage) to state 4 (intermediate dives, but recall that this state includes searching and prey pursuit, but not prey capture) with close vessels. Male response to close vessels could reflect vertical avoidance of vessels (and/or noise)

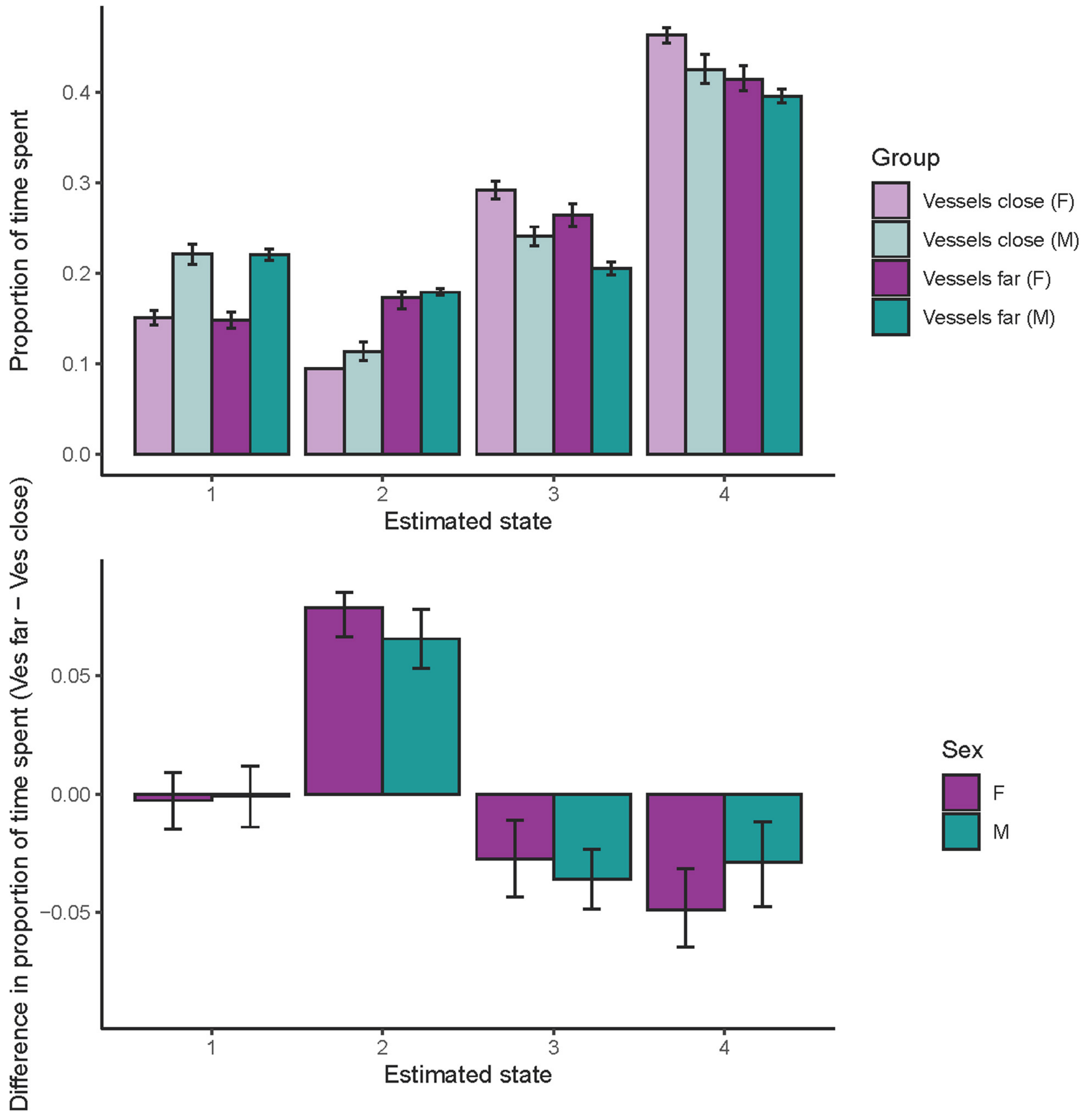

FIGURE 4 | Proportion of time spent in each state. Top panel: proportion of time spent in each state by sex and vessel distance, light purple = females with close vessels, dark purple = females with far vessels, light teal = males with close vessels, and dark teal = males with far vessels. Bottom panel: difference in the proportion of time spent in each state with vessel distance (proportion of time with far vessels minus proportion of time with close vessels) for both sexes. Error bars in both plots indicate the 95% credible interval.

while acoustically searching for prey and failure to track prey after initial pursuit.

Lusseau et al. (2009) used land-based surface observations of behavior to demonstrate that Southern Resident killer whales were more likely to switch from foraging to traveling in the presence of vessels. The aim of the current investigation was to use HMM to sufficiently characterize the subsurface behavior of fish-eating killer whales, including different phases of biosonar-based foraging, that are otherwise difficult to discriminate from surface observations, in order to test a variety of potential vessel effects on behavior. Our analysis, based on animal-borne tag data, characterized more foraging activity than had been reported in some previous studies based on surface-based observations (e.g., Noren and Hauser, 2016). Consistent with earlier studies, but unveiling a sex effect, we found that females switched to a state (state 1, traveling/respiratory) distinctly different from foraging when vessels were close, compared to when vessels were far. Our findings of a sex difference imply that females may experience risk to vessels differently than males, which might be related to group structure. Females are more likely to be associated with younger animals, including juveniles and dependent offspring. Furthermore, the energetic demand of deep diving to pursue prey is likely higher for females given their smaller body size compared to males (Schreer and Kovacs, 1997; Noren and Williams, 2000; Baird et al., 2005). Females of the Northern Resident killer whale population prefer to forage closer to shore compared to males that show no preference, perhaps because of their own physiological limitations or associations with younger individuals with limited dive capacity (Beerman et al., 2016). These findings suggest that females may simply have less three dimensional space to maneuver during prey chases. Thus, females may forego foraging altogether in the presence of close vessels as vessels might pose a higher risk to the group, which may hinder aspects of deep foraging, and/or cooperation, including prey sharing. Williams et al. (2002) found subtle sex-based differences in vessel avoidance in Northern Resident killer whales. Additionally, male and female bottlenose dolphins also respond differently in the presence of vessels (Lusseau, 2003; Symons et al., 2014).

We found that vessel distance affected state occurrence and time spent in each state (**Figure 4**). Overall, whales were less likely to be in states 2–4 (foraging states) than in state 1 (traveling/respiratory, a non-foraging state), and importantly, state 2–4 had a higher occurrence when vessels were far, with the biggest effect for state 2 (deep forage). Furthermore, when we considered time spent in each state, we found that both females and males spent less time in state 3 (acoustic search) and 4 (intermediate dives), and substantially more time in state 2 (deep forage, including prey capture) when vessels were far compared to when vessels were close (**Figure 4**). These findings suggest that deep foraging opportunities can be enhanced when vessels give whales, especially females, more space.

It is important to note that this is an observational study in which vessels that were engaged in whale-watching were subject to various vessel regulations over the course of the study and compliance varied (Eisenhardt and Koski, 2014; Shedd et al., 2018). Additionally, tag attachment sometimes failed before programmed release time. Thus, sample sizes were difficult to balance among covariates, including longer deployments in females. However, in a related study we found no statistical support for including deployment duration as a predictor or offset variable for modeling behavioral states (Tennessen et al., 2019b). Another limitation is that, relative to other dives, dives involving deep foraging and prey capture (state 2 dives reported here) are rare, and even rarer in females (Tennessen et al., 2019a,b), resulting in small sample sizes available for analysis and interpretation. It is also possible that vessel noise mediated the observed effect of vessel distance (via an avoidance response of the noise source). However, because water flow over the tag attached to a moving whale prevented us from calculating uncontaminated noise levels for all dives in a deployment time series, we could not specifically test for this. Lastly, data collection was limited to daylight hours to collect concurrent whale and vessel data, given the study's focus. Thus, time spent in different activities is not fully characterized over a 24-h cycle. Future work to investigate full activity budgets of killer whales with both day and nighttime tag data collection would be valuable to understand if whales made up lost foraging time during different periods of the diel cycle.

The focus of the current investigation was to use data from animal-borne tags to test several vessel effects on foraging-related behavior in an endangered population. We found effects of vessel distance on the state transition probabilities, state occurrence, and time spent among states. Specifically, whales made fewer prey capture dives and spent less time in these dives when vessels had an average distance less than 400 yd. Reduction in foraging activity with vessels is consistent with findings of other cetacean studies (Senigaglia et al., 2016), including Southern Resident killer whales (Lusseau et al., 2009), and has substantial management implications, especially for a population with prey availability and vessel disturbance as risk factors. Furthermore, we found both a sex and vessel distance effect on the state transition probabilities, suggesting that females and males respond differently to nearby vessels. Specifically, females were more likely to transition to a non-foraging (travel/respiratory) state when vessels had an average distance less than 400 yd. A female's decision to forego foraging in the presence of close vessels could hinder her ability to meet energetic requirements to support reproductive efforts, including fetal growth in pregnancy and lactation costs after calving. This is particularly concerning in an endangered mammalian population because recovery cannot occur without successful reproductive outcomes among breeding individuals, particularly in long-lived females with birthing intervals of 3–7 years (Olesiuk et al., 2005). Our findings, suggesting that female killer whales are at greater risk from close vessel approaches than males, can inform future management decisions seeking to preserve foraging opportunities and enhance recovery efforts in endangered populations.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: The NWFSC Public Access to Research Results (PARR)-Data Inventory, www.webapps.nwfsc.noaa.gov/apex/parrdata/inventory/datasets.

ETHICS STATEMENT

The animal study was reviewed and approved by the Northwest Fisheries Science Center's Institutional Animal Care and Use Committee and conducted under research permits (in the United States, NMFS No. 781–1824/16163 and in Canada, DFO SARA/Marine Mammal License No. MML 2010-01/SARA-106B).

AUTHOR CONTRIBUTIONS

MHo and MHa conceived the research idea, obtained permits, and secured funding. MHo, MHa, CE, DG, and JH collected the data. MHo, JT, and EW analyzed the data. MHo wrote the manuscript. All authors edited the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.582182/full#supplementary-material

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The Impact of Vessels on Humpback Whale Behavior: The Benefit of Added Whale Watching Guidelines

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The concurrent increase in marine tourism and vessel traffic around the world highlights the need for developing responsible whale watching guidelines. To determine the impact of vessel presence on humpback whale behaviors in Maui Nui, a land-based study was conducted from 2015 to 2018 in Maui, Hawai'i. Theodolite tracks were used to summarize humpback whale swim speed, respiration rate, dive time, and path directness to determine the potential impacts of various types of vessel presence on whale behavior. Vessel presence, proximity, and approach type in conjunction with biological parameters were used in a generalized additive modeling framework to explain changes in whale behaviors. The results presented here show increases in swim speed, respiration rate, and path directness in conjunction with decreasing dive times, which has been shown to be an energetically demanding avoidance strategy. These observations, in conjunction with increasing awareness on the implication of non-lethal effects of human disturbance and changing oceanic environments on humpback whales, highlights the need for a pre-cautionary approach to management. Stricter guidelines on whale watching will limit the level of disturbance to individual humpback whales in Hawai'i and ensure they maintain the fitness required to compensate for varying ecological and anthropogenic conditions.

Keywords: disturbance, humpback whale, tourism, behavioral response, guidelines, vessel traffic, whale behavior

INTRODUCTION

The concurrent recovery of humpback whale (*Megaptera novaeangliae*) populations from exploitation (Bettridge et al., 2015) along with increases in vessel traffic has resulted in increased interactions between whales and vessels. Whale-vessel collisions (Panigada et al., 2006; Carrillo and Ritter, 2010; Ritter, 2012) and targeted tourism (Orams, 2000; Markowitz et al., 2011; Fiori et al., 2019) are an increasing conservation concern for large whales (Forestell, 2007). In Hawai'i, the frequency of collisions between vessels and humpback whales has increased by ∼150% from 2000 to 2011 (Lammers et al., 2013) in conjunction with a growing tourism industry, which has increased by 25% between 2014 and 2019 (Hawaii Tourism Authority, 2020). In this paper, we quantify changes in whale behaviors arising from vessel presence and highlight the need for additional vessel guidelines in Hawai'i.

The public's interest in viewing whales in the wild has led to a rapidly growing whale watching industry around the world, that generates billions of dollars in revenue each year (O'Connor et al., 2009). This increased demand for marine tourism needs to occur in conjunction with adequate guidelines and regulations that ensure this activity does not harm the target populations. However, in many areas this has not been the case, with growth outpacing the development of new regulations or strengthening of existing ones (Garrod and Fennell, 2004). Hawai'i is no exception, with the number of visitors to the state who participate in vessel-based tourism, including whale watches, having increased by ∼12% from 2009 (Hawaii Tourism Authority, 2020). Between 1999 and 2016, the number of permitted whale watching operators has doubled, resulting in additional targeted tourism for humpback whales (Lammers et al., 2013; Federal Register, 2016). A variety of vessel types are used for commercial whale watching, including large catamarans and smaller vessels equipped with outboard engines (Au and Green, 2000). Outside of the permitted whale watching industry, a variety of commercial and recreation vessels such as kayaks, paddleboards, dive and fishing charters partake in whale watching.

To reduce the risk of harassment or injury to humpback whales in Hawai'i, federal laws, in addition to the Marine Mammal Protection Act, prevent any vessel, person, or craft from approaching whales within 100 yards (∼91 m) or placing themselves in the path of a whale (Federal Register, 2016).

State laws restrict the operation of thrill crafts and parasail vessels from December 15 to May 15 each year in the nearshore leeward waters of Maui. In addition to regulations, the Hawaiian Islands Humpback Whale National Marine Sanctuary, NOAA Fisheries Pacific Islands Regional Office, and the Hawaii Department of Land and Natural Resources have jointly held ocean etiquette workshops that are designed to remind ocean users of the regulations and highlight additional guidelines/recommendations to reduce the potential impacts of wildlife viewing (NOAA, 2020). Compliance with the ocean etiquette guidelines is not monitored, and these remain voluntary.

Humpback whales belonging to the Hawai'i distinct population segment (Bettridge et al., 2015) use the main Hawaiian Islands as their breeding and calving grounds. It is estimated that ∼55% of the North Pacific population of humpback whales use the Hawaiian Islands as their breeding ground (Calambokidis et al., 2008). The highest densities of humpback whales in Hawai'i occur within the Maui Nui region (Mobley et al., 2001), consisting of Maui, Lāna'i, Kaho'olawe, and Moloka'i. While on the breeding grounds, humpback whales participate in a wide range of energetically taxing behaviors associated with breeding and calving, with behaviors largely determined by age class, sex, and reproductive status (Craig et al., 2003). Spatial segregation of mother-calf dyads within the Hawaiian breeding grounds has been observed (Herman and Antinoja, 1977; Ersts and Rosenbaum, 2003; Craig et al., 2014), with shallow nearshore waters being preferred for mothers with a calf in the Maui Nui region (Currie et al., 2018b).

Previous studies have shown that humpback whales may alter their behavior following encounters with vessels (Corkeron, 1995; Scheidat et al., 2004; Schaffar et al., 2013) resulting in non-lethal disturbance (Braithwaite et al., 2015). These changes include altering swim speed and direction of travel (Scheidat et al., 2004; Schaffar et al., 2013), as well as changes in dive behavior, feeding behavior, and surface activity (Corkeron, 1995). Although it can be difficult to extrapolate short-term disturbances into long-term effects on individuals or populations, several studies indicate that cetaceans likely undergo physiological stress along with behavioral changes in response to anthropogenic disturbance (Rolland et al., 2012; Braithwaite et al., 2015; Machernis et al., 2018). For humpback whales, migration to the breeding areas and reproduction represent a large energetic cost for all individuals, an effect that is most pronounced in lactating females (Christiansen et al., 2014; Bejder et al., 2019). Female humpback whales with a calf show a significant decline in body condition over the course of the breeding season (Bejder et al., 2019), and any energy used in response to disturbance could, in turn, affect the calf's own development and survival (Christiansen et al., 2014; Bejder et al., 2019).

The cumulative impacts of repeated disturbances resulting from vessel presence (Pirotta et al., 2019), in conjunction with changing oceanic environments (Cartwright et al., 2019) highlight the need for a pre-cautionary approach to management. Here, we use a land-based platform to investigate the changes in whale behavior arising from vessel presence, by quantifying whale behaviors before, during, and after various types of vessels were present. We describe the parameters of vessel presence that most impacted the observed behaviors and describe how additional guidelines can be utilized to minimize disturbance to humpback whales.

MATERIALS AND METHODS

Study Area and Survey Sites

Data were collected from two land-based sampling locations on Maui, Hawai'i: (1) Papawai Point, (20.7753°N, 156.5365°W; 28.9 m elevation) and (2) Pu'u Olai, (20.6359°N, 156.4492°W; 109.7 m elevation) from December 30, 2015–March 27, 2018. Sites were chosen due to elevation, accessibility, and co-occurrence of humpback whales and vessels within the Hawaiian Islands Humpback Whale National Marine Sanctuary waters (**Figure 1**).

Data Collection

Observation Platform and Theodolite Calibration

To measure horizontal and vertical angles from the sampling locations to the whales we used a Topcon GTS-311 total station, hereafter referred to as a theodolite. For each survey day, the height in meters (m) and precise location (latitude and longitude) of the theodolite (determined using a Garmin Dakota 20 handheld GPS) were recorded and used to obtain an accurate reference angle between the theodolite and a clearly visible land-based reference point of known latitude and longitude. All data were logged using customizable fields in MAGNET Field

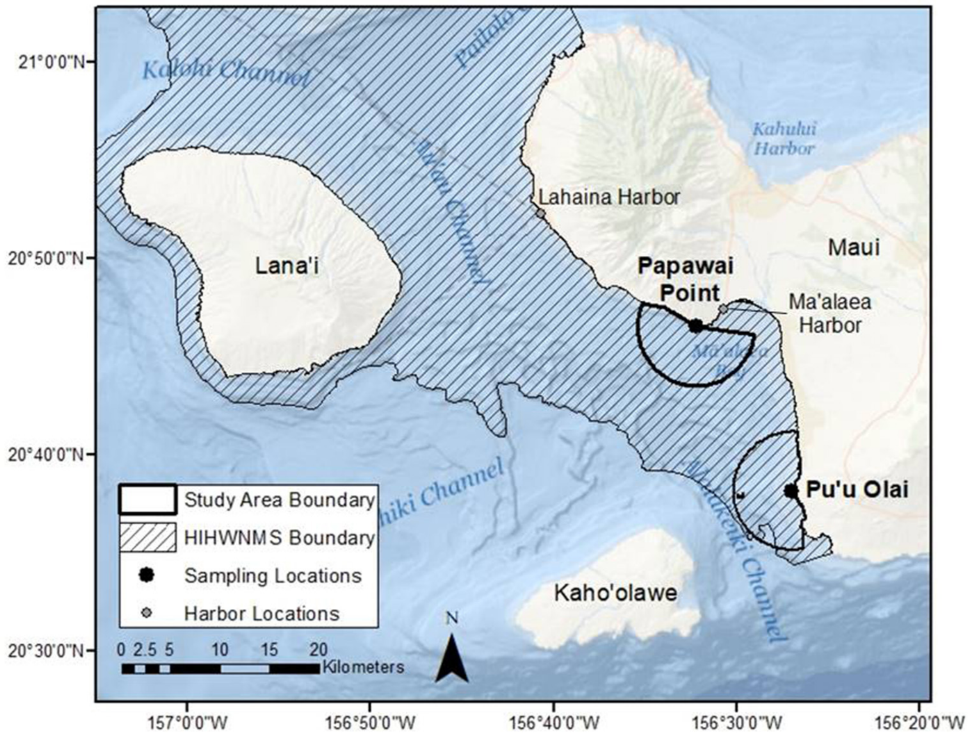

FIGURE 1 | Map depicting the survey area boundaries of the two land-based sites used to observe humpback whale behavior from 2015 to 2018 as well as the extent of the Hawaiian Islands Humpback Whale National Marine Sanctuary (HIHWNMS) in Maui Nui, Hawai'i. Ocean Basemap Source: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors.

software (Topcon Positioning Systems, 2018) run on a laptop computer connected to the theodolite via USB cable.

Scanning Procedures

Surveys took place daily from ~8:00 a.m. to 1:30 p.m. Each survey had a dedicated observer and dedicated data recorder, with roles alternated approximately every hour to reduce fatigue. The observer continually scanned the entire survey area, to a maximum distance of 3 nautical miles (**Figure 1**) until a humpback whale group was observed, which was then considered the focal group. Reticle binoculars were used to determine the 3 nautical mile limit, as well-confirm humpback whale group parameters. Observers used the theodolite to track the position of each focal group of humpback whales for a maximum of 2 h, or until the group traveled beyond the 3 nautical mile limit of the survey area. If a group was not re-sighted within 30 min of a dive, or the observer was unsure if re-surfacing whales belonged to the initial group, the encounter was ended to ensure accurate data collection. At the end of each encounter, scanning for a new group was resumed. To ensure minimal detection bias, surveys were conducted in Beaufort Sea States of four or less.

Whale Group Parameters

A group was defined as a single humpback whale or multiple whales swimming in the same direction within three body lengths of one another. Groups, as referenced here, represent short-term associations and not persistent affiliations. Encounters were started upon the initial theodolite fix and were assigned a unique, sequential group number, and information on group size, location, and composition were collected (**Table 1**). For each observation of whales at the surface, the data recorder logged the observed activity along with a timestamp (hh:mm:ss). Upon each surfacing and dive, the observer centered the theodolite view on the group, and timestamped measurements of the horizontal and vertical angles between the whales and the theodolite was logged by the data recorder.

Observations and research methodologies were approved by the National Marine Fisheries Service under research Letter of Confirmation 18101 issued to J. Currie, Pacific Whale Foundation. The research activities were performed on land and in accordance with the guidelines and regulations outlined above.

Vessel Parameters

When boat(s) were observed within 500 m of the focal group, the observer centered the theodolite view on the vessel to obtain horizontal and vertical angles, and the data recorder logged vessel-specific information: position of vessel, type (categorized as either commercial or recreational), presence/absence of engine, and vessel name (if visible).

Data Analysis

All calculations and statistical analyses were completed using R v. 3.5.1 (R Core Team, 2019). To ensure accurate representation of whale behavior, only groups with an observation time of

TABLE 1 | List of explanatory variables used in GAM to determine the relationship between vessel activity and humpback whale behavior.

Explanatory variables	Description
Encounter type	Factor with three levels indicating whether the observation was (1) before, (2) during, or (3) after a vessel approached.
Vessel present	Factor with two levels indicating whether the observation was in the (1) presence or (2) absence of a vessel(s) within 500 m.
Vessel type	Factor with 4 levels indicating whether the observation had (1) a commercial vessel(s) within 500 m, (2) a recreational vessel(s) within 500 m, (3) a combination of commercial and recreational vessels within 500 m, or (4) no vessel were present.
Vessel count	Numeric value indicating the number of vessels within 500 m of the observation group.
Vessel distance	Numeric value indicating the distance in meters between the closest vessel and the observation group.
Vessel approach	Factor with four levels indicating whether (1) vessels(s) were approaching under federal regulations (no closer than 100 yards), (2) vessels (s) were approaching under additional voluntary guidelines*, (3) a mix of vessels following approaches from 1 to 2 were present, or (4) there were no vessels present.
Group composition	Factor with four levels indicating whether the observation group consisted of a (1) single adult (AD), (2) mother-calf (MC), (3) mother-calf-escort (MCE), or (4) any other composition (OT).
Julian day	Numeric value indicating the Julian day to account for potential effects due to time of year.
Group number	Numeric value assigned to each group to account for potential effects of individual whale groups.

Additional guidelines included: (1) max vessel speeds of 12.5 knots; (2) vessel speeds of six knots or less when whales were within 400 m; (3) max viewing times of 30 min or less when calves present; (4) vessel operations only parallel and to the side of whale direction of travel; (5) max three vessels per group of whales.

≥15 min were included in subsequent analysis. Horizontal and vertical angles of whale groups and vessels measured by the theodolite were converted into latitudes and longitudes using previously published equations (Gailey and Ortega-Ortiz, 2000). All distances were measured using the *distHaversine* function from the geosphere package (Hijmans, 2019) in R to obtain distances between group observations and between each vessel and whale group.

Generalized Additive Modeling

Whale behaviors were modeled as a function of explanatory variables using generalized additive models developed in the *mgcv* package (Wood, 2004, 2017) in R, which allowed for non-normal response variables and testing of potential non-linear relationships. All models were fitted using penalized regression splines (Wood and Augustin, 2002) with default smoothing values (10 knots) in each spline and smoothing parameters estimated using the GCV (generalized cross validation). A quasi family with a log link was selected for all final models, which allowed the dispersion parameter to be modeled from the data. Model fit was evaluated through visual inspection of residual plots and diagnostic information produced using the *gam.check* function in R (Wood, 2001).

Explanatory Variables

Group composition, Julian day, and group number were considered as potential explanatory variables as well as the following vessel characteristics: vessel presence/absence, vessel count, vessel type, distance between whale(s) and vessel(s), encounter type, and method of approach (**Table 1**). Based on vessel name, we identified a subset of vessels belonging to a single operator known to use an approach method which followed these additional guidelines: (1) maximum vessel speeds of 12.5 knots; (2) maximum vessel speed of six knots or less when whales were within 400 m; (3) maximum viewing times of 30 min or less when calves present; (4) vessel was located only parallel and to the side of whale direction of travel; and (5) a maximum of three vessels per group of whales. With the exception of the subset of vessels that were known to follow additional guidelines, it was assumed that all other vessels were following federal approach guidelines only. It is important to note that the manner in which vessels maneuvered and the speed they traveled was not recorded as part of this study. Julian day and group number were included as explanatory variables to account for the potential effects of seasonality and individual differences in whale groups, respectively.

Response Variables

Four metrics were calculated as candidate response variables for whale behavior using previously described methods (McCordic et al., 2017) and included: (1) swim speed (km/h), (2) respiration rate (breaths/min), (3) dive time (minutes), and (4) directness index.

Swim speed as used here represents horizontal speed and was calculated by determining the distance (km) between each pair of discrete behavioral observations and dividing this by the time (hours) between observations. For ease of comparison to other literature, horizontal speed is referred to as swim speed throughout this paper.

Respiration rate was calculated by dividing the number of blows during a surfacing interval and dividing this by the elapsed time (minutes) between the initial and final blows. In cases where multiple whales were present, a single individual was selected and tracked throughout the surfacing interval.

Dive time (minutes) was recorded as the elapsed time between the group's dive and subsequent re-surfacing. If multiple animals were present in a group, and the tracking of a single individual was not possible, dive time was based on the last individual to dive and the first individual to surface.

Directness index calculation followed previously published methods (Scheidat et al., 2004), where straight line distance between the first and last points of a surfacing was divided by the sum of the total distance traveled by the group during the surfacing. Directness index values equal to 100 indicate a straight

TABLE 2 | Summary of top GAM models showing the relationship between humpback whale behavior and vessel activities, where rows represent candidate explanatory variables and columns represent response variables.

	Swim speed	Respiration rate	Path directness–A	Path directness–B	Dive time–A	Dive time–B
Intercept	1.49***	1.14***	3.72***	3.80***	2.39***	2.33***
Julian day	-	*s*(4.32)	*s*(7.92)***	*s*(7.87)***	-	-
Group	*s*(7.85)***	-	-	-	*s*(8.63)***	*s*(8.41)***
Group composition–mother/calf/escort	−0.50***	-	-	-	−0.53**	−0.36*
Group composition–mother/calf	−0.17*	-	-	-	−0.07	−0.08
Group composition–other	−0.10	-	-	-	−0.07	−0.05
Encounter type–Before	-	-	-	-	-	-
Encounter type–During	-	−0.05	0.34***	-	-	−0.34**
Encounter type–after	-	−0.30*	0.38***	-	-	−0.35*
Distance between vessel and group	*s*(6.14)**	*s*(6.71)**	*s*(4.30)***	*s*(4.30)***	-	-
Vessel approach–no vessel	-	-	-	-	-	-
Vessel approach–regulations	-	-	-	0.12*	−0.37**	-
Vessel approach–additional guidelines	-	-	-	−0.15	0.16	-
Vessel approach–mix	-	-	-	0.10	0.19	-
Deviance explained (%)	14.10	27.80	37.40	36.30	32.2	29.0
Number of observations (groups)	720 (49)	143 (50)	192 (51)	192 (51)	178 (51)	178 (51)

The parametric coefficient estimates for factors and the degree of smoothing, s(EDF), for smooth terms included in the final model are presented in the cells.
*Significance of each model term is indicated by an * where: *** p = 0–0.001; ** p = 0.001–0.01; * p = 0.01–0.05.*
Cells with a "-" represent terms dropped from the final model.
Response variables labeled with A and B indicate that two top models were selected for discussion.

path, and directness index values equal to 0 indicate a path that returns to its starting point.

Model Selection

Model selection procedures followed (Wood, 2001) where a fully saturated model was initially fit for each response variable, and a final model was selected based on the GCV score, percent of deviance explained, and fit by reviewing the residual plots. The most parsimonious model was selected by decreasing the GCV score and increasing the deviance explained. Terms were tested for removal if they were (1) non-significant linear terms with a parameter coefficient near 0; or (2) non-significant smoothed terms with estimated degrees of freedom (edf) near 0. The linear form of the term was retained if dropping the smoothed term, with edf near 0, did not decrease the GCV score and increase the deviance explained.

Multicollinearity in explanatory variables was tested, and if present, the term with the least support for inclusion in the final model, based on the model selection criteria listed above, was dropped. In cases where correlated variables also had high support for inclusion in the final model (i.e., did not meet dropping criteria), two separate models were presented, one with each of the correlated variables.

Model Output

Individual variable plots (labeled A) are presented for each term of the best fit models. A value of 0 on the y-axis indicates no effect of the covariate on the estimated response, whereas values above 0 indicate a positive relationship, and values below 0 indicate a negative relationship. The x-axis for each variable plot contains small vertical ticks indicating the locations of observations (i.e., a rugplot). To display the absolute value of the response variable (whale behavior) as a function of the explanatory variable(s), the *predict* function in the stats package (R Core Team, 2019) was used for each of the best fit models and plots created to show the relationship (labeled B).

RESULTS

Survey Effort

We completed 73 survey days between December 2015 and March 2018 and recorded data on 316 humpback whale groups (943 individual whales) and 472 vessel approaches to whales. Of those, 279 focal groups (88%) were of sufficient duration ($\geq$15 min) to use in the analysis and 188 (59%) included data on vessel approaches. The average focal duration across these 279 groups was 19.7 min.

Group Behavior

Swim Speed

The best fit model for swim speed explained 14.1% of the deviance and included smoothed terms for group number and distance between whales and vessels, as well as a categorical term for group composition (**Table 2**). Groups with calves traveled significantly slower than groups without calves (**Table 2**; **Figure 2**).

The distance between whales and vessels was found to significantly impact swim speed (**Table 2**) with the largest positive increase in the parameter estimate observed from 75 to 120 m (**Figure 3A**). Model predictions found similar trends with a second positive increase predicted at 150 to 175 m (**Figure 3B**).

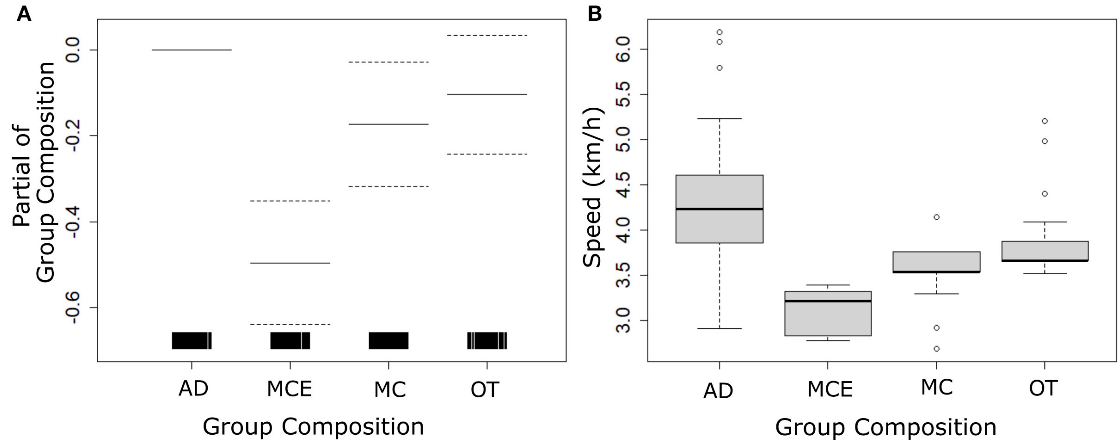

FIGURE 2 | Results from the best fit generalized additive model (GAM) for humpback whale swim speed showing **(A)** model parameter estimates of group composition (AD-adult, MCE-mother-calf-escort, MC-mother-calf; OT-other) and **(B)** model predicted swim speeds based on group composition. Dashed lines in image A represent the 95% confidence intervals of the parameter estimate, and vertical ticks indicate the locations of observations (i.e., a rugplot).

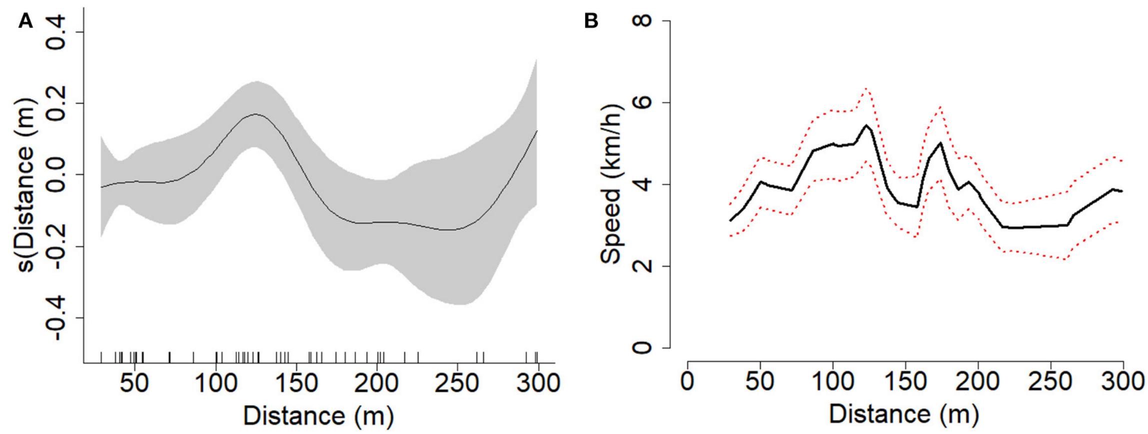

FIGURE 3 | Results from the best fit generalized additive model (GAM) for humpback swim speed showing **(A)** model parameter estimates of vessel distance to focal group and **(B)** model predicted swim speed based on vessel distance. The shaded and dashed lines represent the 95% confidence intervals of the parameter estimates and fitted values, respectively. The vertical ticks on image A indicate the locations of observations (i.e., a rugplot).

Dive Time

Two best fit models were used to explain variations in the dive time, as collinearity between two significant variables (encounter type and vessel approach) precluded inclusion of both terms in a single model (**Table 2**). Both models explained 29–32% of the deviance and included a smoothed term for group, as well as categorical terms for encounter type and method of approach (**Table 2**). In both models, parameter estimates for mother-calf-escort dive times were significantly less than other groups (**Table 2**; **Figure 4A**); however, model prediction found similar mean dive times of 6–8 min across all groups (**Figure 4B**).

Dive times were significantly shorter during and after an encounter with a vessel (**Table 2**; **Figure 5A**), with model predictions showing an average reduction in dive time of 83% during and after (**Figure 5B**).

Dive times were significantly less when vessels approached the focal group following the federal regulations, while no significant difference was observed when vessels approached following additional guidelines (**Table 2**; **Figure 6A**). Model predictions showed a reduction in dive times from an average of 9–5 min (-80%) when vessels approached under federal regulations (**Figure 6B**).

Respiration Rate

The model that best fit the respiration rate explained 27.8% of the deviance and included smoothed terms for Julian day and distance between whales and vessels, as well as a categorical term for encounter type (**Table 2**). The distance between whales and vessels was found to significantly impact respiration rate (**Table 2**) with two peaks corresponding to significant positive increases in the parameter estimate for respiration rate observed

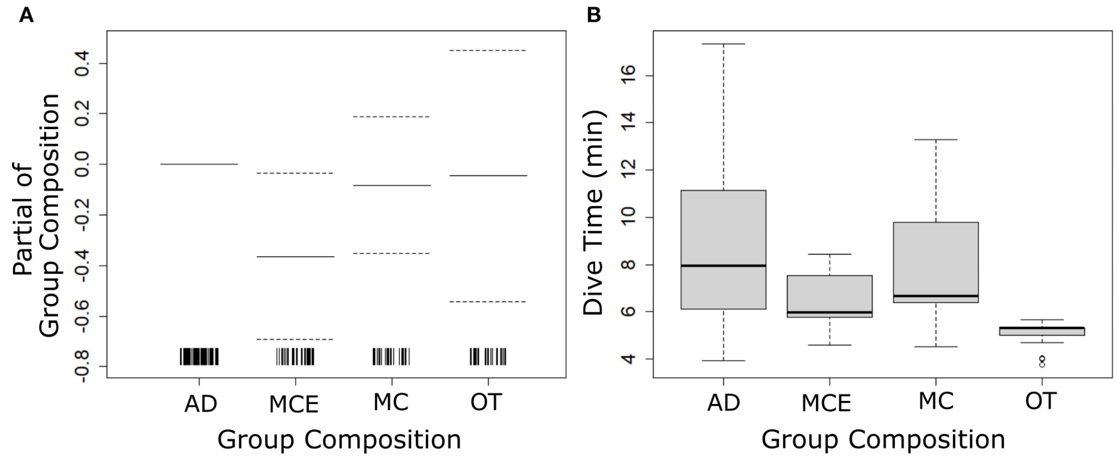

FIGURE 4 | Results from the best fit generalized additive model (GAM) for humpback whale dive time showing **(A)** model parameter estimates of group composition (AD-adult, MCE-mother-calf-escort, MC-mother-calf; OT-other) and **(B)** model predicted dive times based on group composition. Dashed lines in image **(A)** represent the 95% confidence intervals of the parameter estimate, and vertical ticks indicate the locations of observations (i.e., a rugplot).

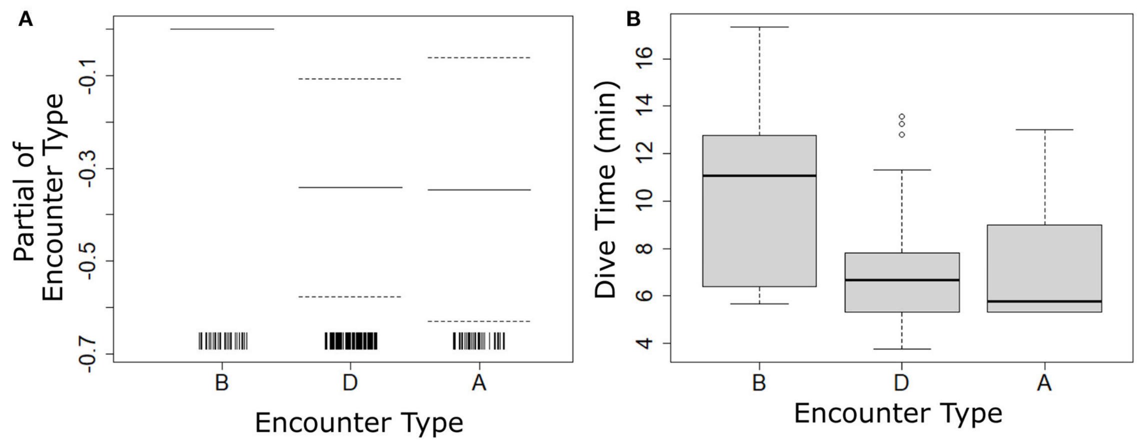

FIGURE 5 | Results from the best fit generalized additive model (GAM) for humpback whale dive time showing **(A)** model parameter estimates for encounter type (B-Before, D-During, A-After) and **(B)** model predicted dive times based upon encounter type. Dashed lines in image **(A)** represent the 95% confidence intervals of the parameter estimate, and vertical ticks indicate the locations of observations (i.e., a rugplot).

at 75 to 150 m and 250 to 340 m (**Figure 7A**). Model predictions found similar trends to parameter estimates (**Figure 7B**).

Respiration rate was found to be significantly less after vessel(s) left a group of whales (**Table 2**; **Figure 8A**). Model predictions found that whales took ∼13% fewer breaths both during and after an encounter with a vessel (**Figure 8B**).

Path Directness

Two best fit models are presented to explain variations in the path directness, as collinearity between two significant variables (encounter type and vessel approach) precluded inclusion of both terms in a single model (**Table 2**). Both models explained 36–37% of the deviance and included smoothed terms for Julian day and distance between whales and vessel(s), as well as categorical terms for encounter type and method of approach (**Table 2**). The direction of travel became less variable (i.e., straighter) when the distance between vessel(s) and whales went from 50 to 170 m, after which the direction of travel become more variable (i.e., random) (**Table 2**; **Figure 9**).

The parameter estimate for directness index was found to be significantly higher during and after vessel(s) approached a group of whales (**Table 2**; **Figure 10A**), with model predictions showing whales traveling in a straighter line both during and after an encounter (**Figure 10B**).

The path directness was significantly higher (i.e., direction of travel was more straight) when vessels approached the focal group following the federal regulations, while no significant difference was observed when vessels approached following additional guidelines (**Table 2**; **Figure 11A**). Model predictions showed similar trends, with whales predicted to travel in a straighter line when vessels approached under federal regulations (**Figure 11B**).

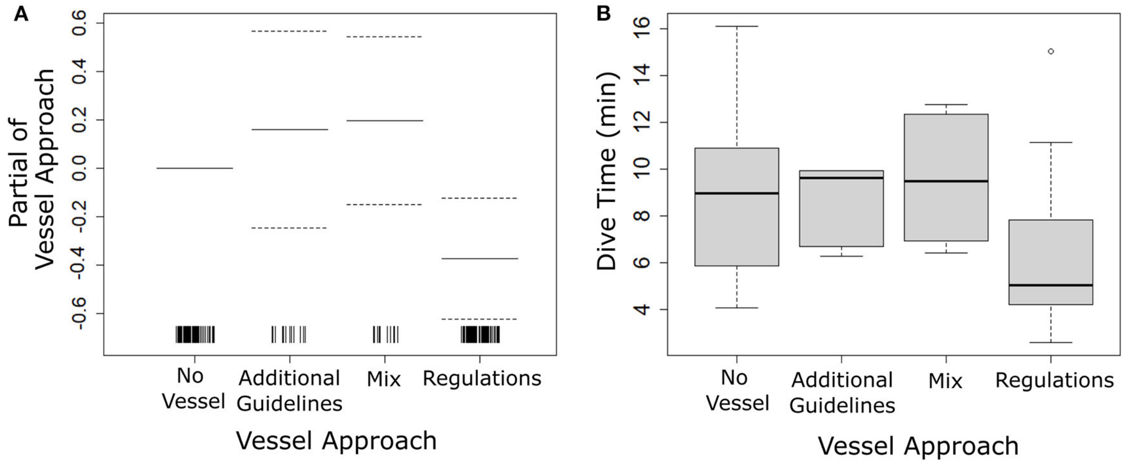

FIGURE 6 | Results from the best fit generalized additive model (GAM) for humpback whale dive time showing group **(A)** model parameter estimates for vessel approach type (No Vessel: no vessels within 500 m; Additional Guidelines: vessels(s) were approaching under additional voluntary guidelines; Regulations: vessel(s) were assumed approaching under federal regulations only; Mix: multiple vessels approaching with one or more following additional voluntary guidelines and one or more following federal guidelines only) and **(B)** model predicted dive times based upon vessel approach type. Dashed lines in image **(A)** represent the 95% confidence intervals of the parameter estimate, and vertical ticks indicate the locations of observations (i.e., a rugplot).

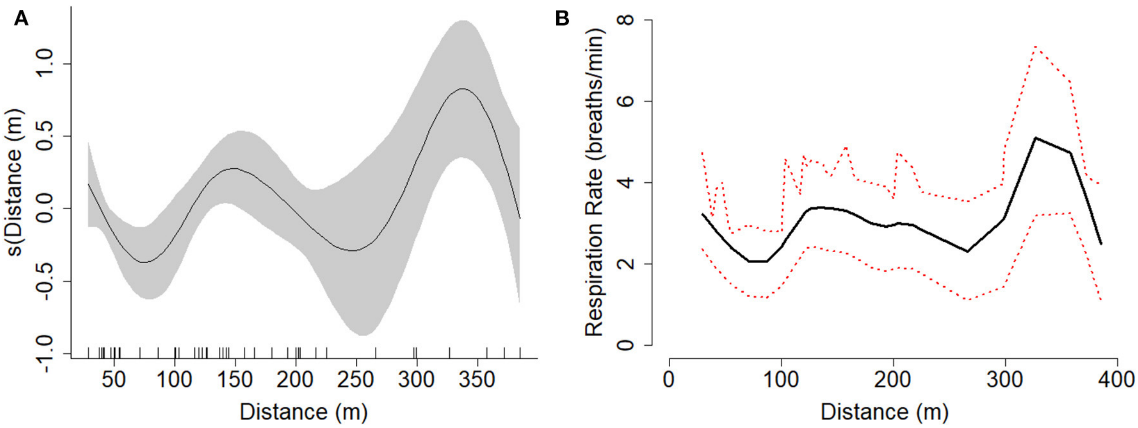

FIGURE 7 | Results from the best fit generalized additive model (GAM) for humpback respiration rate showing **(A)** model parameter estimates of vessel distance to focal group and **(B)** model predicted respiration rate based on vessel distance. The shaded and dashed lines represent the 95% confidence intervals of the parameter estimates and fitted values, respectively. The vertical ticks on image **(A)** indicate the locations of observations (i.e., a rugplot).

DISCUSSIONS

This study used a land-based platform to observe whale behaviors in the presence and absence of vessels. The presence of vessels was found to cause increases in swim speed, respiration rate, and path directness as well as decreases in dive times. The method of approach used by a vessel was found to reduce some of the observed behavior changes. A vessel variable was included in the best fit models for each behavioral response and was the only significant variable explaining whale respiration rate and path directness. These results support the conclusion that vessels in Hawai'i are impacting whale behavior. In the presence of vessels, the observed increase in group swim speed and directness of travel, coupled with decreased dive times suggests humpback whales may be employing a horizontal avoidance strategy (Baker et al., 1983; Frid and Dill, 2002). Vessel proximity to humpback whale groups was found to significantly impact all surface-based behaviors: swim speed, path directness, and respiration rate and aligns with previous work (Williams et al., 2006, 2009; Stamation et al., 2009). However, it is important to note that these relationships are often complex, with various components of vessel presence acting independently on whale behavior (Williams et al., 2006; Stamation et al., 2009). As such, the results cannot be solely attributed to a single cause, but vessel proximity plays a significant role for humpback whales in Hawai'i. Additional biological parameters, such as calf presence, was also found to significantly decrease swim speed and dive time and, as Hawai'i is a calving ground, these groups are frequently

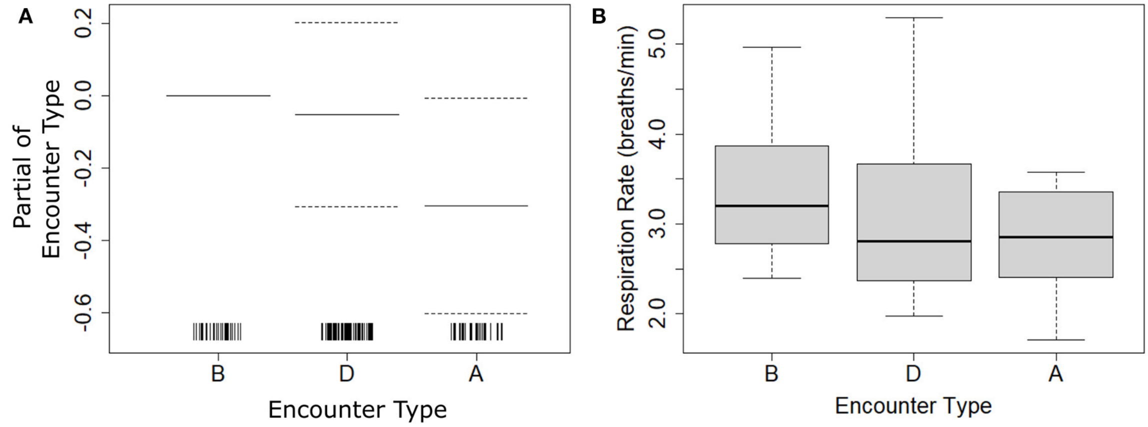

FIGURE 8 | Results from the best fit generalized additive model (GAM) for humpback whale respiration rate showing **(A)** model parameter estimates for encounter type (B-Before, D-During, A-After) and **(B)** model predicted respiration rate based upon encounter type. Dashed lines in image **(A)** represent the 95% confidence intervals of the parameter estimate. Vertical ticks **(A)** indicate the locations of observations (i.e., rugplot).

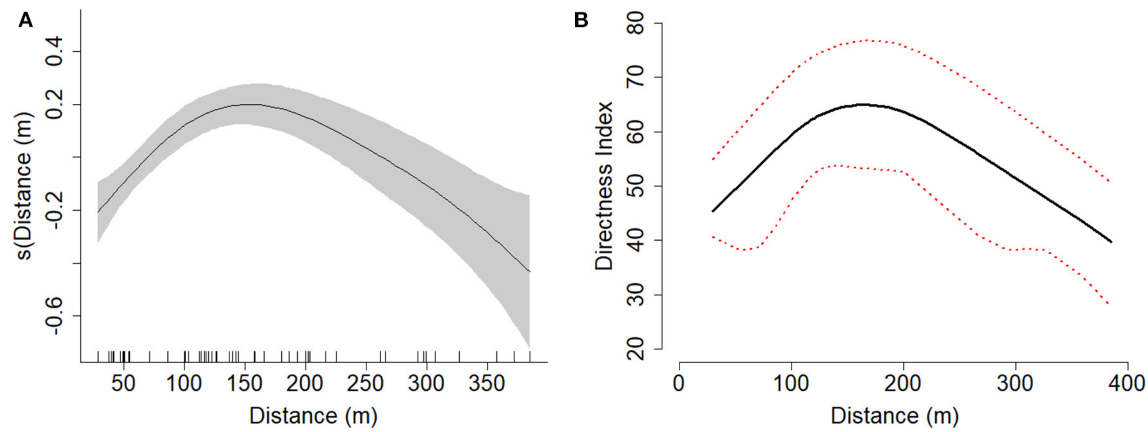

FIGURE 9 | Results from the best fit generalized additive model (GAM) for humpback whale path directness showing **(A)** model parameter estimates of vessel distance to focal group and **(B)** model predicted path directness based on vessel distance. The shaded and dashed lines represent the 95% confidence intervals of the parameter estimates and fitted values, respectively. The vertical ticks on image **(A)** indicate the locations of observations (i.e., a rugplot).

observed within the study site (Mobley and Herman, 1985; Brown and Corkeron, 1995; Pack et al., 2012).

Given that vessel presence and proximity, rather than count were primary drivers of the observed behavioral trends suggests that, within Maui Nui, vessel presence is a more important consideration than specific vessel characteristics or number. For respiration rate, swim speed, and directness index, significant behavioral change was predicted well outside the regulated 100-yard approach distance (~91 m), indicating whales may be responding to vessel presence prior to close approaches. The lack of a behavioral response observed during very close encounters, i.e., <100 yards (~91 m), may be related to the legal requirement that vessels to keep their engines in neutral until the whale swims beyond 100 yards (~91 m), resulting in reduced engine noise at this distance. The slow swim speeds, low directness of travel, and low respiration rates at these close distances are also representative of whales interacting with the vessel. Behavioral reactions to disturbance in humpback whales likely arise from a combination of auditory and visual cues (Higham et al., 2014; Sprogis et al., 2020). However, for humpback whales, hearing is more efficient than sight and can be used at longer ranges (Richardson et al., 1998), with noise level a likely driver of humpback whale disturbance (Sprogis et al., 2020) in addition to potential visual cues at closer distances. Further work is needed to determine the mechanistic link between the observed behavior changes and vessel presence.

Observed Changes to Swim Speed and Respiration Rate

The observed peak in swim speed at 125 m as vessels approached the legal approach distance of 100 yards (~91 m), follows previous observations that showed increases in swim speeds as vessels approached (Scheidat et al., 2004; Williams et al., 2006). These responses may indicate a horizontal avoidance

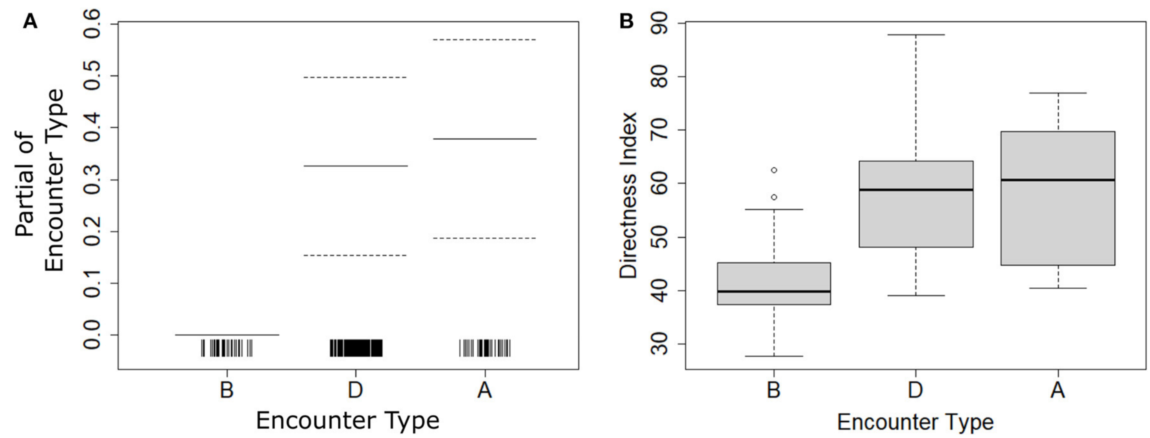

FIGURE 10 | Results from the best fit generalized additive model (GAM) for humpback whale path directness showing **(A)** model parameter estimates for encounter type (B-Before, D-During, A-After) and **(B)** model predicted path directness based upon encounter type. Dashed lines in image **(A)** represent the 95% confidence intervals of the parameter estimate. Dashed lines in image **(A)** represent the 95% confidence intervals of the parameter estimate and vertical ticks indicate the locations of observations (i.e., a rugplot).

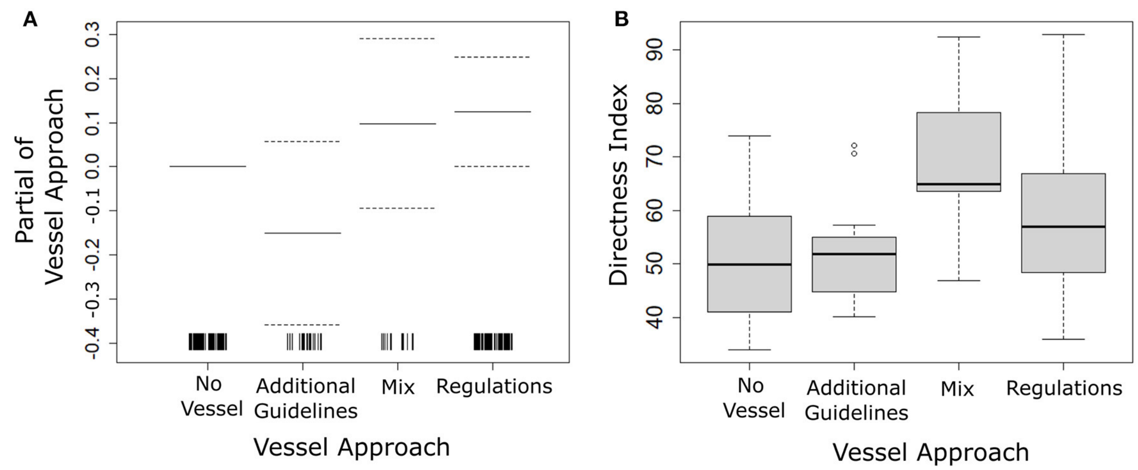

FIGURE 11 | Results from the best fit generalized additive model (GAM) for humpback whale path directness showing **(A)** model parameter estimates for vessel approach type (No Vessel: no vessels within 500 m; Additional Guidelines: vessels(s) were approaching under additional voluntary guidelines; Regulations: vessel(s) were assumed approaching under federal regulations only; Mix: multiple vessels approaching with one or more following additional voluntary guidelines and one or more following federal guidelines only) and **(B)** model predicted path directness based upon vessel approach type. Dashed lines in image **(A)** represent the 95% confidence intervals of the parameter estimate and vertical ticks indicate the locations of observations (i.e., a rugplot).

strategy as noise from vessel engines has been suggested as a driver of disturbance response (Sprogis et al., 2020). The observed increases in swim speed at 100 and 250 m occurred in conjunction with significant increases in respiration rate, and these behaviors are known to be positively correlated (Williams and Noren, 2009). These results indicate an increase in energy use arising from vessel traffic in Hawai'i, which can lead to both individual and population-level consequences (Lusseau and Bejder, 2007; Cartwright et al., 2019) and is of particular concern for the growth potential of calves (Braithwaite et al., 2015). A reduction in respiration rate after vessels left was found to be marginally significant (p-value $= 0.04$) and suggests the behavioral responses may be short-term, as seen in previous work (Scheidat et al., 2004). However, it is important to consider that cumulative impacts from vessel activity, even if short-lived, can have detrimental impacts to individuals and populations (Pirotta et al., 2019).

Observed Changes in Path Directness and Dive Time

The observed trend of an indirect path of travel to a more direct path of travel with vessel approach suggests that whales are changing how they swim when boats approach within 150 m. Even after vessels left, groups were observed to continue swimming in a more direct path than before the vessel had approached, indicating a longer behavioral response. These results contrast observations made for killer whales (*Orcinus orca*), who are thought to travel in a less direct path to evade approaching vessels (Williams et al., 2006). The significant changes observed in path directness were also observed for dive time, with shorter dives observed when vessels were present and after they left. Although previous research has found increases in dive time associated with vessel traffic (Baker et al., 1983; Schaffar et al., 2013; Senigaglia et al., 2016), the results shown here suggest the use of increased swim speeds and faster respiration, in conjunction with shorter dives time and straighter direction of travel, as a possible evasive tactic (Frid and Dill, 2002; Stamation et al., 2009) to move away from vessels.

Observed Changes in Group Behavior Based on Vessel Approach Method

When considering the method of vessel approach and movement around whales, both the path directness and dive time of the whale did not significantly change when vessels followed additional whale watching guidelines. This highlights the potential of further guidelines for approaching humpback whales in reducing behavioral changes. In Hawai'i, nearly half of all licensed whale watching operators conduct tours in the relatively shallow leeward waters of Maui Nui (O'Connor et al., 2009) and given that vessel type did not significantly impact whale behaviors, additional guidelines for all vessels are recommended. The additional whale watching guidelines presented in **Table 1** will likely reduce behavioral responses from target whales (Morete et al., 2007; Currie et al., 2017; Sprogis et al., 2020), given the reduced impact observed in this study. The current regulations in place for protecting humpback whales in Hawai'i include a 100-yard approach distance (∼91 m), no placing of vessels in the direct path of whales and no thrill craft operations during whale season (Federal Register, 2016). However, the global increase in both commercial and recreational whale watching (O'Connor et al., 2009) and recent concern over the health and status of this distinct population segment (Cartwright et al., 2019) highlight the need to follow a precautionary approach to management. Indeed, significant behavior changes for respiration rate, swim speed, and directness index were observed when vessels were well outside 100 yards (∼91 m) at distances up to 400 m. As such, it is important to consider if the current management regimes for whale watching are effective at reducing disturbance. Results presented here, in conjunction with previous work (Morete et al., 2007; Williams and Noren, 2009; Lammers et al., 2013; Currie et al., 2017; Fiori et al., 2019) clearly demonstrate vessel presence as a threat to humpback whales that can be further mitigated with stricter guidelines.

The most important guidelines that vessels followed that minimized whale avoidance behavior related to dive time and path directness were (1) traveling at 12.5 knots and slowing to 6 knots when within 400 m of the whale, (2) limiting viewing time of mom-calf groups to 30 min, and (3) operating only parallel and to the side of whales, never directly in front of or behind the whales. Logistical constraints precluded the use of a second theodolite to simultaneously track vessel movement. Vessels following additional guidelines used a mobile app, Whale and Dolphin Tracker (Currie et al., 2018a), to record their GPS track during trips. Although vessel speed was not recorded as part of this study, informal interviews with captains of this subset of vessels along with review of GPS tracks allowed us to confirm vessel speed as it related to these additional guidelines. There is likely a large variation in how other vessels approached whales which represents a limitation of this study. However, the results show clear differences in whale response to approaches by vessels belonging to the two categories, which suggests that there were different approach types being used. Given these findings, we recommend that these additional whale watching guidelines be implemented within the Hawaiian Islands Humpback Whale National Marine Sanctuary waters. Reduced vessel speeds will allow both whales and boat operators more time to detect and maneuver toward avoidance (Vanderlaan and Taggart, 2007; Currie et al., 2017), while the additional approach guidelines outlined above will avoid unintended disruptions to normal whale behavior (Baker et al., 1983; Stamation et al., 2009).

CONCLUSIONS

The present study found significant changes in humpback whale behavior relating to vessel presence, which suggests that the current regulations are not sufficient for minimizing behavioral responses. However, the observed changes could not be conclusively attributed to a single factor or observation and likely relate to a combination of species biology and vessel activity and further research is needed on this aspect. Although observed changes were likely short-term, the occurrence of disturbance on breeding grounds increases the potential risk by reducing humpback whale energy stores in food limited conditions (Williams et al., 2011). Humpback whales in Hawai'i are not feeding and thus must rely on fat reserves to survive breeding ground activities while maintaining enough energy to be able to endure the long migration back to the feeding grounds. The observed avoidance of vessels by increasing swim speed, respiration rate and path directness, while decreasing dive times is energetically demanding during a time when whales are already expending high levels of energy by engaging in breeding activities, nursing, and calving (Braithwaite et al., 2015). Mothers with calves have a tremendous energetic demand while lactating, with previous work illustrating that seemingly minor, short-term avoidance behaviors such as increasing swim speed and path directness may quickly transition to long term avoidance strategies of an area regardless of age class, if the disturbance persists (Lusseau and Bejder, 2007). Increasing environmental variability and the recent humpback whale decline in Hawai'i linked to reduced productivity of key prey resources in Alaska (Cartwright et al., 2019) highlights the need for a precautionary approach to management of Hawai'i's humpback whales. This requires stricter guidelines on the vessel activities to ensure that vessels operate in a manner that does not compromise the fitness of individual whales and their ability to compensate to varying ecological and anthropogenic conditions.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because this study was undertaken on land where researchers passively observed whale behaviors around normal vessel traffic. This research did not require any interactions between land-based research crew and whales.

AUTHOR CONTRIBUTIONS

JC, SS, and JM conceived and conceptualized the study. Fieldwork was conducted primarily by JM with support from JC, SS, AM, and GO. Data processing and quality control was conducted by JM with analysis completed by JC. Interpretation was carried out by JC and SS. All authors contributed to writing of the manuscript as well as commenting on various drafts.

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Looking Back to Move Forward: Lessons From Three Decades of Research and Management of Cetacean Tourism in New Zealand

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Cetacean tourism in Aotearoa New Zealand is now over 30 years old and has experienced substantial growth in visitor numbers and operations. The industry is remarkably diverse, targeting several dolphin and whale species, and encompassing varied habitats in coastal waters, fiords and submarine canyons. The knowledge and experience collected over these past 30 years has both advanced the global understanding of cetacean tourism, and influenced scientific practices for its study and management. Here we review the approaches taken in quantifying the impact of cetacean tourism in New Zealand, and critically assess the efficacy of the research and management strategies adopted. We place particular focus on the Bay of Islands, Hauraki Gulf, Kaikoura, Akaroa and Fiordland, areas that include the oldest, and longest studied industries nationally. We propose a set of best research practices, expose the most notable knowledge gaps and identify emerging research questions. Drawing on perspectives from the natural and social sciences, we outline the key determinants of failure and success in protecting cetacean populations from the detrimental impact of tourism. We suggest four golden rules for future management efforts: (1) acknowledge cetacean tourism as a sub-lethal anthropogenic stressor to be managed with precaution, (2) apply integrated and adaptive site- and species-specific approaches, (3) fully conceptualize tourism within its broader social and ecological contexts, and (4) establish authentic collaborations and engagement with the local community. Lastly, we forecast upcoming challenges and opportunities for research and management of this industry in the context of global climate change. Despite New Zealand's early establishment of precautionary legislation and advanced tourism research and management approaches, we detected flaws in current schemes, and emphasize the need for more adaptive and comprehensive strategies. Cetacean tourism remains an ongoing challenge in New Zealand and globally.

Keywords: whale watching, dolphin swim-with, wildlife tourism, tourism impact, cetacean conservation, impact research, tourism management

INTRODUCTION

An increasing demand to interact closely with whales, dolphins and porpoises has led to commercial activities targeting wild cetaceans (hereafter cetacean tourism) becoming a burgeoning industry globally (Hoyt, 2018). Prior to the Coronavirus (COVID-19) pandemic of 2020, the industry had significant potential for further growth (Cisneros-Montemayor et al., 2010), even though there were already clear signs that this form of tourism is often not managed sustainably (Higham et al., 2009). The dramatic post-COVID-19 hiatus in tourism provides a unique opportunity to reflect and build on past experience, and to prepare for future scenarios.

Cetacean tourism can benefit human communities and cetacean populations via improving livelihoods, providing opportunities for education and research, and fostering a climate for conservation initiatives (Hoyt, 2018). This, and the often uncertain effects of tourism on cetaceans, have led to considering the activity a lower priority threat compared to those resulting in direct mortality (e.g., bycatch, hunting) or alteration of habitat (Higham et al., 2016). Detrimental effects on the animals, however, are clear (Samuels et al., 2003; Machernis et al., 2018), and cetacean tourism is now recognized as a sub-lethal consumptive industry (Neves, 2010; Higham et al., 2016). As such, its management is best based on a precautionary principle (Bejder et al., 2006b) and on analytical frameworks incorporating the ecological and social aspects of the industry, and the multiple threats to cetaceans (Higham et al., 2009). Moreover, animal welfare (i.e., individual effects) is increasingly recommended as a necessary complement to conservation indicators (i.e., population-level effects) (Papastavrou et al., 2017; Nicol et al., 2020). To date, however, priorities and approaches to cetacean tourism research and management have varied significantly at both local and global scales.

New Zealand has a 30-year history of cetacean tourism research and management. Following the establishment of the first dedicated operation in Kaikoura in 1987 (Donoghue, 1996), the industry flourished in multiple locations, each characterized by a unique combination of ecological, social, research and management features (**Figure 1**). The New Zealand evidence- and partnership-based approach to environmental conservation (Ewen et al., 2013) translates in scientific studies often commissioned by the government (Constantine, 1999; Orams, 2004), and in research and management initiatives involving multiple stakeholders, including local *iwi* (Māori tribes; Simmons, 2014) and tour operators. In some cases, these studies have prompted site-specific management actions. Recent longitudinal studies, however, have exposed the inadequacy of past and present management regimes (Hartel et al., 2014; Bennington et al., 2020; Dwyer et al., 2020) and outlined the financial, procedural and institutional barriers to effective marine conservation (Bremer and Glavovic, 2013; Dodson, 2014). Effective management of cetacean tourism in New Zealand continues to be a challenge.

In this review we draw on our personal experiences of extended engagement in marine mammal and cetacean tourism research, advocacy and community outreach, and advisory roles to national and regional governments and organizations in New Zealand and internationally. Where possible, the perspectives of other interested parties (e.g., governmental agencies, tour operators) are included, based on available literature and personal communications.

Building on previous assessments of the industry (Donoghue, 1996; Constantine, 1999; Orams, 2004), we aim to (1) critically review approaches taken in New Zealand to studying and managing tourism pressures via analysis of five case studies, (2) put forward clear and specific recommendations for the future of research and management of cetacean tourism within a national and international context, and (3) highlight the main knowledge gaps, emerging questions, future challenges and opportunities for managing the industry in light of both welfare and conservation considerations. Overall, we aim to initiate a productive dialogue on the future of cetacean tourism industry in New Zealand.

CASE STUDIES OF CETACEAN TOURISM IN NEW ZEALAND

The Department of Conservation (DOC) is the government agency responsible for administering the Marine Mammals Protection Act (MMPA) New Zealand Government, 1978 and the Marine Mammals Protection Regulations (MMPR) (New Zealand Government, 1992). Under the MMPR, DOC issues permits for commercial operators conducting tours to view and/or swim with marine mammals, and regulates human behavior around the animals with site-specific conditions.

Over the past three decades, in response to the significant growth in international tourism (Upton, 2019), cetacean tourism has become an established industry in the country. The permit system provides a legal structure to regulate its proliferation, but has often been used to formalize already existing commercial activity (Allum, 2009), hence in a reactive, rather than proactive fashion. The number of permits issued by DOC to view and/or swim-with cetaceans increased from one in 1987 to 63 by 1997 (Constantine, 1999), and to 76 by 2020 (DOC, pers. comm.). The number of permits, however, is likely to underestimate the actual increase in tourism pressure over time, as operators can increase the number and duration of trips at their discretion. In addition, wild cetaceans have been increasingly exposed to interactions pursued by non-permitted operations and to opportunistic boat encounters. Data on trip number, frequency and duration, and cetacean daily and cumulative exposure to overall pressure, which would have allowed for a more representative description of tourism evolution, are unavailable or sporadic (e.g., Bejder et al., 1999; Green, 2005; Martinez et al., 2011).

As of today, most current permits allow only viewing cetaceans, while 27 permits grant the additional right to swim with dolphins. The level of enforcement is variable and, depending on the region, boat patrols and "mystery shoppers" are used to assess compliance. Site-specific voluntary codes of conduct often complement but may not contradict the MMPR.

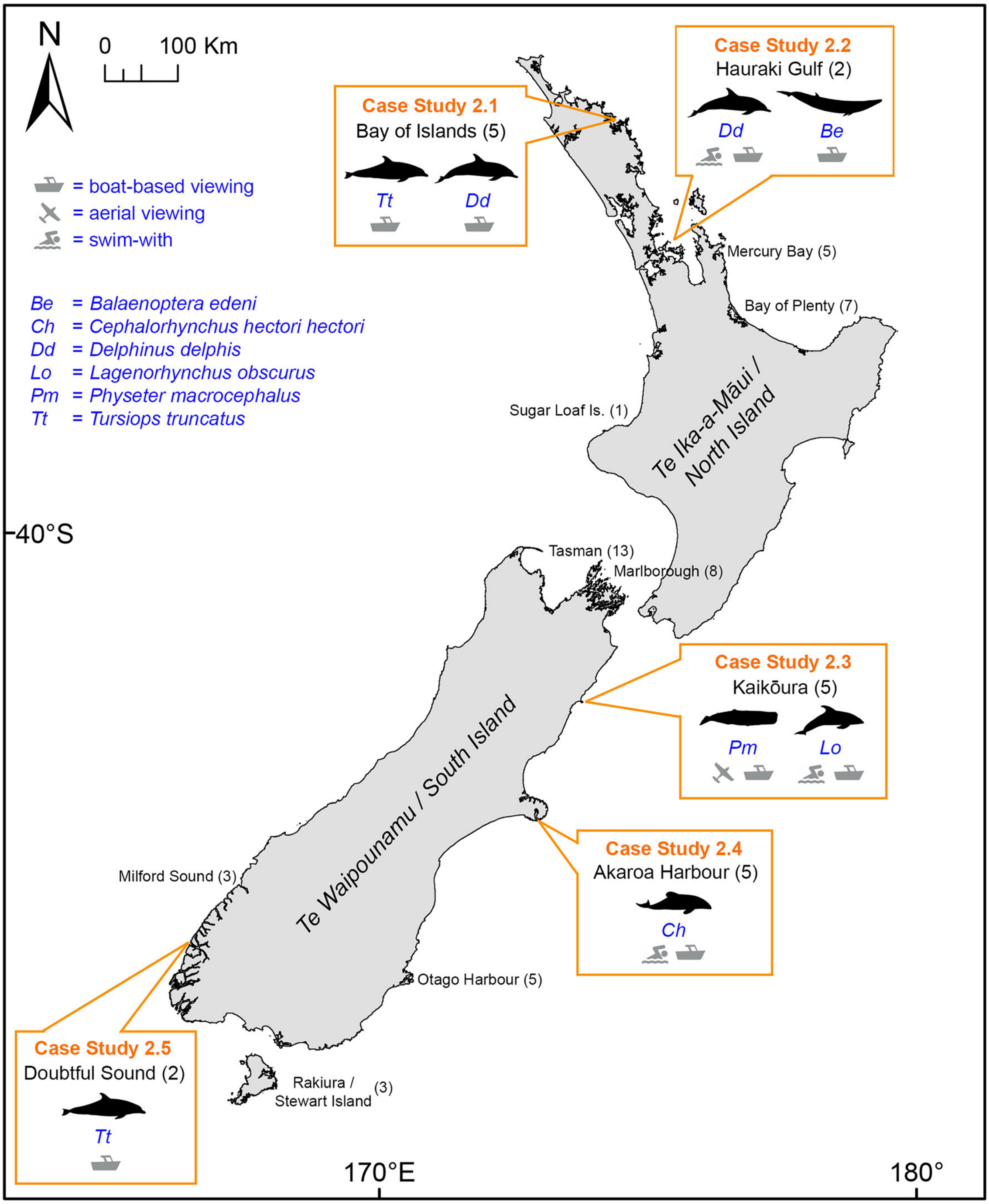

FIGURE 1 | Map of cetacean tourism destinations in New Zealand with permitted operations. For each destination, we report the number of permitted operators (in brackets). For the selected case studies presented in the following sections (boxes), we also indicate species targeted and characteristics of operations.

Commercial activities target predominantly the populations of six species: bottlenose (*Tursiops truncatus*), common (*Delphinus delphis*), dusky (*Lagenorhynchus obscurus*), and the endemic Hector's dolphin (*Cephalorhynchus hectori hectori*), as well as the sperm whale (*Physeter macrocephalus*), and the Bryde's whale (*Balaenoptera edeni brydei*). Substantial research on the effects of tourism on cetaceans has been undertaken at five locations, four of which are the focus of long-term monitoring programs: the Bay of Islands, the Hauraki Gulf, Kaikoura, Akaroa Harbour and Doubtful Sound (**Figure 1**). These are reviewed in detail in this section and in **Tables 1–4**. The literature on cetacean tourism at other destinations in New Zealand is summarized in **Table 5**.

TABLE 1 | Summary of the literature on bottlenose and common dolphin tourism in the Bay of Islands.

Year	Research findings	Research methods	Management recommendations	Management actions	References
1994–95	Behavior of both common and bottlenose dolphins impacted by tourism. Socializing was the behavior most impacted for both species [1]. Documented seasonal shifts in habitat use with both species. Photo-identification studies identified non-resident bottlenose dolphin population [1]. No acoustic response in common dolphins exposed to a controlled series of pass-by and engine start-up. Uncertain evidence for bottlenose dolphins [2]. On-board education significantly improves customer experience [2].	Inclusion of swimmer placement to assess tourism impact. Ethogram describing the dolphins' behavioral responses. Systematic data collection on the operations and effects of the tour vessels on dolphin behaviors. Established methods for population monitoring.	Avoid "in path" swimmer placement [1,3]. Prohibit approaching bottlenose and common when foraging or resting, respectively [1]. Clear definition of "juvenile" [1]. Improve the level of on-board education [2].	Appointed a full-time Marine Mammal Ranger. Recommended swimmer placement to minimize impact. Engaged with tour operators outside of the Bay to ensure lowering potential cumulative impacts. Creation of a Dolphin Care Code and a code of ethics in Paihia.	[1] Constantine and Baker, 1997 [2] Helweg, 1995 [3] Constantine, 2001
1996–2001	Significant change in bottlenose dolphin resting behavior due to increased tourism pressure [1,4,5]. Dolphins sensitized to cumulative effects of swim attempts, with differences in age-class response to swimmers [3]. Identification of preferred resting areas [4]. Estimated 446 dolphins using the Bay. Core users identified. Identified individuals from the Bay in other locations [4,6].	Long-term study on behavioral response to tourism [4,5] Use of CATMOD to determine the interaction effects of dolphin group and vessel/operation variables [5] Habitat use models to identify core habitat and overlap with tour vessel use.	No further permits for dolphin-based tourism [3,4,5]. Creation of dedicated time periods when no vessels should approach dolphins [4,5]. Limitation of the amount of time tour vessels spend with dolphins and number of swim attempts per vessel [4,5].	Creation of "lunch break" to limit all vessel contact time, reduced permitted vessel encounter duration, limit to three swim attempts per permitted tour vessel per trip. Created two new permitted tour vessel exclusion areas based on resting areas. Proposed establishment of a moratorium on new permits. DOC handbook for dolphin tourism operators and outreach materials for the public.	[4] Constantine, 2002 [5] Constantine et al., 2004 [6] Berghan et al., 2008
2003–06	No genetic interchange between bottlenose populations around New Zealand indicates isolation of populations [7]. Annual decline in local abundance of bottlenose of 7.5% (1997–2006). Fewer dolphins used the Bay on a regular basis [8]. Long inter-calf intervals with high rates of calf mortality [9]. Strong association networks with some persisting for almost a decade [10,12].	Population genetics to understand regional connectivity. Genetic identification of individuals to understand population demographics. Long-term dataset for POPAN mark-recapture analysis and assessment of reproductive rates.	Focus on minimizing all anthropogenic impacts [8,9]. Enforcement of tour operators permit conditions [8,9]. Monitoring of demographic and social impacts to determine whether mitigation is effective [8,10]. Urgent conservation action [8,9].	Marine mammal ranger employed to enforce permit conditions, educate non-permitted tour operators and the public.	[7] Tezanos-Pinto, 2009 [8] Tezanos-Pinto et al., 2013 [9] Tezanos-Pinto et al., 2015 [10] Mourão, 2006
2007–12	Significant changes in fine-scale habitat use. The static tourism exclusion zones are rarely used by dolphins [11]. Near-complete abandonment of BOI area by dolphins, evidenced by continued decline in local population size (from 446 in 1994 [4] to 24 in 2012 [12,13]). Fragmented social structure [12].	Spatial ecology tools to reveal habitat shifts. Long-term photo-identification data to determine trends in demographic and social structure.	Replacement of static exclusion zones with dynamic protected areas [11]. Further measures to mitigate impacts [11,12].	Implementation of a 5-year moratorium on new permits. DOC Marine Mammal Handbook updated.	[11] Hartel et al., 2014 [12] Hamilton, 2013
2012–15	Continued high levels of calf mortality and reduction in habitat use. Continued changes in behavioral budgets in the presence of vessels. Poor compliance across all vessel types [13].	Behavioral state transitions.	Greater enforcement of MMPR for all vessels [13]. Adaptive protection measures supported with education.	2019: ban on swimming with dolphins in the Bay of Islands. Encounter time for permitted tour operators further reduced. Voluntary maximum approach distance to pods containing mother calf-pairs.	[13] Peters and Stockin, 2016

TABLE 2A | Summary of the literature on the sperm whale tourism at Kaikoura.

Year	Research findings	Research methods	Management recommendations	Management actions	References
1990–92	Surface intervals and respiratory intervals shorter in presence of vessels, and some evidence for effects on echolocation behavior [1,2]. Outboard-driven tour vessels produce high levels of noise in the frequency range of echolocation buzzes [2].	Serial observations to control for behavioral differences among individuals [1,2]. Passive acoustics [2].	More sensitive boat handling by tourism vessels [1,2]. Use of directional hydrophones to track whales to reduce the need for fast approaches [2]. Continued monitoring to investigate long-term effects of disturbance [2].	Extensive use of hydrophones for tracking. Improved skipper behavior. Shift to waterjet propulsion for new, larger vessels.	[1] MacGibbon, 1991a,b [2] Gordon et al., 1992
1997–98	Diverse demography of visitors. Positive attitudes of local and Māori community toward tourism. Issues and tensions between tourism and locals' aspirations and needs. Significant economic impact of tourism.	Questionnaires, interview.	Develop a comprehensive community-based tourism strategy with strong links to a national tourism strategy. Policy directions: maintain local ownership of key facilities, retain local control in decision making, safeguard carefully tourism's visual impact, and adequately resource and manage key public sites.	None.	Simmons and Fairweather, 1998
1998–2005	Respiratory intervals and time to first echolocation click shorter, surface intervals longer, heading changes at the surface more frequent in the presence of vessels; responses more pronounced for "transient" whales.	Multi-year dataset; shore-based observations; accounting for impact of research vessel; distinction among individual whales. Multi-model inference statistical approach.	No increase to level of permitted activity. Long-term scheme for monitoring behavioral changes required, with cooperation of whale watching companies. Recommendations for improvements in educational material.	10-year moratorium on whale watching permits. In 2005, establishment of Te Korowai o Te Tai o Marokura (the Kaikoura coastal guardians), a volunteer, multi-stakeholder group, to provide leadership about the use and protection of Kaikoura's resources, including in relation to whale watching.	Richter et al., 2003, 2006
2009–11	Respiratory intervals longer in presence of vessels when measured from shore; variance of heading change at surface increased in presence of tour vessels; time to first click and duration of first silence longer in presence of vessels [3]. Decline in the abundance of sperm whales visiting Kaikoura [4].	Research vessel, shore-based observations and platforms of opportunity [3]. Mark-recapture modeling (Cormac-Jolly-Seber) [4].	Current regulations appropriately manage the interactions between tour vessels and whales; continued caution warranted concerning growth of industry [3].	10-year moratorium on whale watching permits.	[3] Markowitz et al., 2011 [4] Van der Linde, 2010
2016–20	Continued decline in abundance, driven by a decrease in numbers during summer [5]. Decline in abundance may be partly driven by oceanographic variability due to climate change [6].	Mark-recapture models (Robust design) [5].	Need to carry out longitudinal study to evaluate impact of tourism on population demography [5,6].	Review of tourism impacts and moratorium due in 2022.	[5] Somerford, 2018 [6] Guerra, 2019

TABLE 2B | Summary of the literature on the dusky dolphin tourism at Kaikoura.

Year	Research findings	Research methods	Management recommendations	Management actions	References
1993–98	Surface activity [1,2], movements [1–3], and group cohesion [1] change in presence of vessels. The number of groups has increased and their distribution is further south since the establishment of tourism [3]. Diverse demography of visitors. Positive attitudes of local and Māori community toward tourism. Issues and tensions between tourism and locals' aspirations and needs. Significant economic impact of tourism [4].	Shore-based theodolite tracking, surface activity levels [1–3]. Questionnaires, observation [4].	Reduce trips between 11 a.m. and 2 p.m.; voluntary or regulated "time off"; no increase in activity, enhance education and enforcement, stricter regulations for private vessels [1]. Comprehensive community-based tourism strategy linked to a national strategy [4].	Adoption of a voluntary summertime midday rest period (11:30–13:30, 1.Dec to 31.March). 10-year moratorium on dolphin watching permits (1999–2009). Guide and skipper course.	[1] Barr and Slooten, 1999 [2] Yin, 1999 [3] Brown, 2000 [4] Simmons and Fairweather, 1998
1998–2008	Resting and socializing decrease in the presence of tourism activities [5,7]. Number of swim drops correlated with behavioral responses [5]. Effects on heading, dispersion, and leaping rate of large groups [7]. Decrease in visits during the rest period (visit/h) [6]. No change in size and location of core area compared to pre-tourism [8]. Importance of education in visitor satisfaction [9].	Shore-based theodolite tracking, boat-based behavioral observation [5–8]. Questionnaires and interviews [9].	Reduce or maintain current level of activity, midday rest period mandatory in October-March, or constant observations, education and encouragement for compliance [6]. Limit the number of swim attempts [5]. Enhance education efforts on tours [5,9].	5-year moratorium on motorized boat-based permits (2009–2014). Mandatory rest period in Nov-Feb, voluntary in March. New limits on swim drops (max. 5/trip) and no. swimmers per boat to reduce no. of vessels In 2005, establishment of Te Korowai o Te Tai o Marokura (the Kaikoura coastal guardians), a volunteer, multi-stakeholder group, to provide leadership about the use and protection of Kaikoura's resources, including in relation to dolphin watching.	[5] Markowitz et al., 2009 [6] Duprey et al., 2008 [7] Markowitz, 2012 [8] Dahood, 2009 [9] Lück, 2003
2008–10	Resting and socializing, and swim speed decrease in the presence of vessels, milling and surface activity increased; number of vessels predict magnitude of changes; change in reorientation rate associated with aircraft [10–13]. The population is relatively resilient to tourism pressure [10].	Theodolite tracking, focal follows. Log-linear analyses of behavioral state transitions; analysis of movements Before-During-After interactions.	Social sciences to update old studies on perceptions, attitudes and desires in local communities and visitors [10,13]. Clarify define regulations; enhance enforcement; define Limits of Acceptable Change; 5-year monitoring and re-evaluation cycle; establish an industry-funded research program integrated within the management scheme [10,13].		[10] Lundquist and Markowitz, 2009 [11] Lundquist et al., 2012 [12] Lundquist et al., 2013 [13] Lundquist, 2014
2011	Tourists on swim-with-dolphin tours displayed high satisfaction rates [14].	Questionnaires	Enhance education and visitors' empowerment		[14] Lück and Porter, 2019

TABLE 3 | Summary of the literature on Hector's dolphin tourism at Akaroa Harbour.

Year	Research findings	Research methods	Management recommendations	Management actions	References
1999–2004	Akaroa dolphin tourism is valued at NZ$1.47 million; swim/tour vessels make up 13.4% of total traffic, but 47.1% of dolphin-boat interactions. Behavioral changes related to vessel presence [1]. Anecdotal evidence of habituation. Doubling of vessel traffic during 1990s [2]. Boat traffic as lethal threat [2].	Theodolite tracking of dolphins and vessels [1,2]. Operator survey questionnaires.	Don't increase tourism activity in Akaroa Harbour. Minimum tour education requirement. Education of recreational boat users. Annual operator workshops.	Informal moratorium on issue of new permits Voluntary code of conduct. Levy on permitted operators to fund research. Review of research [3].	[1] Nichols et al., 2001 [2] Stone and Yoshinaga, 2000; [3] Green, 2005
2005–13	Behavioral changes in response to boats (shift from traveling/diving to milling/socializing) [5–7]. Increased magnitude of effect with additional vessel. Dolphin response to swim encounters varied with swimmer placement, dolphin behavior, and swimmer behavior [7]. Vessels within 300 m of dolphins for 35.2% of observations; 70.4% of dolphin-boat encounters involved commercial vessels [7]. Using sound to attract dolphins associated with sustained and closer encounters [8]. First attempt at standardizing data recording by tour operators in Akaroa Harbour, weaknesses of the 2006–08 operator data collection system using data sheet [9].	Theodolite tracking of dolphins in presence and absence of vessels. Group focal follows. Markov-chain methods on transition probabilities, behavioral budget [7].	Reduce cumulative tourism exposure and/or the number of permits [7]. Establish a moratorium on Hector's dolphin tourism in NZ. Time-area closure systems within the Akaroa Marine Reserve [6]. Ban using sound to attract dolphins [8]. Education of recreational boat users. Annual operator workshops.	Detailed technical report [4]. 2007: Maximum swimming time per trip reduced from 60 to 45 min. 2008: 5-year moratorium on new permits.	[4] Allum, 2009; [5] Martinez, 2010 [6] Martinez et al., 2010 [7] Martinez et al., 2011 [8] Martinez et al., 2012 [9] Martinez and Stockin, 2011
2013–19	Economic impact of tourism in Akaroa estimated at NZ$6–8 million; wider value NZ$22.2–24.9 million in the Canterbury economy, and NZ$27.9–31.3 million nationally [10].			Since 2015: Annual SMART Operator course offered [11]. 2016: 10-year moratorium on new permits. Voluntary reduction in permitted trips from 37 to 34. Tracking systems installed on tour vessels 2019; improved boat ramp signage [12].	[10] Yeoman et al., 2018 [11] Healey, pers. comm. [12] MacTavish, pers. comm.
2020 and ongoing	Analysis of changes in tourism pressures and dolphin habitat use in 1995–2020.	Analysis of existing dataset [1,5] on dolphin distribution related to tourism operations. GPS-based tracking of tour vessels. Automated hillside camera system to quantify vessel traffic, passive acoustic T-POD and SoundTrap monitoring of dolphins an acoustic environment.			University of Otago, in progress

TABLE 4 | Summary of the literature on bottlenose dolphin tourism at Doubtful Sound.

Year	Research findings	Research methods	Management recommendations	Management actions	References
1999–2004	First studies on the short-term effects of tour vessels on dolphins, showing disruption of behavioral budgets [1]. Increased dive intervals with different avoidance strategies in males and females [2]. Increase in some aerial displays and erratic movements [4]. Spatial quantification of critical habitat (areas of high use, including for resting and socializing) [3].	Systematic population surveys and monitoring since 1990, with Photo-ID as core method Development of Markov-Chain methods to quantify impact on behavioral budget [1]. Modeling and controlling for influence of research vessel in assessment of behavioral change due to tour boats [2].	Establish a multi-level marine mammal sanctuary and limit boat traffic where dolphins rest and socialize [3]. Change of tour operator behavior to reduce impact and extent of dolphin interactions.		[1] Lusseau, 2003b [2] Lusseau, 2003a [3] Lusseau and Higham, 2004 [4] Lusseau, 2006
2005–09	Dolphin watching deemed unsustainable [5]. Declines in abundance and calf survival [6,7]. Analysis according to IUCN criteria results in Fiordland bottlenose dolphins being declared critically endangered [8].	Assessment of population trends and conservation status [6–8].	Reiteration of previous recommendations.	2007: public meetings, involvement of external experts. Discussion and consultation document released by DOC outlining options for managing impact of tourism on dolphins [9]. 2008: voluntary Code of Management (CoM) established by committee including DOC, tour operators and researchers [10].	[5] Lusseau et al., 2006 [6,7] Currey et al., 2007, 2009a [8] Currey et al., 2009b [9] Williams, 2007 [10] Department of Conservation, 2008
2010–16	Increase in dolphin excursions beyond the fiord (decreased occupancy) [11]. Changes in group cohesion and acoustic behavior in response to vessels and noise [12]. Groups with calves particularly sensitive to vessels and noise [12]. Significant decline in frequency and length of dolphin-boat interactions since implementation of CoM [13]. Slight recovery in calf survival and population abundance [14,15]. Breaches of Dolphin Protection Zones, but compliance improving over time [16].	Combined visual and acoustic data collection [12]. Staged approach to quantify and account for impact of research vessel [12].	Cap the number of tour vessels and trips operating in the area. Reduce vessel speed and shift in vessel design (e.g., water-jet propulsion) to reduce noise [12,13]. Consider turning voluntary CoM into formal legislation [13].	Effectiveness of the CoM to be reviewed after 10 years of its implementation (due 2018).	[11] Henderson et al., 2013 [12] Guerra et al., 2014 [13] Guerra and Dawson, 2016 [14] Brough and Johnston, 2015 [15] Johnston and Bennington, 2018 [16] DOC compliance monitoring reports
2017–19	Core dolphin habitat highly consistent over more than 10 years (2005–2018), but low overlap with Dolphin Protection Zones (<15%) [17]. Continued support for the CoM by stakeholders [18].	Kernel Density Estimation for quantifying core habitat [17].	Multiple options for changes in Dolphin Protection Zones to increase overlap with core habitat [17]. Extend compliance to wider boating community, review extent and location of Dolphin Protection Zones, and considerations to limit vessel activity [18].	Continuation of CoM and compliance monitoring by DOC.	[17] Bennington et al., 2020 [18] McLeod, 2018
2020 and ongoing				Re-evaluation of CoM [19].	[19] Richard Kinsey (Fiordland DOC office), pers. comm.

TABLE 5 | Summary of the research on cetacean tourism at other New Zealand destinations.

NORTH ISLAND

Location **Mercury Bay, Coromandel**

Species **Common dolphins**

Year	Research findings	Research methods	Management recommendations	Management actions	References
1998–2001	Dolphin response change from attraction, to neutral, to avoidance over the course of the encounter; small groups avoid vessels sooner and more frequently than larger groups; interactions more likely to be sustained when involving larger dolphin group and fewer swimmers. No evidence of disturbance on non-resident dolphins, but risk of cumulative effects of tourism exposure at different locations in their distribution.	Boat-based photo-identification, group size, behavioral state and activity budget.	Limit distance and length of approaches. Introduce a site-specific code of conduct.		Neumann, 2001; Neumann and Orams, 2005, 2006

SOUTH ISLAND

Location **Porpoise Bay, Catlins**

Species **Hector's dolphins**

Year	Research findings	Research methods	Management recommendations	Management actions	References
1995–97	No displacement from core use area, dolphin-boat orientation changes from "toward boat" at onset of encounter to away as encounter duration extends; tighter groups with vessels in the bay. No evidence of disturbance but concerns about chronic, cumulative effects.	Theodolite tracking of dolphins, boats and swimmer positions to assess dolphin-boat orientation and pod dispersion.	Do not exceed current disturbance levels. MMPR to include important features of individuals and populations (age, sex, species, habitat use).	Interpretation panels, posters and leaflets for the public with DOC specific guidelines Southland District Council 's Coastal Plan DOC summer warden Voluntary code of conduct	Bejder, 1997; Bejder et al., 1999
2001–03	Compared to 1995–97: no evidence of displacement, similar habitat use, 3-fold increase in exposure, decrease in boat attraction, longer swims, looser groups when vessels in the bay, decreased diving and increased milling and socializing behavior.	As above (Bejder, 1997; Bejder et al., 1999)	Establish a Marine Mammal Sanctuary in the Bay. Establish time closures in the dolphin core use area. Restrict tourism to one permitted operator for 40 min/day; restrict kayaking area and prohibit on-site renting.	Lone permit revoked for non-compliance	Martinez et al., 2002; Green, 2005

Location **Lyttelton Harbour and Timaru Harbour**

Species **Hector's dolphins**

Year	Research findings	Research methods	Management recommendations	Management actions	References
2000–05	Vessel presence affect group swimming speed and grouping behavior. Group behavior toward vessels changed over a period of 7 years from neutral, to vessel-positive, to avoidance. Low-level tourist vessel activity considered to not be placing undue stress on the population.	Theodolite tracking of dolphin positions and behavior.	Further research on impacts of vessels on dolphins.	None	Travis, 2008

(Continued)

TABLE 5 | Continued

Location	**Queen Charlotte Sound, Marlborough**
Species	**Hector's, bottlenose, dusky dolphins**

Year	Research findings	Research methods	Management recommendations	Management actions	References
1995–2014	Baseline data on dolphin occurrence and distribution. Swim-with industry is relatively new (since 2004) and mainly targets bottlenose dolphins with active pursuit of interactions. Dolphins show neutral reactions to swim attempts	Vessel logbooks and observations from platforms of opportunity. GAMs and GLMs to investigate dolphin occurrence, distribution and habitat use in relation to environmental variables. Behavioral observation of responses to swimmers.	Protection of periods and regions of high density and predicted density. Coherent management of tourism, marine farming, and vessel traffic effects.		Cross, 2019

Location	**Milford Sound, Fiordland**
Species	**Bottlenose dolphin**

Year	Research findings	Research methods	Management recommendations	Management actions	References
1999–2002	Resting and socializing behavior are sensitive to boat interactions, dolphins need at least 68 min between two interactions [2]. Dolphins more frequently absent from Milford Sound during months of intense vessel traffic [3]. Marks of physical injuries caused by boat strikes, calf killed by a tour boat in 2002 [1].	Boat-based visual survey, operator boat traffic data, oceanographic parameters to build discrete time Markov chain of dolphin presence/absence [3]; Markov Chain and log-linear analyses of behavioral state transitions [2].	Reduce vessel traffic and boat-dolphin interactions with protected areas [3].	2006 Marine Mammal Viewing Code of Practice (voluntary)	[1] Lusseau et al., 2002 [2] Lusseau, 2004 [3] Lusseau, 2005

The Bay of Islands, Northland

The Bay of Islands (BOI) is a sheltered habitat containing over 144 islands, and numerous inlets, bays and estuaries. Bottlenose dolphins inhabit the BOI year-round, with 1–3 groups of 15–20 individuals usually present at any time (Constantine et al., 2004; Peters and Stockin, 2016). These dolphins are not exclusively resident in the BOI, but range along the northeast coast of the North Island (Constantine, 2002; Berghan et al., 2008; Tezanos-Pinto et al., 2013), and display seasonal inshore and offshore movements (Constantine and Baker, 1997; Hartel et al., 2014; Peters and Stockin, 2016). Common dolphins are also regularly present in the outer BOI (Constantine and Baker, 1997).

Cetacean tourism started in 1991 with a single vessel offering viewing and swim-with tours with common and bottlenose dolphins (Constantine and Baker, 1997; Constantine, 1999). Two additional companies began tours in 1993–1994. In 1995, bottlenose dolphins became the primary focus of tourism operations, as they were easier to locate and often found closer inshore. Concerns raised by the original tour operator and local Māori over the impact of the industry prompted research on population demographics and tourism impacts on bottlenose dolphins in 1993. The research demonstrated clear behavioral effects on the local dolphin population and recommendations were made to limit expansion of the industry (Constantine and Baker, 1997), which, by then, had already grown rapidly and was operating more tours with larger vessels (**Table 1**). Over the 2000s, despite a moratorium on permits since 1998, heightened pressure from permitted operators was compounded by increasing numbers of private boat users and non-permitted operators seeking out interactions with dolphins. In response, DOC implemented further permit restrictions on the number and duration of trips, swim attempts and swimmers, created static exclusion zones, promoted better education, and continued to hire marine mammal rangers to try and resolve the issues (**Table 1**). These measures were insufficient to mitigate impacts on the dolphin population. The dolphins became rapidly sensitized to swimmers (Constantine, 2001) and behavioral states were altered by vessel presence, with dolphin tour vessels having the greatest impact (Constantine and Baker, 1997; Constantine, 2001; Constantine et al., 2004; Peters and Stockin, 2016). Rapid declines in local abundance (Tezanos-Pinto et al., 2013), changes in fine-scale habitat use (Hartel et al., 2014) and decay in social structure (Constantine, 2002; Hamilton, 2013) continued to indicate a highly impacted population (Hamilton, 2013). In 2019, swimming with the dolphins was banned and interaction times were further reduced. Currently, four permitted companies operate one to two trips per day each. However, existing measures (such as trip duration limits and static protected areas; Hartel et al., 2014) are likely ineffective and are often ignored (Peters and Stockin, 2016). A renewal of the moratorium on permits, the institution of adaptive time-area closure systems, stronger and enforceable limitations for all users and operations, and appropriate consultation processes were strongly recommended (Peters and Stockin, 2016) but, as with previous recommendations, have not yet been comprehensively addressed by management.

The BOI offers an example of inadequate management and rapid, dramatic negative consequences of tourism. Stricter mitigation measures to decrease pressures on the dolphins following identification of impacts from the then low levels of tourism in the early 2000s (Constantine and Baker, 1997) could have prevented the rapid decline of the local population (**Table 1**). Despite robust research advice and cultural significance, the welfare of this population has been largely neglected by management authorities.

The Hauraki Gulf, Auckland

The shores of the Hauraki Gulf (hereafter the Gulf) host New Zealand's largest metropolitan area, with shipping, fishing and aquaculture activities based throughout the Waitematā Harbour. Compared to other parts of New Zealand, cetacean tourism in the Gulf remains relatively small scale and stable, with only two permits currently in existence, of which one is actively used. Tourism focuses specifically on common dolphins and Bryde's whales, although regular encounter by the tour boats have offered insights to other species (Berghan et al., 2008; Hupman et al., 2015).

The common dolphin is the species most frequently encountered by operators (O'Callaghan and Baker, 2002; Stockin et al., 2008a; Colbert, 2019). During encounters with vessels, dolphin groups have been shown to reduce feeding and resting behavior (Stockin et al., 2008b), increase vocalization rate (Petrella et al., 2012), change group cohesion (when calves were present; Schaffar-Delaney, 2004), and alter feeding strategies (Burgess, 2006; de la Brosse, 2010). Annual abundance estimates range from 2,478 (95% CI = 1,598–3,615; Hamilton et al., 2018) to 8,632 (95% CI = 7,738–9,630; Hupman et al., 2018), thus vessel effects are likely diluted across a large population. However, photo-identification efforts along the wider northeastern North Island coastline (Neumann et al., 2002; Meissner, 2015; Hupman, 2016) show that individual dolphins may be subject to cumulative tourism impacts across several locations (Meissner et al., 2015).

A small number of Bryde's whales are present in the Gulf year round. Over the period 2004–2013, seasonal abundance estimates ranged from 38 to 74 individuals, with a super population of 100–183 whales using the Gulf overall (Tezanos-Pinto et al., 2017). The whales forage most actively in daylight (Izadi et al., 2018) and sometimes in association with common dolphins and Australasian gannets (*Morus serrator*) (Stockin et al., 2008a; Wiseman et al., 2011), both of which act to increase the whales' detectability by tour operators. Although globally abundant, the Bryde's whale is considered Nationally Critical in New Zealand (Baker et al., 2019) and yet, to date, there has been no investigation of tourism impacts on the species in the Gulf.

Even though bottlenose dolphins are commonly seen in the Gulf, the impacts of tourism registered in the longer-established industry in the Bay of Islands have led to the species being excluded from swim-with permits, and more recently viewing permits in this area.

The Gulf case study provides an example of a cetacean tourism industry embedded in a context of multiple stressors (aquaculture, fishing, commercial shipping, contaminants), and targeting two species with different life history, behavior and ecology. Despite establishment of the Hauraki Gulf Marine Park in 2000 (the only one of its kind in New Zealand), most of the conservation issues affecting the area remain unmitigated (Hauraki Gulf Forum, 2020). The suitability of dynamic marine protected areas, in combination with minimizing encounters at certain times of the day, and avoidance of feeding and nursery dolphin groups should be investigated for the future management of anthropogenic impacts in this region (Dwyer et al., 2020).

Kaikoura, Canterbury

Kaikoura is the longest established cetacean tourism destination in New Zealand, and tourism is the main driver of the local economy (Orams, 2002; Curtin, 2003). Activities are focused around the Kaikoura submarine canyon, a foraging habitat for dusky dolphins and sperm whales (Childerhouse et al., 1995; Benoit-Bird et al., 2004). Since 1991, there have been three boat-based operations, one focusing on viewing of sperm whales and two on viewing and swimming with dusky dolphins, in addition to three air-based operations. This case study focuses on the research and management of sperm whale tourism (**Table 2A**). The history of tourism and research targeting dusky dolphins is summarized in **Table 2B**.

Kaikoura is one of the few places in the world where sperm whales can be seen close to shore year-round. The individuals encountered regularly at Kaikoura are exclusively males (Childerhouse et al., 1995, Jaquet et al., 2000). Some are resident in Kaikoura for many months at a time, and return regularly; others transit through the area (Childerhouse et al., 1995; Somerford, 2018). The effects of tourism on the local population have been investigated in a series of studies commissioned by DOC at ∼10-year intervals starting in 1990. Several effects due to the presence of vessels and aircraft have been detected (**Table 2A**). These have not always been consistent among studies, but have generally included changes in both surface behavior and echolocation. Although responses have been interpreted as of minor consequence overall, variation among individual whales (especially between "residents" and "transients") and between seasons could act to swamp the real effects of tourism activities (Richter et al., 2006; Markowitz et al., 2011). Precautionary management was therefore recommended, and an increase in the number of boat trips and permits strongly discouraged (Richter et al., 2006; Markowitz et al., 2011).

DOC responded to these calls by issuing 10-year moratoria on permits in 2002 and 2012. The monopoly of one company conducting all vessel-based whale watching tours has caused disquiet among others seeking permits (Simmons and Fairweather, 1998; Orams, 2002; Curtin, 2003; Simmons, 2014), but has likely reduced impacts on the whales. Additionally, this company introduced significant changes to its vessels (switching from 6 m outboard-powered rigid-hulled inflatables to 20 m diesel jet-engine catamarans) and its operations (often using directional hydrophones to track whales). These measures reduced underwater noise and the need for high-speed approaches, hence acted to mitigate disturbance to the whales.

Despite these management decisions, longitudinal studies show a significant decline in the number of sperm whales visiting Kaikoura over the past 30 years, especially during summer (Somerford, 2018). It is now essential to understand whether the detected behavioral responses to tourism may have had direct long-term consequences, or whether they add to the suite of other factors affecting this population (e.g., climate change; Guerra, 2019). In particular, there is growing concern about cumulative impacts of chronic, repeated interactions when very few individuals (<3) are present in the area, as happens commonly in early summer (Guerra, 2019), because this could lead to complex physiological, behavioral and/or ecological long-term consequences (Bejder et al., 2009).

Kaikoura could be cited as a reasonable model for management of tourism on sperm whales. The impacts of tourism on sperm whales have been regularly monitored, there is only one boat-based, long-term operator and the regulations are largely followed (Curtin, 2003). Relationships among tourism operators, researchers, local communities and managers are generally positive, and have helped develop cetacean tourism in an orderly fashion. Continued longitudinal study is necessary to monitor the conservation status of this population, to unveil the effects of chronic exposure on resident individuals, and to understand whether the detected behavioral changes resulting from tourism translate to biologically meaningful effects.

Akaroa Harbour, Banks Peninsula

The Hector's dolphin is endemic to New Zealand. The species is Endangered (Reeves et al., 2013), and the population at Banks Peninsula has experienced significant depletion since 1970 (up to 80%; Slooten, 2007) mainly due to bycatch in gillnets and trawls (Dawson, 1991). The Banks Peninsula Marine Mammal Sanctuary (established in 1988), and further protection measures in 2008 led to an increase in adult survival rate (Gormley et al., 2012), but were insufficient to support population recovery (Slooten, 2013).

Akaroa Harbour is the primary focus of tourism on Hector's dolphins, and is a hotspot of dolphin abundance at Banks Peninsula (Brough et al., 2020). Dolphins are present year-round. Their distribution is concentrated close to shore in the summer months (Dawson et al., 2013) coinciding with calving (Slooten and Dawson, 1994) and the seasonal peak in tourism. Beginning with a daily natural history tour in 1985, dolphin tourism grew into a NZ$1.46 million industry by 1999 (Nichols et al., 2001). In addition, recreational vessel traffic more than doubled over the same time period (Stone and Yoshinaga, 2000).

Research on the potential impact of tourism in Akaroa Harbour began in 1999 (**Table 3**). Studies provided evidence of changes in behavioral state and directionality of travel (Nichols et al., 2001), cautioned about calf vulnerability to boat-strike (Stone and Yoshinaga, 2000), and indicated that dolphin response to swim encounters varied with swimmer placement and behavior, dolphin behavior, and possibly the dolphins' previous exposure to tourism (Martinez et al., 2011) (**Table 3**). Researchers lauded operators' compliance with some permit conditions (e.g., swim encounter duration), but cautioned that growth in operations, and the tendency to "hand-over" dolphin groups from one tour boat to the next, could cause the same dolphins to be repeatedly targeted over the course of the day (Nichols et al., 2001; Martinez et al., 2011). Martinez et al. (2011) emphasized that in-water interactions, even when initiated and apparently well-tolerated by dolphins, could have long-term detrimental effects on the dolphin population. Further development of the industry was therefore discouraged. In 2008, after granting two new permits to already existing non-permitted operations (Allum, 2009) (from four to six permits), and allowing permitted operators to increase their number of trips (from 25 to 37 trips/day), DOC issued a 5-year moratorium on new permits, which was later followed by a 10-year moratorium in 2016. Currently, five permitted and multiple non-permitted operators are active in Akaroa Harbour.

Adherence by commercial operators to the MMPR and permit conditions (Martinez et al., 2011), combined with moratoria and voluntary initiatives, has reduced the potential effects of tourism on the local Hector's dolphin population. However, an increased number of visitors and a recent surge in cruise ship tourism have resulted in a longer "peak season," leading to an overall increase in tourism pressures. In addition, recreational boat traffic, predominant in the harbor, is frequently in breach of the MMPR (Martinez et al., 2011).

A 2019 economic assessment revealed the importance of the industry both locally (NZ$6–8 million in direct annual operator income) and regionally, and tied its fate to that of the dolphin population (Yeoman et al., 2018). In 2018, DOC commissioned a new study to investigate changes in dolphin distribution at varying levels of tourism. Such longitudinal studies of behavior, habitat use, and demography provide the best hope of quantifying the consequences of anthropogenic pressures, especially in the context of multiple threats (e.g., permitted tourism, non-permitted and recreational operations, bycatch, cruise ship traffic, and aquaculture), as well as forecast the future of the industry.

Doubtful Sound, Fiordland

Doubtful Sound is one of the most popular nature tourism destinations in New Zealand. The fiord is home to a small (65–71 individuals), isolated, largely closed and resident population of bottlenose dolphins (Currey et al., 2009a; Bennington et al., 2020) currently listed as Critically Endangered by the IUCN (Currey et al., 2013). Researchers have monitored the population in collaboration with DOC almost continuously since 1990 (**Table 4**), when the first boat-based scenic cruise operation was established. Interactions with the dolphins are an iconic feature of scenic cruises, and have been a cause of concern since the early 2000s (Lusseau, 2003a,b; Guerra et al., 2014). As of 2020, two permitted companies operate in Doubtful Sound year-round, offering multiple daily and overnight trips.

Studies conducted between 2000 and 2009 showed a range of behavioral responses to tour vessels, determined the location of critical resting and socializing habitats (Lusseau and Higham, 2004) and detected a worrisome downward trend in calf survival and abundance (Currey et al., 2007, 2008) (**Table 4**). Concerns were voiced that tourism levels were unsustainable for this dolphin population (Lusseau et al., 2006), and DOC released a Threat Management Discussion Paper (Williams, 2007) offering several options for managing tourism operations. In 2008, DOC, in conjunction with tour operators and scientists, developed a voluntary Code of Management (CoM) to leave dolphin encounters to chance, restrict vessel traffic in "Dolphin Protection Zones," and reduce the extent of dolphin-vessel interactions. These "Dolphin Protection Zones" partially and loosely overlapped with the critical habitats identified by Lusseau and Higham (2004). Nevertheless, the implementation of the CoM led to declines in the frequency and duration of dolphin-vessel interactions, suggesting that tourism pressure on the population had eased (Guerra and Dawson, 2016). It also coincided with a reversal of the downward trends in calf survival and abundance recorded in the 1990s and 2000s (Currey et al., 2007, 2008), which had possibly been caused by tourism, demographic stochasticity and/or other impacts (e.g., construction and operation of a power plant) (Henderson et al., 2014; Brough and Johnston, 2015; Brough et al., 2016).

The generalist focus of scenic cruises, the voluntary nature of the CoM, and the close cooperation between DOC, scientists and tour operators in the development of management measures, all seem to have contributed to generally high compliance by tour operators (Guerra and Dawson, 2016). However, continued behavioral reactions to vessels and noise, and vulnerability of groups with calves (Guerra et al., 2014), low compliance among members of the recreational and non-permitted boating community, and the limited extent of the static Dolphin Protection Zones undermine the effectiveness of the plan in protecting this population. The CoM was reviewed in 2018 (McLeod, 2018) prompting a re-evaluation of spatial protection measures, formalization of the CoM, and further limitations on vessel activity.

Doubtful Sound is similar to other case studies in that it experienced an initial phase of management inaction, a failure to fully and promptly integrate science-based management recommendations (e.g., multi-level marine mammal sanctuary; Lusseau and Higham, 2004), and ongoing compliance issues. However, voluntary management measures appear to have contributed to reducing exposure of dolphins to vessels, and overall, the fiord represents an example of relatively successful evidence-based management. The small size, isolation, and history of low calf survival and rapid fluctuations in abundance (Currey et al., 2007, 2009b; Brough and Johnston, 2015) emphasize that continuing monitoring and research, combined with decisive and effective management action, will continue to be critical for the Doubtful Sound dolphin population.

EFFECTIVE RESEARCH STRATEGIES

To ensure a genuinely sustainable industry that safeguards the well-being of cetacean individuals and populations requires rigorous scientific evidence to quantify impacts, develop management options, and evaluate their effectiveness (Bejder and Samuels, 2003). Based on 30 years of research on tourism impacts in New Zealand, and in the light of recent assessments of global research on cetacean tourism (IWC Sub-Committee on Whale Watching, 2019), we outline five key points to consider in the development of research strategies.

Comprehensive Research on Short- and Long-Term Responses

Documenting short-term behavioral responses is the most common approach to evaluating tourism impacts on cetaceans (**Tables 1–4**, **6**). Although they should not be taken as sufficient indicators of detrimental impacts (Corkeron, 2004; Bejder et al., 2006a, 2009), they represent an important first step to identifying tourism effects on animal welfare, forecasting likely biological consequences on populations (Christiansen and Lusseau, 2015; New et al., 2015, 2020; Booth et al., 2020), and designing and monitoring management intervention. A robust approach to research requires baseline knowledge of population biology and ecology, and employs multiple tools, such as the quantification of behavior changes (e.g., Lusseau, 2003a; Meissner et al., 2015), acoustic responses (e.g., Richter et al., 2006, Guerra et al., 2014), patterns of habitat use (e.g., Lusseau and Higham, 2004; Hartel et al., 2014), and health variables (e.g., Rowe and Dawson, 2009; Dwyer et al., 2014). These indicators of change would also be useful to investigate individual well-being through the Welfare Assessment Tool for Wild Cetaceans (WATWC), a framework being developed with the support of the International Whaling Commission (Nicol et al., 2020). The tool is used to characterize consequences of potential welfare hazards to nutrition, environment, health, behavior, and affective state of exposed animals, and to compute a score indicating the severity of harm to the individuals or populations assessed (Nicol et al., 2020). Until the WATWC and welfare frameworks for wildlife are established, key metrics for the computation of welfare risk are the intensity and duration of impacts over the life-span of individuals, and the number of individuals affected (De Vere et al., 2018; Nicol et al., 2020).

Inevitably, however, short-term responses do not provide information on latent effects, those that appear elsewhere or at a lagged time, or on individuals that may already be avoiding the area due to disturbance. Moreover, short-term behavioral responses must be interpreted with caution, as they display significant variation between and within populations, groups and individuals (e.g., due to sex, Lusseau, 2003b; presence of calves, Guerra et al., 2014; previous exposure to disturbances, Constantine, 2001; Bejder et al., 2009; among others).

There is thus a vital need to identify the long-term consequences of tourism disturbance on cetacean populations (e.g., abundance, reproduction and survival rates). Identifying how non-lethal impacts result in population-level consequences has proven a challenge (Lusseau and Bejder, 2007; New et al., 2014; King et al., 2015), but remains an important objective to understand the mechanisms that lead to detrimental effects (e.g., stress, displacement from quality habitat, compromised foraging and resting). Long-term datasets offer precious opportunities to analyze demographic and distribution trends in the context of tourism development and management (e.g., Tezanos-Pinto et al., 2013; Somerford, 2018; Bennington et al., 2020) and shed light on the long-term consequences of tourism disturbance on cetacean populations.

Control Data

One crucial feature of effective research on both short- and long-term responses is the availability of control data (Bejder et al., 1999; Bejder and Samuels, 2003). These data should be gathered at appropriate temporal (before/during/after) and/or spatial scales (control/impact sites) (Bejder and Samuels, 2003), and using research methods unlikely to influence cetacean behavior (e.g., land-based, unmanned aerial vehicles, remote cameras, passive acoustic methods; Lundquist et al., 2013). In the absence of true control data, modeling to factor out the impacts of research activities and platforms is advised (Nowacek et al., 2001; Lusseau, 2003a; Richter et al., 2006; Guerra et al., 2014; Christiansen et al., 2020). Moreover, long-term data covering periods of step-wise changes in tourism (e.g., Constantine et al., 2004; Bejder et al., 2006b), and data from populations exposed to different levels of tourism (e.g., Lusseau, 2004; Fumagalli et al., 2018), have much more explanatory power than short-term data from one site. Lastly, information from benchmark studies at other locations can significantly enhance investigation and management of tourism effects, especially in data-deficient situations. In New Zealand, the research and management experience at the Bay of Islands and Doubtful Sounds influenced permit conditions in Waikato, Marlborough and Bay of Plenty, among others, where the bottlenose dolphin is now excluded from viewing and swim-with activities.

At many locations, where so far it has been difficult to observe cetaceans in the absence of vessels and/or swimmers, the COVID-19 pandemic may be creating unprecedented opportunities to collect control data.

Tourism Within the Context of Additional Pressures

Tourism often co-occurs alongside other potential stressors, such as bycatch, climate change, pollution, shipping, or habitat modification. Even when its impact is considered to be mild, cetacean tourism has the potential to aggravate the combined pressures on wild individuals and populations. Research should therefore aim to assess and manage potential cumulative impacts in unison (Maxwell et al., 2013; New et al., 2014), rather than in isolation. As evidenced by the case studies presented here, complementing tourism research with broader investigations of population exposure and responses to other threats helps gain a comprehensive picture of population conservation status, interpret and contextualize tourism effects. In addition, it can help identify management opportunities, capitalize on existing strategies, and eliminate redundant legislation to optimize governance. Finally, considering tourism within the context of multiple pressures generates the knowledge needed to negotiate management trade-offs between concurring industries affecting the same populations.

Evidence-Based Management Recommendations

Studies with a clear focus and specific research questions can deliver targeted recommendations, which in New Zealand have been particularly useful for the establishment of permit

TABLE 6 | Recommended actions to increase management efficacy of cetacean tourism at national and local destination level in New Zealand.

	Precaution	Adaptation	Holistic Approaches	Multi-Stakeholder Collaboration
National level	• Develop a National Plan for cetacean tourism • Clarify **ambiguous terms** (e.g., define "*juvenile,*" "*sufficient* education") in permit conditions • Address lack of **enforcement** of the permit system (e.g., "on the spot" ticketing for violations) • Enable precaution with **adequate policy tools** (e.g., shift burden of proof) • Devise a sustainable **financial system** to support the necessary long-term science (e.g., tourism levies)	• Enhance legal tools to promptly **reverse and adjust measures** based on the regular assessment and monitoring of management efficacy, compliance and cetacean responses • Add regulations for **revoking** permits and penalties for non-compliance • Early, frequently and regularly **revise management of tourism,** particularly of industries targeting distinct, small, declining populations • Improve and set standards for delivery of effective **educational, conservation-oriented information** on tours	• Regularly assess priorities and update the Marine Mammal Action Plan considering the integrated impacts of **global** and **national** stressors, the scientific information on individual welfare and population-level effects, and public interest and attitude toward cetacean tourism • Use of emerging techniques including **health and welfare assessments** to be incorporated into tourism impact assessments • Facilitate the formation of dedicated **interdisciplinary research** consortia, both nationally and locally	• Strengthen frameworks for **consultation** with recreational and non-permitted operators, tourism agencies and other stakeholders • Enhance **participation in and support of research** (sharing knowledge, data collection) • Establish collaborations with existing agencies and groups (e.g., boating education and certification agencies) to promote **knowledge and compliance to regulations** among the broader boating community • Ensure consistency of conservation and management messages in **marketing** and **delivery** of tourism activities
At each destination	• Extend enforceable obligations to **non-permitted** and **recreational** operations • Assess the suitability of site-specific **time-area closures** to tourism	• Establish the **legal basis** for adaptive management at local and regional level • Shift to **least obtrusive practices** in tourism (e.g., land-based, watching only) and research (e.g., land-based, platforms of opportunity) • Distinguish impacts from different segments of boating public, to articulate **specific management measures for the relevant boat users**	• Support **long-term studies** on behavior, distribution and population biology in partnership with local stakeholders • Identify **control sites or times** for the collection of control data • Assess the suitability of the **WATWC framework**, validate and improve the tool • Launch research efforts to characterize **stakeholders** (operators, researchers, government, visitors, local community) which ought to be integrated in management frameworks • Analyze and conceptualize tourism within relevant local, regional and national threats, and their **cumulative effects**	• Enhance **education and communication** of national and site-specific regulations and conditions
Bay of Islands	• Renew moratorium	• Modify the current static area-closure system • Reduce the number of vessels on the water • Revise regulations regarding the number of trips allowed daily and the practice of "handing over" groups	• Coordinate research and management regionally to protect dolphins exposed to multiple threats	• Enhance education of permitted, non-permitted and recreational users
Hauraki Gulf	• Prevent tourism increase		• Coordinate research and management regionally to protect dolphins exposed to multiple threats • Begin research on the impacts of tourism on Bryde's whales	• Capitalize on the ongoing engagement with the voluntary shipping Transit Protocol to promote science-based and social process in management
Kaikoura	• Renew moratorium • Reduce interactions with individual whales during summer, when whale abundance is particularly low	• Clarify and revise regulations for air-based operations • Consider ceasing dolphin-swimming activities and restrict tours to dolphin-watching	• Combine research on short-term whale responses with studies of long-term population dynamics • Investigate long-term changes in spatial distribution and abundance of dolphins relative to the changing extent of tour operations	• Enhance communication and awareness of risk of decline in whale abundance during summer, and of need to minimize impact from tourism
Akaroa Harbour	• Renew moratorium • Establish regulations for cruise ship traffic and monitor the resulting effects	• Revise regulations regarding the number of trips allowed and the practice of "handing over" groups	• Continue monitoring of the population, at local and regional level, the threats it is exposed to, and their effects on welfare and conservation • Update research on short-term responses to tourism operations, and on long-term population dynamics	• Enhance education of non-permitted and recreational users

(Continued)

TABLE 6 | Continued

	Precaution	Adaptation	Holistic approach	Multi-Stakeholder collaboration
	• Include tourism in the updated Threat Management Plan for the species			
Doubtful Sound	• Renew moratorium	• Review the extent and location of Dolphin Protection Zones • Upgrade voluntary guidelines into formal legislative framework applicable to all vessels and users	• Update research on short-term responses to operations and long-term population dynamics • Design a regional research program incorporating fiords and populations experiencing high, medium and no tourism disturbance	• Enhance communication with the broader boating community to improve compliance with guidelines

conditions and moratoria. Pre-tourism studies should be undertaken, if possible, to assess the impacts of the proposed industry, define initial regulations and establish a baseline for future monitoring (Martinez, 2003; Higham et al., 2009). At the onset of the industry, as well as regularly throughout its development, a main priority is the identification of situations in which cetacean tourism is incompatible with the welfare and conservation of the targeted individuals and populations. For example, there is a moratorium on tourism activities focused on the Critically Endangered and endemic Māui dolphin (*Cephalorhynchus hectori maui*), and it is currently illegal to approach bottlenose dolphins (*Tursiops truncatus*) and southern right whales (*Eubalaena australis*) in several regions. The identification of sensitive habitats is another essential first step in the design of tourism exclusion zones to effectively limit or prevent interactions in critical situations (Constantine et al., 2004; Lusseau and Higham, 2004; Lundquist, 2014).

In many locations, a key impediment to developing effective management strategies is the lack of information on the impacts of different segments of the boating community. For example, it is easy to focus on commercial operators, when they may not be the major source of impact. It is therefore important to quantify the frequency and effects of interactions with different vessel types, including recreational and non-permitted, in addition to permitted tour operators. The assessment of impacts where there are no permitted operations (e.g., Porpoise Bay, New Zealand) can be particularly useful. By understanding what specific activities lead to identifiable negative impacts, regulations can be targeted to specific activities. This will also help to devise measures that apply to the general public in places where the tourism industry does not have a role in managing impacts on cetaceans.

The social sciences and humanities, so far underrepresented in cetacean tourism research, can not only describe the social, economic and political aspects of the industry, explain and predict its evolution, and provide evidence-based recommendations for its advancement, but also facilitate and promote conditions that enable effective partnerships between stakeholders (Orams, 1996; Beausoleil et al., 2018; Whitty, 2018). Such partnerships can help design and implement management measures (Duffus and Dearden, 1990; Higham et al., 2009), and find best strategies to develop more unobtrusive and educational, and yet commercially viable, practices.

New Avenues for Research

The literature on cetacean tourism is substantive. Efforts should now focus on making full use of the existing datasets, and on addressing emerging gaps, new questions and evolving research approaches, rather than continuing to replicate descriptive findings which are now well-understood. The question is no longer *if* tourism can cause detriment, but *how* can we best predict, prepare for, and minimize it.

Beside advancement in the natural sciences, additional opportunities involve the social sciences and humanities (see section Evidence-Based Management Recommendations above), traditional ecological knowledge (*Mātauranga Māori* in New Zealand), animal welfare science (Papastavrou et al., 2017; Beausoleil et al., 2018; Nicol et al., 2020), and new analytical/modeling techniques and technological innovations (Pirotta et al., 2014; Nowacek et al., 2016; Booth et al., 2020; New et al., 2020). In particular, we encourage colleagues with adequate resources and datasets to (1) advance research on early warning signs and strategies to detect thresholds or tipping points in population dynamics (Scheffer, 2010); (2) develop quantitative metrics for animal welfare that, alongside population-level metrics, can guide evidence-based decision making (Papastavrou et al., 2017), validate and enhance emerging frameworks (e.g., WATWC, Nicol et al., 2020), and contribute working toward a common understanding of welfare (see Beausoleil et al., 2018); (3) advance tools and technologies to minimize or eliminate the use of invasive methods in tourism research, which can cause additional disturbances or mask tourism impacts; (4) design more robust protocols for collection and analysis of policy-relevant data from platforms of opportunity and through citizen science (Lusseau and Slooten, 2002; Cheney et al., 2013; Embling et al., 2015; Hupman et al., 2015); and (5) advance research on the human dimension of the tourism industry, in particular the socio-economic drivers of management response and pathways to overcome obstacles to management success in order to achieve more effective protection.

DETERMINANTS OF MANAGEMENT EFFICACY

One key lesson to extract from the New Zealand experience is that it is critical to heed early signs of impacts of cetacean tourism. Early management intervention is more likely to be effective and more easily implemented. Once there are clear indications that cetacean populations are declining, it may be too late to reduce tourism (and other) impacts to sustainable levels. An essential prerequisite of management efficacy is a policy framework that enables decision makers to receive and act upon rigorous scientific information early and decisively (Mangel et al., 1996; Higham and Bejder, 2008). Policies should clearly express what levels of risk and change are tolerated, where possible defining clear, measurable and adaptive management criteria and thresholds (e.g., stopping rules). In practice, management of tourism in New Zealand has ranged from examples based on robust, science-based and actionable policies, to those more influenced by economic and political pressures. We identify four key features of successful interventions: precaution, adaptation, holistic approaches, and multi-stakeholder collaboration.

Precaution

A precautionary approach establishes a framework of protective measures to prevent an activity from inflicting serious or irreversible impact, even if the evidence of such harm is lacking or uncertain (Cooney, 2004). The need for precaution arises from the acknowledgment that cetacean tourism is a non-lethal anthropogenic stressor and a form of consumptive exploitation (Neves, 2010; Higham et al., 2016) whose impacts on a particular population are often unknown, uncertain or ignored.

Precaution calls for tourism on vulnerable, small, isolated, threatened, or resident populations, or in priority habitats, to be minimized or avoided (Constantine and Bejder, 2008; Ross et al., 2011; Johnston, 2014). This is best achieved by confining operations to populations able to sustain tourism pressure (International Whaling Commission, 2006) and by prohibiting tourism in certain areas or times (i.e., temporal and/or spatial closures) (Tyne et al., 2014). One time- and area-based management strategy could involve assigning different spaces to permitted tour operators, non-permitted operators and the public, while ensuring "no-access" zones or times where cetaceans are fully protected (Lusseau and Higham, 2004; Fumagalli et al., 2018).

Maintaining a precautionary approach may require managers to be resolute in the face of demands from industry and the public, and this is why precaution is more effective when formulated as a legal obligation within policy frameworks, planning, and management tools (e.g., the MMPR in New Zealand). It is also important that the burden of proof rests with the proponents of the activity (Bejder et al., 2006b; Constantine and Bejder, 2008) and that regulations are clear, unequivocal, and effectively enforced (Constantine and Baker, 1997; Childerhouse and Baxter, 2010; Lundquist, 2014; Peters and Stockin, 2016). Under some circumstances, voluntary guidelines can provide an effective first step in management (Schaffar et al., 2010) or complement official regulations to further reduce tourism pressure (Guerra and Dawson, 2016).

A clear statement on what level of impact can be tolerated is a necessary step toward more precautionary and effective management strategies. These may include the use of quantitative tools (e.g., risk thresholds) to monitor impact and assess management success (e.g., Limits of Acceptable Change; Duffus and Dearden, 1990; Higham et al., 2009). Setting measurable risk thresholds, however, first requires addressing some critical questions, such as what agencies set the thresholds, how are these set, how thresholds are monitored, and what should be done at sites where there are insufficient data to set thresholds. We suggest that thresholds should require regular validation and adjustment based on emerging information, apply a precautionary approach, and be set only if there is robust evidence of their safety. Where terminology is vague (e.g., "harassment"), unambiguous definitions are required, and should be linked to specific indicators.

Adaptation

It is important that management approaches can adapt to changing conditions and new information to improve protection (Higham et al., 2009, 2014; Hartel et al., 2014). They should allow for careful monitoring of impacts and assessment of management interventions. Furthermore, regulations should be easily modified on the basis of the best available evidence. For instance, welfare concerns could initially prompt gradual reductions in tourism, which would likely be less drastic and costly than those required once a population has already declined or been displaced (Papastavrou et al., 2017). If population-level effects are detected, however, targeted actions should be swiftly implemented.

Tour operations that are more generalist and do not exclusively rely on cetacean tourism (e.g., scenic and wildlife viewing tours) offer more scope for adaptation to changes in management, and should therefore be more resilient. In turn, this may help facilitate compliance with new regulations.

Holistic Approaches

Ideally, science for policy is comprehensive and multi-disciplinary. Defining management strategies requires information on the target species, the tourism operations, and how both have changed over time at the site (Duffus and Dearden, 1990; Higham et al., 2009). Aspects to take into account include (1) the health and ecology of the cetacean population, (2) cetacean exposure to tourism and other threats, (3) the characteristics of tourism activities, (4) policy and governance, and (5) social, economic and political aspects of the community where the tourism activities occur (Higham et al., 2009).

In this context, it is important to realize that impacts of tourism on cetaceans are partly due to a mismatch in the timeframe of social, economic and political processes (e.g., short-term profits, election cycles) and biological factors (sustainability of cetacean populations over a 50–100 year timeframe). Furthermore, data on (1) and (2) above may already indicate what is required for impacts on the target species to be sustainable but, when other layers are added, there is an argument made for compromise. The politics of compromise can be insidious, and undermine actions needed urgently. It is crucial that biological viability remains a core, non-negotiable goal; impacts on the target species should not be trumped by social need. A solid understanding of the social dimension (including tourism dynamics, policies, societal values and stakeholders' attitudes) should help identify the most effective course of management action. There is a risk, however, that a quest for holism may result in complexity and delay, so achievement of this ideal may need to be balanced with the need for urgency.

Information outputs need to be communicated effectively to managers, tour operators, and policy makers to facilitate translation into management action. This requires genuine engagement and continued collaboration, ideally with long-term relationships and working groups integrating four key stakeholders: the management agencies, the biologists, the tourism operators, and the social scientists (Higham et al., 2009). This approach should help to (1) streamline the development of management measures in response to research findings, (2) ensure that the lessons learnt from previous failings and successes extend beyond scientific reflection, and (3) incorporate valuable insights gained by managers, policy makers and tour operators into research considerations.

Multi-Stakeholder Collaboration

The management of cetacean tourism is chiefly about managing human behavior (Forestell and Kaufman, 1993). Understanding and involving the local human component is therefore essential for an effective transition to activities that are lower impact and truly sustainable. It is important for management agencies to collaborate with tour operators, community representatives, and researchers in the development of guidelines and regulations (Higham et al., 2009). Participatory, democratic and transparent forms of governance can contribute to management efficacy (Cooney, 2004) but a balanced oversight is needed to ensure that management remains timely, evidence-based and focused on shared objectives.

Permitted commercial tour operators represent arguably the most important, yet underestimated agency of positive change in the management of cetacean tourism. Studies of visitor experiences when engaging with rare and endangered species in New Zealand have highlighted the potential for commercial operators to contribute positively to conservation outcomes (Higham and Carr, 2003). Although not all operators conduct their businesses sustainably, there are visionary businesses which contribute directly to research programs, and offer leadership in community stewardship and conservation advocacy. The recently established "SMART Operator" program (Sustainable Marine Mammal Actions in Recreation and Tourism Participation), a voluntary collaboration between commercial boat operators and DOC, is providing interested operators with training and certification to operate more responsibly around marine mammals. While researchers need to remain independent of the industry, these operators can become strong allies in seeking positive change.

It is noteworthy that the Tourism Futures Taskforce (TFT) has recently been appointed by the Minister of Tourism to provide advice on rebuilding a sustainable, climate-safe New Zealand tourism industry following the COVID-19 pandemic (Tourism Futures Taskforce, 2020). The TFT seeks a post-COVID focus for tourism that shifts from mass tourism to values-based tourism, is aligned with the aspirations of local communities and measured in terms of net benefits in relation to the Living Standards Framework (LSF) and the four capitals (social, economic, environmental and cultural) (*Te Tai Ohanga* The Treasury, 2019). This move will require tourism operators to fundamentally shift from a depletive, volume-based approach, to a new "regenerative" sustainable tourism paradigm in nature-based tourism.

It is recognized that business models determine how cetacean tourism is practiced (Neves, 2010). In *te ao Māori* (the Māori worldview) the well-being of people cannot be separated from the well-being of the environment (Upton, 2019). *Kaitiakitanga* (guardianship of natural resources) is a concept embedded in the national legislation (Simmons, 2014), whereby cetaceans form part of the identity of a community. Indigenous business models (e.g., Whale Watch Kaikoura) founded on the principles of *kaitiakitanga*, *manaakitanga* (hospitality), and *tino rangatiratanga* (self-determination), seek to achieve long-term ecological integrity, the protection of *taonga* (treasures), cultural renaissance, community well-being and inter-generational wealth creation. These outcomes align with the principles of management efficacy and improved sustainability, and the role of such business models in reshaping cetacean tourism will need to be fully embraced in the emerging tourism paradigm (Upton, 2019; Tourism Futures Taskforce, 2020).

Research and conservation projects that build local expertise, resources and capacity are more likely to be resilient and to continue independently from the principal investigators (Parsons et al., 2017). Moving away from "parachute research" (i.e., foreign scientists conducting research until their funding runs out and then leaving the site; Parsons et al., 2017) is a step toward ensuring conservation in areas where booming cetacean tourism lacks local research and management expertise, as it is often the case in developing countries and emerging destinations.

Working collaboratively, tourism operators, researchers and local communities can shift the essence of the visitor experience from fleeting entertainment, to deep and enduring engagement (Higham et al., 2014; Johnson and McInnis, 2014). Permit regulations currently compel tour operators to provide education and interpretation onboard their tours, however requirements are vague and effectiveness poorly documented. Evidence-based education, advocacy of conservation, awareness of animal welfare needs, and promotion of less obtrusive human-wildlife engagement could ultimately lead to higher compliance with existing regulations (Hoyt, 2012; Orams et al., 2014; Filby et al., 2015; Finkler et al., 2019; Lück and Porter, 2019). Involvement of tour participants in citizen science may also help promote public action (McKinley et al., 2017).

FUTURE CHALLENGES AND OPPORTUNITIES

The successful integration of precaution, adaptation, and community involvement into a more holistic approach to cetacean tourism is an important challenge. While some examples of addressing this challenge have been introduced in previous sections, specific recommendations for further implementation are presented in **Table 6**. At a national level, we encourage improvements in legislation, policies and practice. Among the priority actions listed, we suggest a revision of the current permit scheme and protected areas, a development of a National Plan for cetacean tourism, an update of the 2005–2010 Marine Mammal Action Plan, as well as the issue of more site-specific regulations applying to all users, including non-permitted operators and the public. Long-term multi-disciplinary research programs, research-informed advancement in education and engagement of the public, and ongoing collaboration between research and management are needed at each New Zealand destination. Finally, we report the latest recommendations issued by researchers in the five case studies (**Table 6**).

We emphasize that a prompt intervention to address current management weaknesses is particularly important as increasing anthropogenic threats, and in particular climate change, exacerbate pressures on marine ecosystems and will inexorably have societal repercussions (Hughes, 2000; Hoegh-Guldberg and Bruno, 2010). Health and welfare of cetaceans are already in decline (Gulland and Hall, 2007) and expected to worsen (Simmonds, 2017; Nunny and Simmonds, 2020) due to effects on their habitat and biology (Learmonth et al., 2006; Kaschner et al., 2011, 2019; Schumann et al., 2013). Inevitably, cetacean tourism operations will also be affected (Lambert et al., 2010). We must now use the tools available to identify species and populations most vulnerable to climate change (e.g., Dawson et al., 2011; Silber et al., 2017; Simmonds, 2017; Becker et al., 2019), and act to increase their resilience by mitigating effects of non-climatic threats (including tourism). As environmental conditions continue to change, multi-stakeholder systems need to ensure continued support to cetacean tourism research, conservation and management.

CONCLUSIONS

New Zealand has several destinations with mature cetacean tourism industries, a research community with a long history of engagement in marine conservation, a well-educated population, a strong economy, and a society with a strong connection to natural heritage. These characteristics place the country in a privileged position of advantage to manage tourism impacts well and responsibly. Nonetheless, the history of cetacean tourism is complex. On one hand, New Zealand has a reasonable regulatory base (MMPA and MMPR, site-specific permit conditions), established partnerships for evidence-based management, and long-term studies and monitoring. As evidenced by a few case studies, cetacean tourism can be managed in ways that are economically successful while reducing disturbance to populations (e.g., Doubtful Sound, Kaikoura, Hauraki Gulf). On the other hand, it has largely failed to timely intervene on populations experiencing local declines (e.g., Bay of Islands), there is no national plan for managing cetacean tourism, and no strategy to manage the multiple, co-occurring anthropogenic threats to cetaceans. In most cases, evidence-based recommendations have been ignored or partially implemented. In others, scientific data to guide tourism management is still completely missing.

This review indicates that the availability of robust scientific information, and recommendations to be precautionary are not sufficient preconditions for sustainable management to take effect. Conflicting interests, socio-economic pressures, ambiguity, political power struggles, ineffective scientific guidance, lack of societal vision and momentum, or all of the above, can weaken or stymie management actions. The proximal and ultimate causes of management inefficiency are complex and often difficult to tease apart. It is paramount that proactive collaborations are established between the interested parties, including scientists, managers and tour operators.

A necessary step forward, in New Zealand and elsewhere, is to declare in clear, unambiguous terms what levels of risk to marine mammal individuals and populations we are willing to tolerate. Once this moral, scientific, and societal decision is reached, scientists will be in a much better position to devise appropriate research in support of actionable policies. The research community has also the great responsibility to advocate for, and to help catalyze the transition to more resilient management systems, engaged communities, and research programs causing the least detriment to wild cetaceans, while providing timely and robust information for policy. The majority of current New Zealand permits and moratoria expire in 2022–2026: there is a window of opportunity for comprehensive action on the next generation of permitted operations and the post-COVID scenario. Looking forward, we recommend that stakeholders engage without delay in formulating a clear policy and vision for this industry, and in developing an integrated, holistic and adaptive research and management system to tackle the future of cetacean tourism and conservation in New Zealand.

AUTHOR CONTRIBUTIONS

SD encouraged and initiated the study. MF and MG led the design of the study and the writing of the manuscript with contributions and support from all authors. The preparation of the case studies received significant support from TB and RC (Bay of Islands), TB and KS (Hauraki Gulf), WC and ES (Akaroa Harbour), WR (Kaikoura), SD and JH (Doubtful Sound). WC contributed the artwork. All authors critically reviewed the final manuscript.

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Whale-Watching Management: Assessment of Sustainable Governance in Uramba Bahía Málaga National Natural Park, Valle del Cauca

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As the growth of the whale-watching activity increases rapidly around the world, the challenge of responsible management and sustainability also rises. Without suitable management, operators may try to maximize their own profits by breaking the rules, which may negatively affect cetaceans. In this paper, the applicability of conditions for sustainability governance in humpback whale-watching was evaluated. To achieve this purpose, semi-structured interviews were conducted in Uramba Bahía Málaga National Natural Park, Colombia. Results of this study showed that humpback whale-watching is characterized by unevenness in connections with markets, income inequality and the distribution of operators across several villages and cities. The combination of which restricts cooperation between operators. Nevertheless, there are informal agreements among the operators, and some operators are motivated to form associations. Besides, environmental entities have been responsible of regulation in lack of community-based management. However, this still does not achieve effective enforcement of the rules. Stakeholders (communities and government authorities) must mediate trust and reciprocity among operators to improve the situation. It is important to involve all operators to fill gaps in the limited government monitoring capacity and absence of sanctions. This is relevant to continue monitoring the evolution of the whale-watching in this and other Marine Protected Areas, so that the sustainability of the activity is not affected in the future.

Keywords: common-pool resources, management, humpback whale-watching, sustainability, Uramba Bahía Málaga National Natural Park, governance, case study, marine tourism

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INTRODUCTION

The whale-watching activity is a multi-billion-dollar business that is rapidly growing around the world (Senigaglia et al., 2016). However, the high costs of globally regulating marine ecotourism makes cetacean populations openly accessible for almost anyone, even inside Marine Protected Areas (MPA) (Lusseau, 2004; Moore and Rodger, 2010). Without oversight, tour operators drive their boats in ways that could negatively affect wild animals as a means to maximizing profits

(Higham et al., 2016). The negative impacts around whale-watching include changes in cetacean surfacing, acoustic and swimming behaviors that would reduce resting, foraging, traveling and socializing activities (Senigaglia et al., 2016). This could affect the viability of wildlife populations and hence the operators' future payoffs (Pirotta and Lusseau, 2015). Efforts to reduce the anthropogenic impacts are in the form of statutory regulations and voluntary codes of conduct or guidelines. However, neither of them ensure enforcement of the rules yet (Parsons et al., 2016; Parsons and Brown, 2017). The level to which operators comply with the regulations depends also on political, social, cultural, economic and environmental specific dynamics (Higham et al., 2009). To date, studies focusing on understanding relations between stakeholders within the whale-watching activity are still very few (e.g., Mustika et al., 2012, 2013; Dimmock et al., 2014; Heenehan et al., 2015; Silva, 2015). It is relevant to analyze sustainability governance with a case study, because of specific characteristics of the activity and heterogeneity of stakeholders for every place in the world (Yin, 2009).

Common-pool resource (CPR) theory was initially proposed as an attempt to solve the degradation of resources, by providing government or privatization solutions (Hardin, 1968). Recently, CPR theory has been applied to understand marine mega-vertebrate tourism management practices (Moore and Rodger, 2010; Pirotta and Lusseau, 2015) such as community-based regulations of whale-watching (Heenehan et al., 2015). In that sense, resource users have been seen as potential managers when they cooperate, self-organize, and create their own rules, to help govern resources sustainably (Ostrom, 1990). Therefore the knowledge of local communities are a key part in defining responsible resource use (Dimmock et al., 2014). In wildlife tourism, Moore and Rodger (2010) identified 30 enabling conditions of CPR management that will allow the sustainable use of resources (**Table 1**). The 30 conditions were grouped into four categories: (1) resource system characteristic, (2) user group characteristics, (3) institutional arrangements, and (4) external environment qualities that included technology, articulation with external markets, and the support of external entities (**Table 1**). Pairwise combinations of the first three categories were also explored. These conditions provided a comprehensive description of whale shark tourism at Ningaloo Marine Park, in Australia, and could be considered as a tool that may offer great potential in enhancing the sustainability of wildlife tourism. For this, more research using these conditions are needed.

Uramba Bahía Malaga NNP is considered the most important humpback whale-watching destination in Colombia, with 10,000 whale watchers in 2006 for a total revenue of $1,600,000 USD (O'Connor et al., 2009). It is also recognized as the main breeding ground of the humpback whale G stock on the Colombian Pacific coast (Avila et al., 2013). Management of Uramba Bahía Malaga NNP is highlighted in the country for having a joint management strategy. This means that the NNP's environmental authority works together with the Afro-Colombian community councils of La Plata-Bahía Málaga, Juanchaco, Ladrilleros, La Barra, Chucheros and Puerto España-Miramar (Parques Nacionales Naturales, 2019) (**Figure 1**). Since 1996, different

TABLE 1 | Moore and Rodger (2010) enabling conditions associated with sustainable wildlife tourism.

Enabling condition	Condition met in whale-watching
(1) Resource system characteristics	
(i) Small size	X
(ii) Well-defined boundaries	X
(iii) Low levels of mobility	X
(iv) Possibilities of storage of benefits from the resource	X
(v) Predictability	✓
(2) User group characteristics	
(i) Small size	X
(ii) Clearly defined boundaries	X
(iii) Shared norms	✓
(iv) Past successful experiences – social capital	✓
(v) Appropriate leadership – young, familiar with changing external environment, connected to local elite	X
(vi) Heterogeneity of endowments, homogeneity of identities and interests	X
(vii) Low levels of poverty	X
(1 and 2) Relationship between resource system and user group characteristics (industry)	
(i) Overlap between user group residential location and resource location	X
(ii) High levels of dependence by group members on resource system	X
(iii) Fairness in allocation of benefits from common resources	X
(iv) Low levels of user demand	X
(v) Gradual change in levels of demand	-
(3) Institutional arrangements	
(i) Rules are simple and easy to understand	✓
(ii) Rules that are adaptable and locally re-negotiable	X
(iii) Locally derived access and management rules	X
(iv) Ease of enforcement of rules	X
(v) Monitoring of resource, users and interactions (Ostrom, 1990; Ostrom, 1995)	X
(vi) Graduated sanctions	X
(vii) Availability of low-cost adjudication	X
(viii) Accountability of monitors and other officials to users	X
(1 and 3) Relationship between resource system and institutional arrangements	
(i) Matches restrictions on harvests to regeneration of resources	-
(4) External environment	
(i) Technology and markets	
Low-cost exclusion technology	X
Time for adaptation to new technologies	X
(ii) Low levels of articulation with external markets	X
(iii) Gradual change in articulation with external markets	-
(iv) State	
Central governments should not undermine local authority	X
Supportive external sanctioning institutions	X
Appropriate levels of aid to compensate local users for conservation	-
Nested levels of appropriation, provision, enforcement, governance	-

The conditions met in whale-watching at Uramba Bahía Málaga NNP, Colombia, were marked with a (✓), those absent with an (X) and unevaluated with a (-).

institutions have trained Bahía Málaga communities to raise awareness about responsible whale-watching (Trujillo and Ávila, 2013). In 2001, whale-watching guidelines were established with the scientific support of the ONG Fundación Yubarta and the governmental institutions: Dirección General Marítima (DIMAR) and Corporación Autónoma Regional del Valle del Cauca (CVC) (DIMAR, 2001). Regardless of these efforts, the rapid growth of the whale-watching activity has prevented attempts at control, thus generating potential negative effects on humpback whale populations, which may have long-term displacement impacts on them (Avila et al., 2015). Based on Moore and Rodger's 30 enabling conditions, the aim of this study was to characterize and analyze humpback (Megaptera novaeangliae) whale-watching in Uramba Bahía Malaga Natural National Park (NNP), Colombia. These conditions were applied to understand relationships between stakeholders and how this could benefit or affect sustainability practices.

MATERIALS AND METHODS

Ethics Statement

Ethical review and approval was obtained by the Ministry of Interior with the record number 0FI15-000029149-DCP-2500 12 August, 2015 according to local legislation and institutional requirements. The participants provided recorded informed consent to participate in this study.

Study Area

Uramba Bahía Málaga was declared a National Natural Park (NNP) in August 2010. It is located at the middle of the Colombian Pacific coast, 36 km North of Buenaventura city (**Figure 1**) (INVEMAR, 2006). In addition to the people who belong to the Afro-Colombian communities, members of other ethnic groups live in the area, such as indigenous and mestizo people (Arboleda, 1993). Social tourism in the NNP is one of the most important economic activities, followed by fishing, mining, forestry and hunting (Avila et al., 2015). Humpback whale-watching activities in this area began in 1994 by fishermen's boats in Bajos de Negritos – an area in front of Bahía Málaga (Trujillo and Ávila, 2013) (**Figure 1**). The city of Buenaventura and villages within the Bahía Málaga region (Juanchaco, Ladrilleros and La Barra) are the most important places for whale-watching in Colombia because they attract most of the whale-watching tourists in the country (Arias-Gaviria et al., 2011).

Data Collection

A total of 70 semi-structured interviews were conducted between October and November 2015, in the Juanchaco, Ladrilleros and La Barra communities, and Buenaventura's tourism dock. The aim of this semi-structured interviews was to obtain detailed data of situations, interactions, processes and perspectives of key actors (Aguirre, 1995). Questions were formulated from a selected set of topics to address the same issues and to collect the same information, according to each key actor (Bonilla and Rodri guez, 1997). Actors fell into the following categories: whale-watching operators, which included boat drivers and skippers (27 interviews); Buenaventura whale-watching companies' owners and administrators (3 interviews); dispatchers, which included company personnel in charge of accommodating tourists and authorizing and sending boats (3 interviews); hotel managers (23 interviews); and park officials, which included rangers and environmental interpreters trained by NNP to serve as naturalists and safety contacts (2 and 12 interviews, respectively). Only park officials were interviewed as local authorities since currently the NPP is the only official entity who is in charge for the management of the whale-watching activity in this area. In this paper, interviews with tourists were not conducted because the research focus was on the management of whale-watching actors.

Qualitative Data Analysis

Data analysis was done in ATLAS.ti 7 software. The interviews were coded by the following subjects: commercial whale-watching operations, networks among key actors, collaborative and competitive relationships, and conditions for sustainable management according to Moore and Rodger (2010) list (**Table 1**). Some conditions were not evaluated due to their lack of information and/or inapplicability to the species in consideration. Such conditions included: heterogeneity of endowments, gradual changes levels of demand, matches restrictions on harvests to regeneration of resources, gradual change in articulation with external markets, appropriate levels of aid to compensate local users for conservation and nested levels of appropriation, provision, enforcement, governance.

RESULTS

According to the list of 30 conditions for sustainability in the management of wildlife tourism provided by Moore and Rodger (2010), five conditions were not evaluated. This means that out of 25 conditions that were evaluated, twenty one (84%) were not met and only four (16%) were met in humpback whale-watching at Uramba Bahía Málaga National Natural Park (**Table 1**). Explanations of these results are described below.

User Group Characteristics and External Environment

User Group Characteristics

The operators were identified as users of the resource. Tourists must travel from the Buenaventura's tourism dock to the Juanchaco's tourism dock within the Marine Protected Area, to do whale-watching (**Figure 1**). Six authorized companies in the Buenaventura's tourism dock provide transportation and whale-watching services. The whale-watching trip can be a round trip, or tourists can lodge in Juanchaco or Ladrilleros, where there are local operators and branch offices of the Buenaventura companies. Some tourists travel to La Barra instead and, once there, are carried by local operators into the whale-watching area.

Different factors can contribute to or hinder the user's cooperation. Some operators have had successful experiences with local associations, which can contribute to social capital or cooperation with their prior knowledge (2iv, **Table 1**). Likewise, there are informal agreements to distribute the tourists between operators. These agreements are based in trust and reciprocity and allow rules of behavior by mutual agreement or shared norms

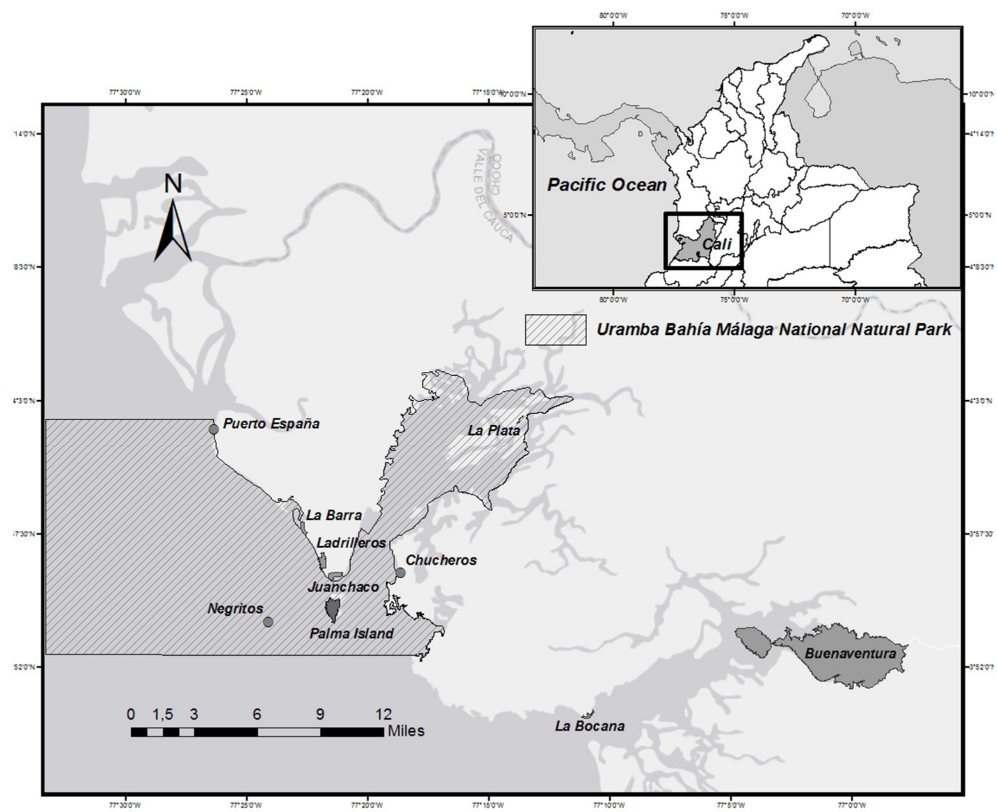

FIGURE 1 | Map of National Natural Park Uramba Bahía Málaga showing nearby villages and city of Buenaventura.

(2iii, **Table 1**). Occasionally, in Juanchaco's tourism dock, local operators make verbal agreements to distribute tourists by turns. They collaborate with each other in giving up and gathering enough tourists in a single boat. This avoids economic losses for boats that would otherwise leave with a low number of tourists and places the interests of the group over the individuals (Pretty, 2003). In La Barra, the low flow of tourists does not allow for distribution by turns. However, occasionally agreements are made when the number of tourists are too few to cover expenses. Those who cannot carry tourists, transfer them to another local operator that has the same or greater number of tourists. The ones whose boat is used can reward the operators who gave up their tourists by passing tourists to them later, by dividing the profits, or by giving them a small commission. Also, if someone has too many tourists at the same time, they will collaborate by talking with other local operators to take the extras, and sometimes receive a commission as a result.

There are also informal agreements or shared norms between Buenaventura companies (2iii, **Table 1**): an association of seven companies and a three-company alliance. The tickets are sold to tourists from several offices, but all those tourists are combined into the same boats until capacity is reached before another boat is filled. Depending on demand, the dispatch order changes when tourism decreases. During these times, the companies agree to send their boats in turns according to a predetermined list, and departure times become defined in three times a day. This prevents losses from carrying too few passengers on too many tours "...the fuel is very expensive, and we need to sustain the routine. It is necessary to make agreements..." (Company owner, Buenaventura).

Most operators are from different origins, but they generally have lived more than 10 years in the area. They have thus become part of the community councils and have at least 1 year of experience in whale-watching. This indicates that the operators have homogeneous identities (2vi, **Table 1**), sharing a common understanding of living situations, trust and a common interpretation of rules that allow for trust and reciprocity (Baland and Platteau, 1996; Ostrom et al., 2002).

External Environment

Markets

This study revealed that there are some problems with the whale-watching price. The price of a whale-watching trip in 2015 was ∼$8.30 USD (COP 25,000) per passenger per trip, plus the transportation cost of round-trip tickets from Buenaventura to Juanchaco, which were sold for $27.00 USD (COP 80,000). A competition-driven discounts given by whale-watching operators and intermediaries (see below) cause the prices to vary. The intermediaries are agents that connect the tourists with the operators as travel agencies, hotels, cabins, restaurants, or commission agents (**Figure 2**). Commission agents are independent persons who advertise whale-watching to tourists and sell the tickets after negotiating with operators to reach an agreed upon price. Most of intermediaries work on commission. The Juanchaco and Ladrilleros hotels maintain informal agreements with local operators and Buenaventura companies, thus profiting when tourists pay for the service through their businesses. On the other hand, cabins and restaurants in La Barra connect tourists with local operators who may or may not be required to pay a commission to intermediaries.

According to testimonies of some local operators, sometimes the commission agents negotiate a lower price, which is an economic loss for the operator "…the commission agent never tells you how much he has charged.…there are some [commission agents] who want to pay $4.60 USD [per whale-watching trip], others $5.00 or $6.00 USD, because the passengers are paying for it cheap" (Boat driver, Juanchaco).

The price variability and connections with intermediaries affects informal agreements between operators in Juanchaco's tourism dock. Several of the interviewees referred to two local operators who had the greatest number of connections with Juanchaco and Ladrilleros hotels, gaining a large number of tourists. Therefore, the unevenness in articulation with markets generates income inequality (4ii, **Table 1**) (Ostrom et al., 2002). The operator's connections can range from working independently (no connections) to having many connections with hotels and travel agencies "…they [some operators] have agreements with hotels here, therefore if us who are independent do not have those agreements, what can we get? …" (Boat driver, Juanchaco). This unevenness, in how many connections each operator has, breaks informal agreements that contribute to fairness in allocation of benefits from the resource of whale-watching (1 and 2iii, **Table 1**). Some give up participation in agreements when they have the possibility to fill their boat to capacity. This creates an inequality of sacrifices willingly made by members of the community. Not all are willing to desist from income they may obtain individually for collective benefit (Ostrom et al., 2002). Other reasons that operators claim is that it has been impossible to organize themselves in Juanchaco's tourism dock because of the independent work of local operators. One interviewee said that "…until now that I know, not everything is independent, everything is individual" (Environmental Interpreter, La Barra). There is a general unwillingness to organize themselves and they lack a leader to form an association and persist in achieving it. Furthermore, no government or community entity has supported the creation of such an association, although one of the interviewees had sought to look for support from environmental entities, such as CVC. Therefore, the lack of competent operators with the necessary knowledge to establish government relations and to become respected local leaders with previous experience, makes it difficult to form an association (Baland and Platteau, 1996; Ostrom, 2009) (2v, **Table 1**).

Technology

There is a perception of economic disparity between operators from Juanchaco, Ladrilleros and La Barra and operators from Buenaventura (4i, **Table 1**). Buenaventura operators have primary access to tourists because of their opportunistic location (**Figure 1**). They also have advantages in boat capacity, between 20 and 46 passengers, with engines of 115, 150, or 200 horsepower (hp), and equipment compliance required by the marine authority. Instead, local boats are smaller with capacities between 4 and 25 passengers and engines of 15 to 40 hp. To transport tourists, all boat drivers must have a navigation license. The boat must comply with a large amount of required equipment according to DIMAR. When complying with the requirements, the authorized boat is allowed to be affiliated with an authorized company with a valid operating permit. However, local boats do not have equipment required by DIMAR and they are not affiliated with a company because "…most of the people here are low income…" (Boat driver, Juanchaco) or relative poverty (2vii, **Table 1**). However, most of the local boat drivers claim to have the necessary equipment for whale-watching: boats in good condition, life jackets for passengers, and two engines for one to be a back-up during whale-watching.

Even so, this heterogeneity of equipment and relative poverty is not shown to translate into a disadvantage for local operators. Most of the whale-watching tourists were managed by operators of Bahía Málaga communities in 2015 (Avila et al., 2015; Parques Nacionales Naturales Consejos comunitarios, 2015). There are informal agreements between Buenaventura companies and local operators of Juanchaco and Ladrilleros. These agreements are coordinated, respectively with dispatchers in charge of Buenaventura companies, in Juanchaco's tourism dock. The agreements occur when there are not enough Buenaventura companies' boats available or when the number of tourists is too low to cover the costs, using their large boats. These agreements allow local operators to have an access to those tourists who purchased tickets in Buenaventura. Therefore, there is no exclusion of benefits in terms of geographic location or variable equipment between users (4i, **Table 1**) (Baland and Platteau, 1996).

To deal with the problems of income inequality and price variation, some operators in Juanchaco's tourism dock have considered the possibility of starting a cooperative or microenterprise association. The association's plan would be to distribute trips in turns, no matter if the number of passengers is low for some trips. The association would also be the only entity that could sell whale-watching tickets in Juanchaco. The prices would be standardized, without intermediaries or Buenaventura companies intervening. Others suggest that local operators should handle most of the whale-watching trips. This will still allow Buenaventura companies to handle passenger transport to other sites.

Relationships Between Resource System and User Group Characteristics

Establishing an association with all whale-watching operators from different communities comes with other restrictions. Operators are scattered over a large area, so for some of them there is no overlap between their residential location and the prime whale-watching locations (1 and 2i, **Table 1**). Consequently, the geographical distribution of operators creates a barrier to forming relationships that could help establish and interpret the rules to support cooperation (Wade, 1988; Baland and Platteau, 1996). Besides, the operators depend in different

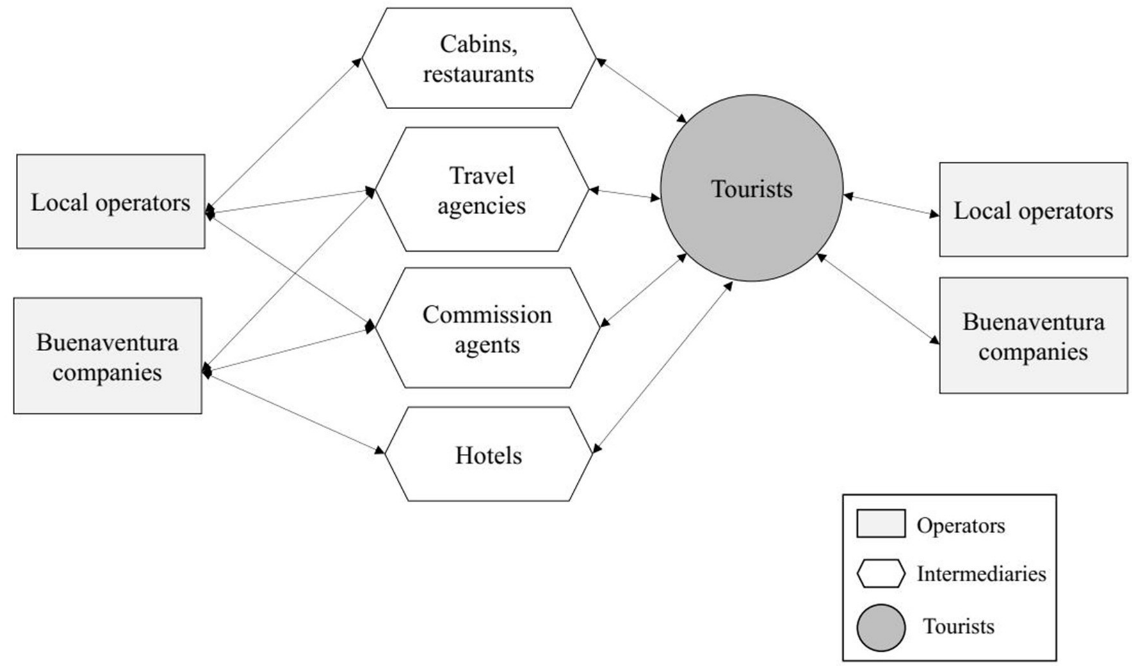

FIGURE 2 | Relations among key actors in the tourism chain of whale-watching, National Natural Park Uramba Bahía Málaga.

degrees on whale-watching (1 and 2ii, **Table 1**). Local whale-watching operators have other sources of income. These include serving as tour guides from other nearby attractions (for example, mangrove tours) and fishing. Boat drivers in Buenaventura are mainly dedicated to tourism and transporting passengers between villages as there are no roads between them, only two of them have other occupations "... after the whale-watching season... I do not have another activity that I can do, we used to fish, but now tourism is the main activity and we must wait for the next peak tourism season ..." (Boat driver, Buenaventura). Some highlight the whale-watching season as the time when they have the highest income annually, and its advantage over other tours that take more time. Since the whale-watching tours are several times a day, it offers greater profits than other tourism activities that depend on tide level. In La Barra, whale-watching represents a fixed income as compared to other activities, such as fishing. However, most of the boat drivers in La Barra diminish the importance of whale-watching trips, because it is just an occasional service that occurs only during a season in the year. Therefore, the low dependence on the natural resource by some operators lessens the importance of the resource sustainability and therefore, generates an heterogeneity of interests (Baland and Platteau, 1996) (2vi, **Table 1**).

Resource System Characteristics and Institutional Arrangements

According to common pool resource theory, one of the most important conditions for successful management is the well-defined boundaries of the resource system and user group (1ii, 2ii **Table 1**). These prevent the arise of free-riders, i.e., individuals that can appropriate benefits without participate in collective actions or their behaviors can contribute to resource degradation (Ostrom, 1990).

In the study area, the environmental authorities have been responsible to establish boundaries on the resource system, user group, rules and monitoring actions (1ii, 2ii, 3iii, and 4v, **Table 1**). From 2001, with the development of guidelines, the CVC was responsible for enforcing them. At the beginning of each whale-watching season the "Local Interinstitutional Committee of Whales" in Buenaventura meets to plan the launch and to delegate commitments. Sometimes the committee meets at the end of the season to make an evaluation. Those who participate are the institutions and actors with environmental, political, social or cultural influence related to whale-watching. Since October 2010 with the establishment of Uramba Bahía Málaga as NNP, the NNP authorities were delegated to assume the whole responsibility of enforcing the guidelines and direct the committee (Ferrero-Ronquillo, 2015; Avila et al., 2015). The NNP holds seven contracts with local experts from six communities: Juanchaco, Ladrilleros, La Barra, La Plata, Chucheros and Puerto España-Miramar. It is "... one person for each community, except two from La Plata and, the councils of Chucheros and La Barra, which decided to assume the commitments of the local expert to contribute to the park team, the NNP coordinates some jobs with local experts and thus provides a salary ..." (Park official, Ladrilleros).

Whale-Watching Guidelines

According to the committee, the operators should keep several requirements to participate in whale watching. Before the whale-watching season starts, operators must attend a training workshop about whales, rules, and procedures provided by NNP, CVC and DIMAR. At the end of the training, they receive a whale-watching card that identifies them as authorized operators. Training workshops are conducted in Buenaventura, La Barra and Juanchaco. Workshops in Juanchaco are also attended by operators of other communities, such as Ladrilleros, Chucheros, La Plata and Puerto España (**Figure 1**). Once the whale-watching season officially starts, operators must report to the NNP authorities in Juanchaco's tourism dock or in La Barra, between 8 a.m. and 4 p.m. every day to obtain a trip authorization. To obtain the authorization, the participation in the training is verified. The park official or person in charge registers them and gives the operator a flag and one environmental interpreter. The flags are used as a sign to identify boats authorized for whale-watching and to confirm that operators know how to comply with all regulations.

The occurrence of "environmental interpreters," as they are currently known, emerged in 2011 as an initiative of NNP with local communities during the committee. Before the whale-watching season, NNP authorities, with the support of other entities, train young persons from the local communities in on different aspects about the surrounding territory, marine mammals and other local species, and on how to carry out responsible tourism in the Bahía Málaga ecosystem (Vásquez, 2015). To limit the number of boats on the sea (2i, 2ii, **Table 1**), a maximum of 15 flags are distributed at any given time. Meaning that only 15 boats at a time can be doing whale-watching. Additionally, tourists are supposed to be given an informative talk on land, before departure, about the protected area, the whales, and recommendations for whale-watching in the facilities where the park officials are located. The talk can be given by park officials or environmental interpreters.

Application of Whale-Watching Guidelines

Regarding rules, most of the operators report that the guidelines are easy to understand and apply (3i and 3iv, **Table 1**). Some operators, though, mentioned that certain rules about keeping a safe distance from the whales were difficult to apply. This is because there are times when groups of whales, most of them with calves, will approach boats closer than 200 m on their own. The boats cannot reasonably move away in order to abide strictly by the rules. Therefore, the rules do not adjust to local conditions, since Bahía Málaga is characterized as a breeding area (Avila et al., 2013) (3ii, **Table 1**). Besides, most operators interviewed say they understand the rules and commit to following them before every whale-watching season. However, several key actors admitted to not trusting others' compliance of the rules. Relations of trust could contribute with monitoring when individual trusted each other to act as they should (Pretty, 2003).

More important, even if the operators agree to comply with the rules, they will not be fulfilled if nobody invests in monitoring and sanctioning activities (Ostrom, 1990). Park officials are currently the entities that have been in charge of monitoring enforcement at sea (3v, **Table 1**), with some support from the CVC, the Navy-Coast Guard and environmental interpreters. The environmental interpreters serve as supervisors for monitoring boat equipment and capacity (passenger overcrowding) and ensuring that the whale-watching rules are adhered to on board. Moreover, if it is necessary, they give a warning to the boat driver or make a note to report bad behavior to the NNP. Nevertheless, their verbal warnings, as a means of enforcement, is perceived by the operators as having low authority. In addition, some operators, mainly from Buenaventura, Juanchaco and Ladrilleros, tend to supervise each other as a result of by-product of using the commons (Ostrom, 1990) (3viii, **Table 1**). They scold each other personally at sea or later on land, particularly when someone is too close to the whales. Only a few of those incidents are later reported to park officials. However, some mentioned that, when doing these actions, they generate conflict and are called "toads" (a slang word for gossips or "tattle tales") by their peers. However, despite the efforts to establish clearly defined boundaries of user group (2i, 2ii, **Table 1**) and monitoring actions, there are still gaps. In La Barra, one of the operators interviewed in the community did not attend the trainings and therefore was not granted the whale-watching card. Several other interviewees even mentioned that operators would give whale-watching trips without the training and a flag. Nor did most of the local operators take an environmental guide with them or give the pre-departure talks to tourists. In La Barra, this is likely due to the fact that the environmental interpreter training began in 2015. In the same year, the flags and report about operators started to be recorded and delivered in La Barra by environmental interpreters. When park officials find an unauthorized boat, they can request the suspension of the whale-watching activity and ask them to go to the Juanchaco's tourism dock. Once on land, other park officials give the operator a small talk if he did not participate in the training workshops in order to provide him with a flag and an environmental interpreter. On the other hand, if a boat breaks a rule of whale-watching, the boat driver will receive a verbal warning by environmental authorities (NNP or CVC) and it is recorded as a note. After the whale-watching season ends, all recorded notes are discussed in the "Local Interinstitutional Committee of Whales" to consider whether sanction measures are necessary. The existence of unauthorized operators in the sea may derive from the characteristics of the humpback whale habitat that raise the costs of defining boundaries, monitoring and knowledge of the state of the resource (Wade, 1988; Ostrom, 2009) (1i,1ii, and 1iii, **Table 1**). Nonetheless, most of the boats leaving from Buenaventura, from areas surrounding the Park, and from the communities that are part of it, do whale-watching near of Juanchaco's tourism dock in Bajos de Negritos (**Figure 1**), where there is the highest probability of observing whales. This natural congregation facilitates monitoring and set boundaries (3v and 1ii, **Table 1**). Also, the profits are ensured every year by the high predictability of the arrival of humpback whales for their reproductive season (1v, **Table 1**).

Sanctions

According to testimonies from park authorities, there are not currently sanctions concerning whale-watching (3vi, **Table 1**). However, there were some inconsistences between the guidelines and testimonies from environmental authorities and some boat drivers. The guidelines specify legal sanctions to those who do not comply with recommendations of whale-watching. These are considered as infractions to naval rules (DIMAR, 2001). Some boat drivers claimed the existence of sanctions such as suspensions of whale-watching for days or all season, economic fines, jail time, and retention or immobilization of the boat. Moreover, several key actors recognized the importance of establishing sanctions (3vi, **Table 1**) to enforce compliance "…because it would be good, because [then] people would always respect the rules …" (Boat driver, Juanchaco).

DISCUSSION

The aim of this study was to analyze the characteristics of humpback whale-watching in Uramba Bahía Malaga National Natural Park through Moore and Rodger (2010) 30 enabling conditions for sustainability of governance. Since only 16% of the conditions were met, current management of the whale-watching activity in the area could jeopardize sustainability of governance in the mid- and long-term. Conflict and competition among operators, the unwillingness to work together, the lack of a whale-watching operators' association, and the lack of support from government organizations appear as some of the main reasons for this lack of sustainability. These issues have also been identified in whale-watching industries in the Azores (Bentz et al., 2013; Silva, 2015). This suggests that some problems identified in this study could be occurring in different regions of the world. It is important to notice also that these problems have not hindered the informal agreements between different key actors and operators to share tourists or to share information about the location of whales. Interestingly, this has also been observed in other regions of the world (Silva, 2015).

Moreover, some recommendations arise from these analyses. To tackle these social problems and the perception of a lack of enforcement in humpback whale-watching at the Uramba Bahía Málaga NNP, it is necessary to have joint management support by involving stakeholders, local communities, operators, and government entities (Higham et al., 2009; Dimmock et al., 2014; New et al., 2015). Local operators could participate in the development of local guidelines. This could help to develop rules on specific behaviors that should be adapted when humpback whales are nearby (Ostrom, 1990; Gjerdalen and Williams, 2000). Local councils and individuals with previous experience in similar associations could assist in conflict resolution to promote trust and reciprocity among operators during activities by implementing regular meetings (Young, 1999; Heenehan et al., 2015). Several studies have also shown that it is possible to equally distribute benefits of whale-watching and to foster cooperation to resolve disagreements and consolidate competition by forming local associations (Young, 1999; Allen et al., 2007; Mustika et al., 2012). This could also help the operators to be recognized as a legitimate voice in whale-watching management (Lawrence et al., 1999).

It is important to empower environmental interpreters by bolstering their perceived low authority. This would improve surveillance mechanisms. Tourists could also monitor and report bad behaviors during whale watching. The most effective sanctions and monitoring methods applied by the authorities or by the operators themselves should also be identified. Furthermore, if the authorities seek to limit the number of operators in the future, the operators' opinion should be considered. Those who do not agree with limiting the number of operators state that officials "…cannot deny our right to work unless they have subsidies to carry out the activity…" (Boat driver, Juanchaco). In this way, limiting the number of operators should be complemented by policies to reduce poverty levels (Mustika et al., 2012).

CONCLUSIONS

The CPR analysis of humpback whale-watching based on enabling conditions for sustainability governance developed by Moore and Rodger (2010), revealed the complexity of the system. Only external entities define the boundaries and rules of local management of the resource system, user group and institutional arrangements. In addition, the high cost of surveillance, which derives from the characteristics of the resource system, prevents to adequately monitor the compliance of the rules. The analyses showed also that sustainability governance of the whale-watching activity may be in jeopardy in the mid- and long-term since only some of the conditions were met. Government and community authorities have the challenge to improve the relationships between stakeholders and to better control the local agreements and price of the activity. Regular meetings between operators may resolve social problems, and inconsistences in rules and sanctions. The creation of operator associations could lead to socioeconomic equality and enhance their participation in whale-watching management. Difficulties in monitoring could be reduced in the future if operators really considered environmental interpreters as authority officers. Through informative talks, tourists could also get involved in monitoring and could report bad behaviors during whale watching.

Moreover, in whale-watching areas in which only the biological approach has been prioritized, it is advisable to apply the methodology presented here. This could allow to deepen in other factors that may be affecting the sustainability of the whale-watching industry. Further researches on humpback whale-watching as a "tragedy of the commons" in Colombia and in other regions of the world are also needed. This will help to better understand the relationships between each of the conditions to enable sustainability governance and to identify cases of management failure but also of cooperation success between key actors.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was obtained by the Ministry of Interior with the record number 0FI15-000029149-DCP-2500 12 August, 2015 according to local legislation and institutional requirements. The participants provided recorded informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Dolphin-Watching Boats Affect Whistle Frequency Modulation in Bottlenose Dolphins

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Bottlenose dolphins' whistles are key in social communication, conveying information about conspecifics and the environment. Therefore, their study can help to infer habitat use and identify areas of concern due to human activities. Here we studied the whistles of bottlenose dolphins (*Tursiops truncatus*) in two sites of the archipelago of Bocas del Toro, Panama, that contrast in boat traffic. Almirante Bay is a site dominated by taxi-boats and Dolphin Bay is a major location for boat-based dolphin watching. Recordings were made using bottom-mounted hydrophones and from the research boat using an over-the-side hydrophone and a broadband recording system. A total recording effort time of 1,726 h was analyzed. Our results show significant differences in boat detection between sites, and a higher number of whistles detected per minute in the site with tour-boat traffic. Furthermore, whistle modulation accounted for most of the differences between sites, boat presence, and whistle types. Dolphin whistle modulation is thought to be a potential indicator of emotional states including danger, alertness, and stress. In this study, dolphin signature whistle modulation increased significantly with boat presence in both sites but changes in modulation were greater in Dolphin Bay where tour-boats directly and sometimes aggressively interact with the animals. These results support a potential association between whistle modulation and stress (or alertness). These findings indicate that if tour-boat captains behave more like taxi-boat captains by e.g., reducing the distance of approach and contact time during dolphin interactions, dolphin communication, and emotional state would be less disrupted. These measures are implemented in the national guidelines for whale-watching and are known to tour-boat operators. The key to protecting these dolphins is in finding ways to effectively enforce these operator guidelines.

Keywords: dolphin-watching tourism, boat traffic, acoustic behavior, ecotourism, soundscape

INTRODUCTION

Bottlenose dolphins (*Tursiops truncatus*) have a rich acoustic repertoire used in a variety of contexts. They produce echolocation clicks to navigate and locate food (Au, 1993), and social sounds such as whistles, calls, screams, barks, pops, and quacks when communicating with each other (Jones et al., 2020). Among the latter sounds, whistles are the most studied (e.g., Caldwell et al., 1990;

Janik, 2009). These whistles are narrow banded, and frequency modulated and can be further categorized into "variants" or "signature" whistles based on their function and pattern of emission (Caldwell et al., 1990). Variant whistles are non-stereotypic sounds produced in a wide range of social contexts, often at a greater frequency than signature whistles (Sayigh et al., 1990; Rachinas-Lopes et al., 2017). In contrast, signature whistles are stereotypic sounds that encode information about individual identity and thus are used as contact calls (Caldwell et al., 1990). Signature whistles facilitate group cohesion (Janik and Slater, 1998; Janik, 2009), development and maintenance of male-male alliances (King et al., 2019), in communication between mother and calf pairs (Smolker et al., 1993); and they are also used as a greeting signal when dolphins groups meet in the wild (Quick and Janik, 2012). Signature whistle contour can vary in modulation which can be measured in terms of number of loops and number of inflection points (changes in the slope) (e.g., Janik et al., 1994; Esch et al., 2009). Studies of signature whistles during capture-release situations suggest that contour traits such as loop number and loop duration could indicate stress (Esch et al., 2009). Such associations between signature whistle contour characteristics and stress could help generate a better understanding of the impact of boat traffic and associated noise on dolphin communication. For example, May-Collado and Wartzok (2008) compared two neighboring populations of bottlenose dolphins in Costa Rica and Panama that had different levels of boat traffic and showed significant differences in dolphin whistle modulation (measured in number of inflection points). The dolphin population exposed to greater boat activity emitted significantly more modulated whistles than the one with low boat activity. Also, Marley et al. (2017) showed that Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) produce whistles in which the number of inflection points increased with noise levels.

Bottlenose dolphins show a remarkable ability to modify their whistle acoustic frequencies to different acoustic environments (Morisaka et al., 2005; May-Collado and Wartzok, 2008) and behavioral activities (e.g., Díaz López, 2011). This ability has been widely documented in coastal dolphin populations where their acoustic environment is often dominated by small boats producing sounds at frequencies (2–10 kHz) that overlap with the frequency range of dolphins (Wenz, 1962; Kelly et al., 2004; Bittencourt et al., 2014; Erbe et al., 2019). For instance, in response to small number of boats, dolphins are reported to increase whistle rate production, and change whistle frequencies and duration (e.g., Buckstaff, 2004; Guerra et al., 2014). For example, in the Cres-Lošinj Archipelago in Croatia (Rako-Gospiæ and Picciulin, 2016), the archipelago of Bocas del Toro in Panama (May-Collado and Wartzok, 2008), and in Japan (Morisaka et al., 2005), bottlenose dolphins produced whistles at frequencies that would minimize signal masking when ambient noise levels were higher as a result of anthropogenic activity. However, not all boat traffic affects dolphin acoustic behavior in the same way, and not all interactions are equal. In encounters with non-tourism vessels in the Fremantle Inner Harbor in Australia, Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) whistles were higher in maximum, end, and delta frequencies in response to increasing noise (Marley et al., 2017). Similarly, in Lampedusa Island, Italy researchers found that in the presence of trawlers, dolphins produced whistles that were higher in most frequency variables, longer in duration, and more modulated (La Manna et al., 2013). In contrast, in Doubtful Sound, New Zealand, in the presence of tour-boat activity, changes in whistle frequency also depended on dolphin group composition (Guerra et al., 2014). Dolphin groups without calves responded to tour-boat presence by shifting to lower frequency whistles, whereas dolphin groups with calves shifted to higher frequency whistles (Guerra et al., 2014).

The archipelago of Bocas del Toro in the Caribbean waters of Panama is home to a small and genetically isolated population of bottlenose dolphins (May-Collado and Wartzok, 2008; Barragán-Barrera et al., 2017). Photo-identification and residence patterns of site fidelity data suggest that these dolphins are distributed throughout the archipelago, with dolphins in Dolphin Bay showing the greatest levels of residency (May-Collado et al., 2017). Throughout the archipelago, dolphins are exposed to small taxi-boat traffic. However, the most prominent area of dolphin-taxi-boat overlap is at Almirante Bay, where boats use pre-established routes and schedules to transport people between the mainland and the main island of the archipelago (May-Collado et al., 2017). At Dolphin Bay, by contrast, resident dolphins are primarily exposed to tour-boat traffic. Here, dolphin-tour-boat interactions are often intense due to the lack of compliance with national regulations (Sitar et al., 2016). As a result, dolphins are often disrupted from foraging and social behaviors (Kassamali-Fox et al., 2020), and mother-calf pairs are often separated and sometimes injured (May-Collado et al., 2017). During dolphin-tour-boat interactions, dolphin groups produced high-frequency whistles (May-Collado and Wartzok, 2008), however, shifts in whistle frequency were particularly evident when the dolphins were engaged in foraging activities (May-Collado and Quiñones-Lebrón, 2014).

In this study, we evaluated the effect of two types of boat traffic: taxi-boats and tour-boats on dolphin acoustic presence, dolphin whistle detection rate, and acoustic structure in the dolphin population of Bocas del Toro, Panama. We hypothesized that dolphin whistle presence, detection rate, and acoustic structure would vary between types of boat traffic, because of the differences in which they interact concerning the number of boats and intensity of the interaction with the dolphins. The taxi-boats maintain schedules and pre-established routes (**Figure 1**) that result in less disruptive interactions with the dolphins. In contrast, tour-boats follow dolphins for long periods often in large numbers (2–40 boats) (May-Collado et al., 2017). May-Collado and Wartzok (2015) reported that in Dolphin Bay ambient noise [measured in dB Root Mean Square (RMS)] increased with the number of tour boats. As a result of the large boat aggregations (and associated noise) dolphin behaviors are often disrupted (Kassamali-Fox et al., 2020) and group members are separated (May-Collado et al., 2017). Under such circumstances, dolphins are likely to become stressed and more alert, and based on previous work by Esch et al. (2009) these emotional states can be detected in the modulation of the contour of signature whistle (e.g., loops and number of inflection points).

Therefore, we expected that dolphins would produce more modulated signature whistles in the presence of boats than in their absence, and the pattern should be greater when interacting with tour-boats than with taxi-boats. Bottlenose dolphin whistles are the foundation of their fission-fusion society, and thus understanding how they are impacted by boat traffic can have important contributions in ongoing mitigation efforts.

MATERIALS AND METHODS

Study Site

This study took place in the archipelago of Bocas del Toro on the Caribbean coast of Panama. The archipelago consists of shallow and clear waters <20 m in depth with coral reefs, mangrove forest and seagrass meadows surrounding the islands and it is home to a resident population of bottlenose dolphins. Genetic data classify this dolphin population as the "inshore" ecotype, which live in isolated and small populations (effective population size Ne = 73 individuals), and where both males and females show high levels of philopatry (see Barragán-Barrera et al., 2017). Isotope data indicate that these dolphins have a diverse diet as expected in an area with coral, mangrove, and seagrass communities; including fish like the mutton snapper, yellowfin mojarra, and the dwarf round herring (Barragán-Barrera et al., 2019). Dolphin watching in Dolphin Bay has grown to the point that now days up to 40 boats can be seen following the same group of dolphins within 1 h. This is the result of lack of concurrent training and compliance of national whale watching guidelines (Resolution N° Dm-0530-2017, 2017).

Recordings were done in two locations within the archipelago that differ in the type of boat traffic: Almirante Bay (AB) and Dolphin Bay (DB) (**Figure 1**). In Almirante Bay, transport boats are the main type of boat activity. Three taxi-boat companies run every 30 min each way between mainland and the archipelago from 6 a.m. to 6 p.m. In Dolphin Bay, the main type of boat activity is related to dolphin watching. These tour-boats often approach the dolphins not following recommended national conduct guidelines. Dolphin watching boats arrive to Dolphin Bay every day between 9 a.m. to 12 p.m. Once a group of dolphins is spotted, they are approached by boats at distances of 50 m or less. As they are followed (sometimes for hours) tour boats tend to make rapid changes in speed and direction, resulting in mother-calf and group member separation (Sitar et al., 2016), disruption of key behaviors like foraging and socializing (Kassamali-Fox et al., 2020) and sometimes injuries and death due to boat collision (Trejos-Lasso and May-Collado, 2015; May-Collado et al., 2017).

Recordings

Passive Acoustic Recordings Using Bottom-Mounted Hydrophones

Recordings of dolphins and boats were made using the μRUDAR-mK2 autonomous recorders (−169 dB re:1 V/μPa, 1–96 kHz) from Cetacean Research Technology. The recorders were attached on a pole 1.5 m above the seafloor and anchored with a ∼30 kg block at 12 m depth. In Almirante, the location of the deployment was a sandy bottom with patches of coral reef and in Dolphin Bay the bottom was mainly muddy and seagrass with a few patches of coral reef. These bottom-mounted hydrophones recorded dolphin whistles without interference from the research boat and were scheduled to, simultaneously and continuously, record the acoustic environment in a 24-h cycle and at a sampling rate of 48 kHz and 24 bits. Recordings were continuously made for up to 10 consecutive days, approximately once a month, between September 2017 and June 2018, in files of 30 min (**Table 1**). The recorder deployed in Almirante Bay malfunction several times resulting in unequal sampling of both sites. The total recording effort was 1,670 h (Dolphin Bay = 1,406; Almirante = 264).

The 1,670 h of passive acoustic recordings were then manually processed following our lab protocol for passive acoustic data. First, a 1-min recording sample was manually taken every 10 min resulting in six files of 1-min per hour, yielding a total of 10,705 1-min files (∼178 h) (Almirante Bay n = 1,709 1-min files, Dolphin Bay n = 8,996 1-min files). These 1-min files were then uploaded to the online platform RFCx ARBIMON (Rainforest Connection, 2020) for sharing among collaborators and inspection using a spectrogram. Each 1-min file was annotated with information about the presence (1) or absence (0) of boats and dolphin sounds to create a 0–1 matrix by time of day and site. Dolphin presence was marked as one when either or a combination of these sounds were present: echolocation clicks, buzzes, calls, and whistles. This procedure is entirely manual and is routinely followed in our lab to generate a sample of acoustic "vouchers" for all sites where passive acoustic recorders have been deployed as it facilitates identifying those recordings with sounds of interest.

Because our main interest is in the dolphin whistles, we used these 1-min files to locate in the original file (which was 30 min in length) dolphin whistles. This file was opened in RAVEN PRO 1.5 build 37 (Center for Conservation Bioacoustics, 2014) and a spectrogram was opened with a fast Fourier transform (FFT) size of 1,024 points, an overlap of 50%, and using a 512-sample Hann window. All whistles that were manually detected in a consecutive fashion within a period were assigned to an "acoustic group." For example, if the 1-min file in RFCx ARBIMON indicated the presence of whistles at 1:10, we would then go to that point in the long recording and determine when the first and last whistle was detected in the recording. In total, five acoustic groups were identified for Almirante Bay, all distanced from each other by more than 2 h of recording time, while in Dolphin Bay 15 acoustic groups were identified, which were separated from each other by more than 3 h of recording time. **Figure 2** is a flowchart of this process using an example spectrogram of the actual data. However, there is no guarantee that more than one dolphin group was recorded at the same time, or that what we considered was two independent acoustic groups were in fact not.

Once dolphin whistles were found we proceeded to (1) count all the whistles visible in the spectrogram within the acoustic groups and (2) classify dolphin whistles into signature and variants using the Signature Identification (SIGID) method (see Janik et al., 2013). This method consists of manually inspecting whistle contours. Because signature whistles are produced in bouts, any whistle of the same contour type occurring within

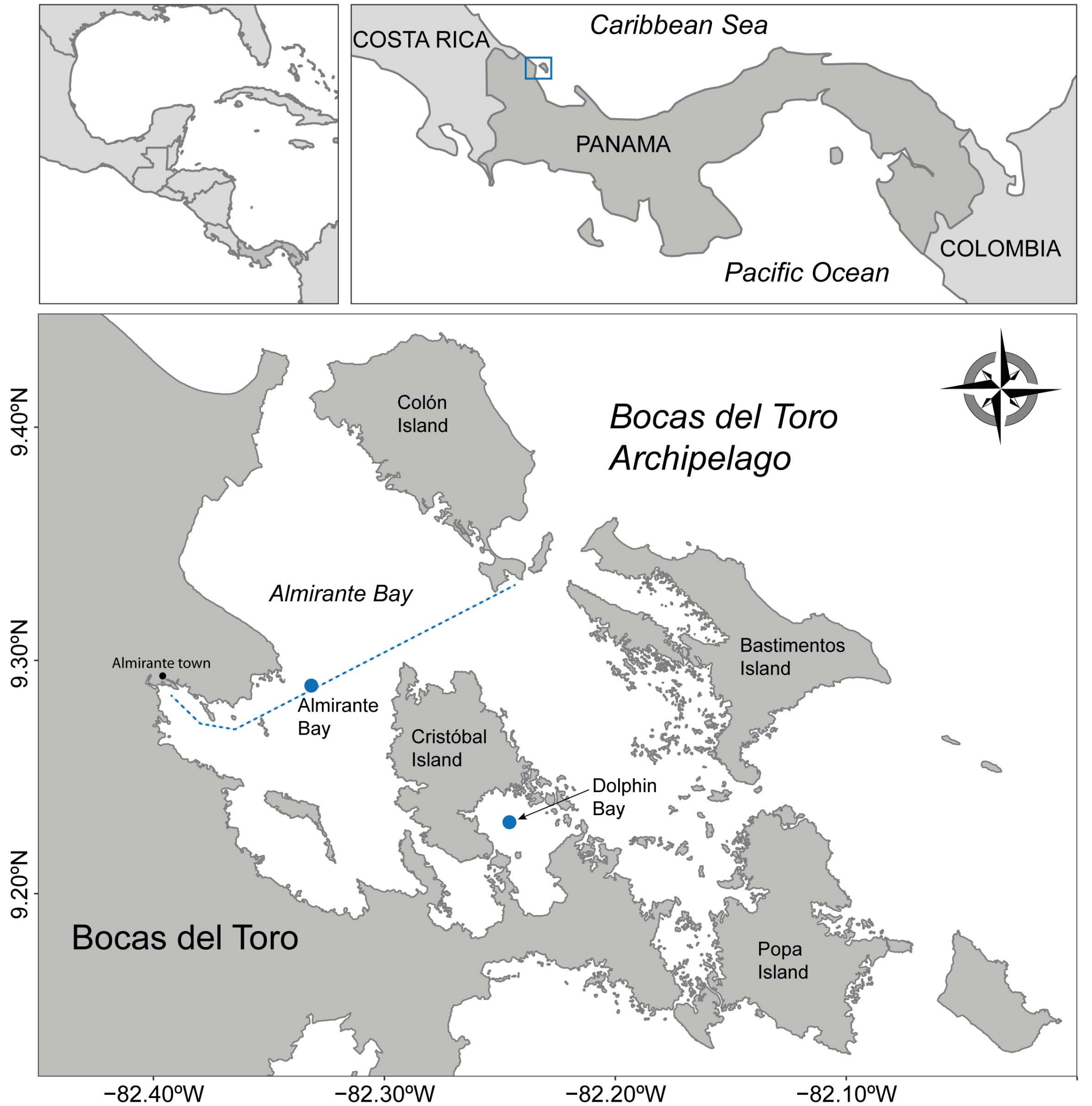

FIGURE 1 | Archipelago of Bocas del Toro, Panamá. Location of the two sites where bottom-mounted underwater hydrophones were deployed (Almirante Bay and Dolphin Bay). The dashed line corresponds to the main route used by taxi-boats from Almirante Bay to the main Island of the archipelago. Dolphin Bay is the location where dolphin watching activities takes place in the archipelago.

1–10 s is considered a signature whistle. For each acoustic group, we identified all possible signature whistles, and for variant whistles we maximized the selection of different whistle contour types. Since we do not know the actual size of the dolphin groups been recorded, we assumed the whistle selection protocol used in this study was conservative, while at the same time maximizing the representation of the whistle repertoire of the dolphins in this population.

Finally, only whistles with a clear and dark contour from start to end and a signal-to-noise ratio (SNR) above 8 dB were selected for acoustic data extraction. SNR was estimated using the Inband Power measurement in RAVEN[1]. This selection process resulted in a total of 1,035 whistles (Almirante Bay = 242; Dolphin Bay = 793). For each of these whistles the following standard acoustic variables (e.g., Morisaka et al., 2005; May-Collado and Wartzok, 2008; Marley et al., 2017; **Figure 2**) were extracted: low frequency (LF) (measures the frequency in the lowest point in the contour), high frequency (HF) (measures the frequency at the highest point in the contour), duration (D), delta frequency (DF) (this is the difference between HF and LF), center frequency (CF) (represents the midpoint frequency between the lower and upper cutoff frequencies), peak frequency (PF) (frequency where the maximum amplitude occurred), and peak frequency contour number of inflection points (PFC Num Inf Pts) (measures the number

[1]https://ravensoundsoftware.com/knowledge-base/signal-to-noise-ratio-snr/

TABLE 1 | Coordinates and deployment schedule of the bottom-based recorders at each site in the archipelago of Bocas del Toro.

Site	Coordinates	Date		Total duration (h)	Total hour recorded	Total hours analyzed
		Deployment	Retrieval			
AB	9.289 N, −82.332 W	Nov 8	Nov 8	15	264	27.5
		Jan 27	Jan 27	14		
		Mar 28	Apr 7	235		
DB	9.230 N, −82.246 W	Sep 13	Sep 18	120	1,440	148
		Nov 8	Nov 13	120		
		Jan 27	Feb 6	240		
		Feb 28	Mar 10	240		
		Mar 28	Apr 7	240		
		May 3	May13	240		
		May 28	Jun 7	240		

AB, Almirante Bay (taxi-boats); DB, Dolphin Bay (tour-boats).

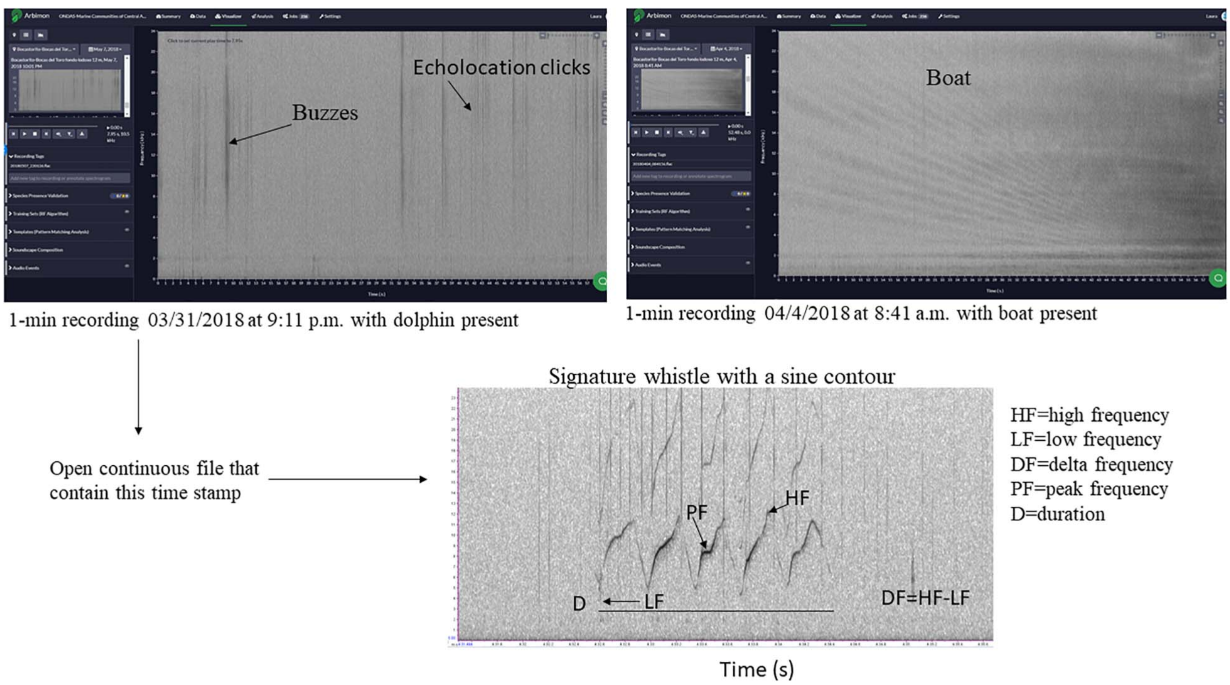

FIGURE 2 | Example of 1-min files used to locate recordings with dolphin whistles, and to create a presence-absence matrix for boat and dolphin presence. The spectrogram of the signature whistle at the bottom of the figure highlights some of the whistle acoustic variables measured in this study.

of times the slope changes sign in peak frequency contour slope) (**Figure 2**).

Passive Acoustic Recordings From the Research Boat Using an Over-the-Side Hydrophone

From 2004 to 2012 dolphins were recorded in Dolphin Bay from the research boat in the presence and absence of tour-boats. Recordings were made using a broadband recording system that consisted of a RESON hydrophone 4,033 (−203 dB re:1 V/µPa, 1–140 kHz; RESON Inc., Goleta, CA, United States) was connected to an AVISOFT recorder and Ultrasound Gate 116 Hb with discrete gain settings (sampling rate 400–500 kHz, 16 bit; Avisoft Bioacoustics, Berlin, Germany) that sent the signals to a laptop computer. The recording effort was 56 h. All recording sessions were done in the presence of focal groups ranging from 2 to 10 individuals (May-Collado and Quiñones-Lebrón, 2014). A focal group was defined as a group of dolphins moving in the same direction and engaged in similar behaviors within five body lengths of each other (Mann, 1999). For each recording session recordings were made continuously and saved in files of 3 min in length. Each of these 3-min files was accompanied by an observation of the predominant surface behavior obtained by scan-group sampling every 3 min (Martin and Bateson, 2010). The presence or absence of tour-boats was also noted for each 3-min recording. Dolphin group membership varied and based on photo-identification effort (photograph of natural marks on the dorsal fin of dolphins, a standard method to "mark" individual dolphins) the same 47 dolphins were recorded under different combinations and when engaged in three main behavioral activities: socializing, foraging, and travel (May-Collado and Wartzok, 2008; May-Collado and Quiñones-Lebrón, 2014). In an early analysis of this dataset, we found high intergroup variability (May-Collado and Wartzok, 2008) and that changes in whistle acoustic structure between the research boat and tour-boats occurred when the dolphins were engaged in foraging activities (May-Collado and Quiñones-Lebrón, 2014). Foraging is the most disrupted behavior by tour-boats in this dolphin population (Kassamali-Fox et al., 2020) highlighting the impact that tour-boats have on both surface and acoustic dolphin behavior. Given that signature whistles are specific to each dolphin, they are likely the reason for this variation, different combinations of individuals in a group will have different combinations of signature whistles (Quick and Janik, 2008). For this study, these past recordings were resampled and only whistles below 25 kHz were selected to be able to compare to whistles obtained by the bottom-mounted recorder. Furthermore, we followed the same whistle selection process described in the passive acoustic section regarding classification of whistles into variants and signature and selection of a diversity of whistle contours that had a SNR above 8 dB.

Statistical Analysis

Descriptive statistics were calculated for all boat and whistle variables. The Likelihood ratio with a Fisher's Exact test (Fisher, 1934) was used to test for association between boat and dolphin detections within sites, and a Kolmogorov–Smirnov Test (Smirnov, 1939) to determine if the diel distribution of these variables differs between sites. The temporal association between the mean of number of files with dolphin and boat for Almirante Bay and Dolphin Bay were evaluated using time series cross-correlation analysis. This analysis determines how much one variable is predicted to change in relation to the other variable. Dolphin whistle detection rate and frequency, duration, and modulation variables were not normally distributed even after being Box-Cox transformed (Shapiro–Wilk Test $P < 0.05$) (Shapiro and Wilk, 1965). A permutation multivariate analysis of variance (PERMANOVA) (Anderson, 2001, 2006) was used to compare the dolphin whistle acoustic structure considering the effect of sites (Almirante Bay and Dolphin Bay), boat presence/absence, and whistle type (signature and variants). PERMANOVA assumption of homogeneity of multivariate dispersion was assessed with the homogeneity dispersion test ("betadisper"). Dolphin whistle acoustic variables were transformed to $y = \ln(y + 1)$ as recommended by La Manna et al. (2013). Data was then transformed using Euclidean distance and the analysis was conducted with 999 permutations of the residuals under a reduced model. A dissimilarity percentage test ("simper") based on Bray-Curtis dissimilarity index was performed to find which whistle acoustic variables contributed the most to the observed differences. In Dolphin Bay, recordings were made from the research boat and a bottom-mounted hydrophone. To determine the potential impact of the research boat on dolphin whistle acoustic structure, a Mann–Whitney *U* test (Mann and Whitney, 1947) was used. Specifically, we tested if dolphin whistle acoustic structure varied between recordings made only in the presence of the research boat and recordings with no boat present from the bottom-mounted hydrophone. To account for the effect size for the statistic we calculated the following test $n^2 = z^2/N\text{-}1$ (Fritz et al., 2012). We found significant differences in whistles delta frequency ($z = -2.78$, df = 1, $P = 0.005$), duration ($z = 2.35$, df = 1, $P = 0.018$) and PFC Num Inf Points ($z = 3.85$, df = 1, $P < 0.0001$), but these variables explained less than 1% of the differences, suggesting that if there is an impact by the research boat, it is minimal. Therefore, we felt justified in merging the data from both recording methods for the PERMANOVA analysis. Descriptive and non-parametric analysis were performed in JMP 14. (SAS Institute, NC, United States) and SPSS Statistic 26 (IBM Corp., 2019). Time series cross-correlation and PERMANOVA were performed in the statistical software R v.4.0.3 (R Core Team, 2020) and RStudio v.1.2.5042 (RStudio Team, 2020), using the "stats" package (R Core Team, 2020), and "vegan" package (Oksanen et al., 2020) respectively. The level of statistical significance for all analyses was $P < 0.05$. To simplify reporting of results we will use the sites names to represent the type of boat activity, Almirante Bay for taxi-boats and Dolphin Bay for tour-boats.

RESULTS

Boat and Dolphin Detections

After accounting for differences in sample size, boat and dolphin detections were significantly higher in Almirante Bay than in Dolphin Bay (Boats: Likelihood Ratio = 584.6, df = 1, $P < 0.0001$; Dolphins: Likelihood Ratio = 13.9, df = 1, $P = 0.0002$). However, in Dolphin Bay when dolphins were detected they produced 4.7 times more whistles per minute (Mean: 1.09 #whistles/min, SD: 1.84, CV: 168.6, Range: 0–4.8) than dolphin in Almirante Bay (Mean: 0.23 #whistles/min, SD: 0.78, CV: 344.7; Range: 0–0.73 #whistles/min). **Figure 3** shows the diel distribution of mean boat and dolphin detections for each site and the associated standard deviations bars. The diel distribution of boat presence between Almirante Bay and Dolphin Bay was significantly different (Kolmogorov-Test = 418, $P = 0.004$), but no significant differences were found in dolphin presence ($P > 0.05$). The times series analysis for Dolphin Bay and Almirante Bay indicates that the mean of boat and dolphin detections are not significantly correlated ($P > 0.05$); however, in Almirante Bay there was cross-correlation between the *lag*−6 and −3, with the strongest correlation at *lag* −4 (**Supplementary Figure 1**). This indicates that a higher-than-average boat presence leads to a lower-than-average dolphin presence three to 6 h later. There was also a positive cross-correlation at *lag* 8 and 9, in which boat and dolphin presence increased simultaneously suggesting the influence of other external factors (**Supplementary Figure 1**).

Whistle Acoustic Structure

A total of 1,996 dolphin whistles were analyzed from the bottom-mounted and research boat hydrophones, 242 whistles from

TABLE 2 | Statistical description of whistle parameters for bottlenose dolphins in two locations of the Archipelago of Bocas del Toro.

Location	Statistics	Whistle Type	Low (kHz)	High (kHz)	Peak (kHz)	Center (kHz)	Delta (kHz)	Duration (s)	PFC Num Inf Pts
AB	Mean (SD)	Overall	6.05 (2.92)	10.37 (4.52)	7.53 (3.26)	7.76 (3.10)	4.32 (3.58)	0.63 (0.55)	25.46 (27.10)
	CV		48.26	43.65	43.33	39.90	83.76	87.60	106.38
n = 133	Mean (SD)	SW	5.63 (2.42)	9.76 (4.13)	7.08 (2.90)	7.30 (2.67)	4.12 (3.46)	0.62 (0.51)	23.7 (24.70)
	CV		43.10	42.43	41.00	36.60	84.02	83.00	104.31
n = 109	Mean (SD)	VW	6.55 (3.36)	11.11 (4.87)	8.10 (3.60)	8.31 (3.50)	4.56 (3.71)	0.64 (0.60)	27.60 (29.68)
	CV		40.00	23.5	30.00	19.28	39.45	46.83	78
DB	Mean (SD)	Overall	5.38 (2.10)	13.80 (3.95)	9.24 (2.94)	9.31 (2.21)	8.42 (4.18)	0.96 (0.71)	234.10 (232)
	CV		38.72	28.66	31.83	23.80	49.70	73.78	99.11
n = 493	Mean (SD)	SW	5.00 (1.97)	14.82 (3.50)	9.34 (2.76)	9.50 (1.90)	9.82 (3.87)	1.27 (0.60)	327 (255.20)
	CV		51.40	44.00	44.42	42.00	81.30	93.00	107.35
n = 1261	Mean (SD)	VW	5.52 (2.10)	13.40 (4.05)	9.20 (3.00)	9.24 (2.34)	7.87 (4.17)	0.84 (0.71)	196.93 (211.32)
	CV		38.10	30.26	32.68	25.37	53.03	84.94	78.34

[Almirante Bay (AB): taxi-boats; Dolphin Bay (DB): tour-boats] for signature whistles (SW) and variant whistles (VW).

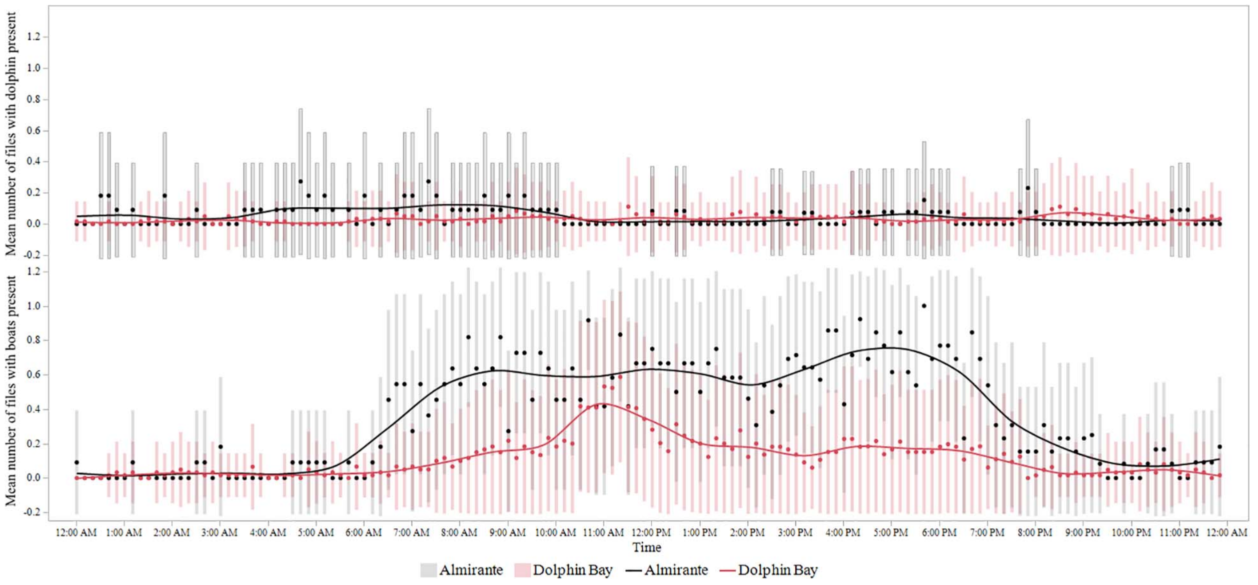

FIGURE 3 | Mean number of 1-min recordings with boat and dolphin sounds by time of day. The horizontal lines represent the mean, and the two-sided bars represent the standard deviation (Almirante Bay = taxi-boats; Dolphin Bay = tour-boats).

Almirante Bay (variant = 109, signature = 133) and 1,754 (variant = 1,261, signature = 493) from Dolphin Bay. **Table 2** summarizes the statistical description of each dolphin whistle acoustic variable by site and whistle type. The multivariate PERMANOVA indicates that the overall dolphin whistle acoustic structure is significantly different between sites (Pseudo-$F_{1, 1995}$ = 529.64, P = 0.001), boat presence (Pseudo-$F_{1, 1995}$ = 75.67, P = 0.001), and whistle type (Pseudo-$F_{1, 1995}$ = 104.94, P = 0.001). **Table 3** shows the PERMANOVA results for each dolphin whistle variable accounting separately for each factor and their interaction. Although they were significant in dolphin whistle frequency and duration between sites, boat presence, and whistle type; the dissimilarity percentage test indicates that about 60% of the variation in whistle acoustic structure was explained by the whistle modulation variables PFC Num Inf Points (site = 39.1%, boat presence = 37.5%, whistle type = 36.8%) and delta frequency (site = 20.1%, boat presence = 18.70%, whistle type = 18.70%). Both modulation variables were significantly higher in Dolphin Bay, when boats were present, and when dolphins produced signature whistles (**Figure 4**).

DISCUSSION

Our results indicate that the nature of the two boat types affects differently the whistle acoustic structure of the residence dolphins. The effect was particularly important in the modulation of their individual signature whistles, highlighting the importance of distinguishing signature from

TABLE 3 | Results from the PERMANOVA on the comparison of dolphin whistle acoustic structure using a Euclidean matrix, log-transformed data, and using 999 permutations.

Whistle variables	Source	Df	Mean square	Pseudo-F	P (perm.)
Low frequency (Hz)	Site	1	1.93	12.28	**0.002**
	Boat presence	1	0.02	0.14	0.702
	Whistle type	1	4.99	31.70	**0.001**
	Site × whistle type	3	5.76	12.20	**0.001**
	Boat presence × whistle type	2	0.44	1.41	0.235
High frequency (Hz)	Site	1	27.77	236.99	**0.001**
	Boat presence	1	0.07	0.62	0.436
	Whistle type	1	3.10	26.48	**0.001**
	Site × whistle type	3	30.58	88.31	**0.001**
	Boat presence × whistle type	2	0.46	2.00	0.130
Peak frequency (Hz)	Site	1	12.45	105.17	**0.001**
	Boat presence	1	3.28	27.74	**0.001**
	Whistle type	1	< 0.01	< 0.01	0.966
	Site × whistle type	3	14.92	< 0.01	**0.001**
	Boat presence × whistle type	2	3.82	< 0.01	**0.001**
Center frequency (Hz)	Site	1	11.68	143.79	**0.001**
	Boat presence	1	0.86	10.56	**0.002**
	Whistle type	1	0.10	1.30	0.240
	Site × whistle type	3	11.68	143.79	**0.001**
	Boat presence × whistle type	2	0.86	10.56	**0.001**
Delta frequency (Hz)**	Site	1	171.85	383.58	**0.001**
	Boat presence	1	0.65	1.46	0.221
	Whistle type	1	27.13	60.57	**0.001**
	Site × whistle type	3	180.85	135.97	**0.001**
	Boat presence × whistle type	2	1.55	1.74	0.167
Duration (s)	Site	1	10.94	120.32	**0.001**
	Boat presence	1	0.03	0.37	0.555
	Whistle type	1	17.20	189.17	**0.001**
	Site × whistle type	3	18.86	70.25	**0.001**
	Boat presence × whistle type	2	0.10	0.55	0.605
PCF Num. Inf. Points**	Site	1	944.0	776.30	**0.001**
	Boat presence	1	163.8	134.66	**0.001**
	Whistle type	1	181.4	149.16	**0.001**
	Site × whistle type	3	987.3	275.56	**0.001**
	Boat presence × whistle type	2	173.5	72.65	**0.001**

*Significant P values are in bold; **variables that together explained ~60% of the dissimilarity between sources.*

variant whistles when studying the effects of boat traffic on dolphin communication.

The mean number of 1-min files with dolphin presence was greater in Almirante Bay than Dolphin Bay throughout the day, however, in Dolphin Bay dolphins produced 4.7 times more whistles per minute than in Almirante. Additionally, in Almirante Bay, the mean number of files with dolphin detections was slightly higher in the early morning when there were fewer boats present, whereas, in Dolphin Bay no significant patterns were found. However, it is important to note that we did not perform propagation experiments, and that differences in dolphin presence (measured as mean number of files with dolphin sounds and number of whistles detected per minute) may be due to differences in substrate characteristics between sites. Quintana-Rizzo et al. (2006) found that in Sarasota Bay, Florida dolphins detection range was limited by noise and substrate characteristics. The authors found that in shallow areas with a mud bottom, Sarasota dolphins whistles could be heard by other dolphins up to 2 km, while in seagrass the acoustic contact was limited to <500 m. Dolphin Bay consists primarily of a muddy bottom, if such substrate allows for greater sound propagating distance as compared to the seagrass in Almirante, that could explain the greater number of whistles detected per minute in this location. Given the importance of bottom type in sound propagation the dolphin detection results should be taken with caution. Finally, it is also important to note that the number of whistle detected per minute can be influenced by a number of factors including group size (Quick and Janik, 2008), behavior and group composition (Hawkins and Gartside, 2010), and direct interactions with boats (e.g., Scarpaci et al., 2000; Buckstaff, 2004;

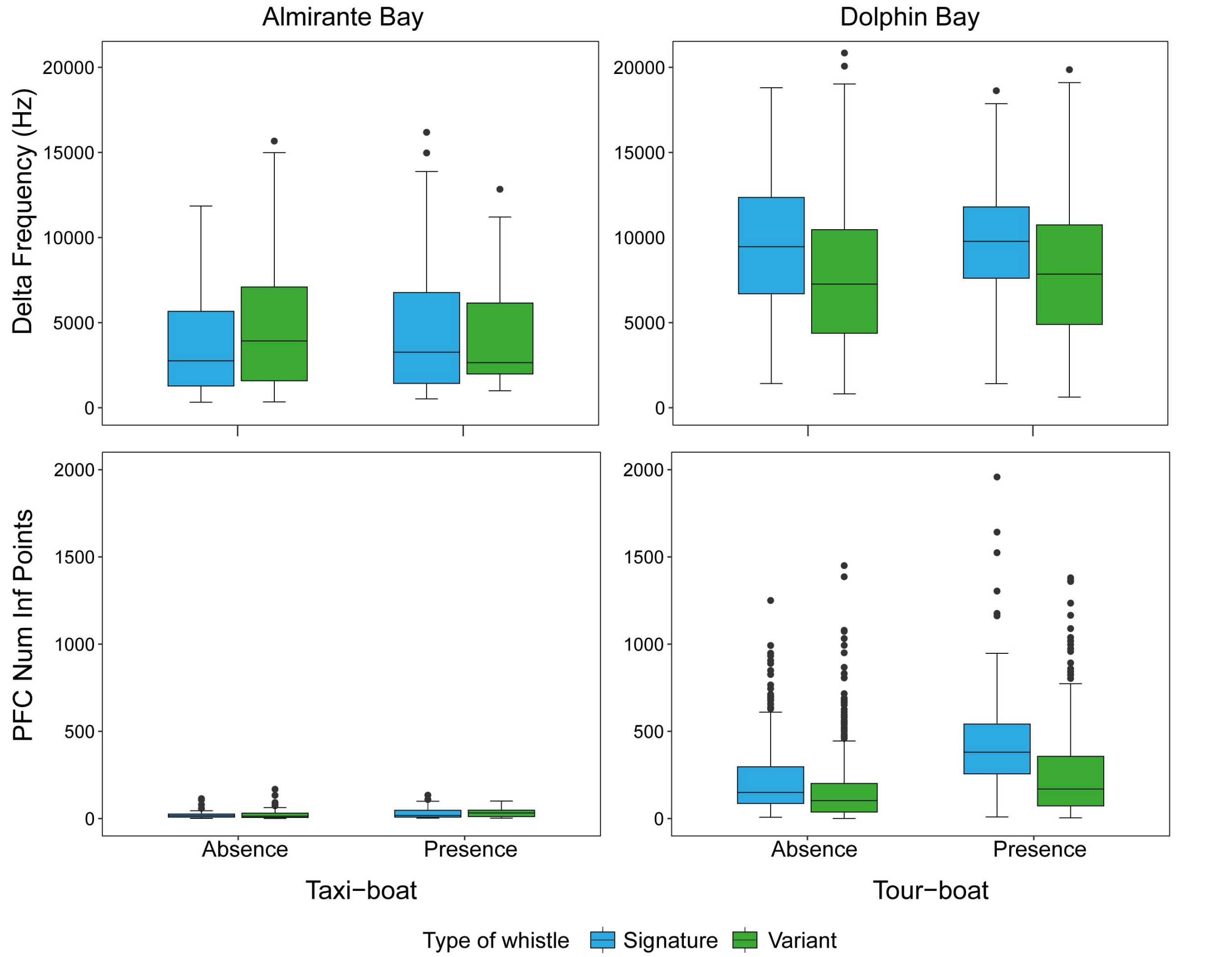

FIGURE 4 | Dolphin whistle frequency modulation measured as delta frequency (Hz) (top panel) and PFC Infl. Points (low panel) by site (Almirante Bay = taxi-boats; Dolphin Bay = tour-boats), whistle type, and boat presence.

Esch et al., 2009; Guerra et al., 2014), all of which we were unable to account for due to the passive acoustic recording nature of the recording system used in this study.

In animal acoustic communication, a sender's signal results in behavioral changes of one or more receivers (Bradbury and Vehrencamp, 2011). However, because the environment in which these animals live can affect signal propagation and detection (e.g., masking), it is expected that they can make frequency and temporal adjustments to optimize signal transmission (Morton, 1975). Such adjustments have been reported in frogs (Velásquez et al., 2018; Bignotte-Giró et al., 2019), birds (e.g., Boncoraglio and Saino, 2007), and some lineages of mammals including bats (Luo et al., 2015), primates (e.g., de la Torre and Snowdon, 2002; Tanaka et al., 2006), and dolphins (e.g., Papale et al., 2015; Fouda et al., 2018). Our results indicate that dolphins in the Almirante Bay and Dolphin Bay make frequency modulation adjustments depending on the type of boat traffic dominating their acoustic space (see **Table 3**). For example, in Almirante Bay, taxi-boat presence is high, spans a period ranging from 6 a.m. to 6 p.m., and follows pre-established routes, resulting in indirect interactions between dolphins and boats. Here, dolphins produced less frequency modulated whistles than those produced by dolphins in Dolphin Bay, the site where tour-boats dominate the acoustic environment. Lower frequency modulation (simpler whistle contours) (Morisaka et al., 2005; Fouda et al., 2018) may counter the masking effects of the background noise made mainly by boats in the contexts of this study, enabling them to communicate more effectively. Rako-Gospiæ and Picciulin (2016) and Morisaka et al. (2005) found similar acoustic plasticity in the bottlenose dolphins of the Cres-Losinj Archipelago in Croatia and Indo-Pacific bottlenose dolphins in Japan, respectively.

In contrast, dolphins in Dolphin Bay emitted whistles with an increase in frequency of ∼2–4 kHz, an average increase of 30 s in duration, and ∼9 times more modulation than the dolphin whistles recorded at Almirante Bay (see **Table 3**). These whistle variables showed lower coefficients of variation than those recorded in Almirante Bay. Similar "shifts" in frequency have been described in other sites (e.g., Papale et al., 2014; Heiler et al., 2016). For example, in Walvis Bay, Nambia, bottlenose dolphins did an upward shift of 1.99 kHz in several whistle frequency variables when they were in the presence of tour-boats compared to the research boat (Heiler et al., 2016). Tour-boats have outboard engines that are loud (149–152 dB re 1 μPa root mean square at 1 m) and broadband (0.2 and 40 kHz) (Jensen et al., 2009), and when boats are present in large numbers (up to 40 boats/h) as in the case of Dolphin Bay, noise levels increase (May-Collado and Wartzok, 2008, 2015).

Although changes in whistle frequency and duration were found between boat presence and absence, most of the variation was explained by whistle frequency modulation (delta frequency and PFC Num Inf Points). Changes in dolphin whistle modulation may provide insights into their "emotional" state during the interactions with tour-boats. Esch et al. (2009), compared signature whistle acoustic structure between brief capture-release (isolation of individuals from the group, including mother-calf pairs) and undisturbed conditions, and found an increase in whistle frequency modulation. The authors suggested that such changes in modulation could indicate stress or alertness. Since increased whistle frequency modulation has been linked to a more stressed emotional state in previous work, and our results found significant increases in whistle modulation between different boat type presence, it is reasonable to assume that Dolphin Bay is a more stressful environment than Almirante Bay. Overall, Dolphin Bay dolphins produced two times more modulated whistles when interacting with tour-boats than when followed by the research boat and when tour-boats were absent. Among the predicted impacts of tour-boats is stress (Rolland et al., 2012). Although the brief capture-release conditions of Esch et al. (2009) might not be representative of the harassment experienced by dolphins in Dolphin Bay during interacting with tour-boats, it may provide insights of their response to separation, which is often the product of the encounters with tour-boats in the bay (May-Collado et al., 2017; Kassamali-Fox et al., 2020).

Using a combination of passive acoustic monitoring data and recordings during focal follows, our study provides information about the variability of boat detections in two sites that contrast on boat activity. We show that dolphins respond differently to each of these boat activities primarily in their whistle acoustic structure. In natural conditions, dolphins' communicative signals are predicted to propagate over tens of kilometers (Janik, 2000); however, in heavily transited habitats such as the ones studied here, dolphins make adjustments in whistle acoustic variables associated with avoidance of signal masking. Furthermore, when accounting for dolphin whistles function (variants vs. signature whistles), our results agree with experimental studies showing a potential association between increase in signature whistles modulation and stress or alertness.

In summary, our results can be translated into mitigation strategies to reduce the impact of tour-boats on Dolphin Bay's dolphins. If tour-boat captains behave more like taxi-boat captains by (1) reducing distance of approach and contact time, (2) reducing the number of boats in contact with the dolphins, and (3) increasing time between interactions, their communication, and "emotional" state would be less disrupted. These measures are contemplated in the national guidelines for whale-watching, which are known to most tour-boat operators. Furthermore, if tour companies make small changes in their schedules when visiting the bay, that could also lead to an important decrease in boats inside Dolphin Bay. Finally, the key for all these mitigation recommendations to work is enforcement. With ongoing efforts to make Dolphin Bay a protected area there is an opportunity for implementing these mitigating strategies and enforcing compliance.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The animal study was reviewed and approved by AICUC #2019-0201-2022.

AUTHOR CONTRIBUTIONS

BP-O, LM-C, and RD contributed to the conception and design of the study. BP-O and LM-C collected field data. BP-O, BP, LM-C, RD, and EG processed field recordings, analyzed the data, and organized the database. LM-C and BP-O performed the statistical analysis. LM-C and BP-O wrote the first drafts of the manuscript. RD, BP, and EG revised and contributed to the draft manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.618420/full#supplementary-material

Supplementary Figure 1 | Cross-correlation function (CCF) analysis between the proportion of boats and dolphins by site. The y-axis represents the cross-correlation coefficient, and the x-axis is the number of time periods (lag) that separate two time series. The horizontal dotted blue lines are the 95% Confidence Intervals. The correlation is considered statistically significant at $p < 0.05$ when the correlation coefficients fall outside these lines.

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frontiers in Marine Science

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Impacts of Whale-Watching on the Short-Term Behavior of Fin Whales (*Balaenoptera physalus*) in a Marine Protected Area in the Southeastern Pacific

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Whale-watching (WW) is an activity which has been increasing worldwide due to the great interest of tourists and the economic benefits it provides to local communities. However, it has been reported that this activity affects the behavioral patterns of some cetaceans, although for some species such as the fin whale (*Balaenoptera physalus*) this has not been extensively studied. To identify the effects of WW on the behavioral patterns of this species, we studied its traveling and resting behaviors in a locality of north-central Chile from 2015 to 2018. Using a theodolite, we calculated the response variables of swim speed, directness index, and reorientation for each behavior. We used the number of WW boats and the WW scenarios of "before", "during", and "after" the presence of boats as possible factors to explain the differences in the response variables of the whales, along with the factors of year, month, group size, and distance from the observation point. Reorientation increased significantly and the directness index decreased significantly for both traveling and resting behaviors from "before" to "during" WW scenarios, indicating more erratic and sinuous movements in the presence of boats. These changes in movement patterns are a commonly reported evasion response of cetaceans to the presence of WW boats. For traveling behavior, the swimming speed significantly increased, and trends showed increased reorientation and a decrease in the directness index in the "after" WW scenario, which suggests perturbation of the whales potentially associated with the speed and the direction in which the boats left. During resting behavior, the trajectories of the fin whales became straighter (decrease in reorientation) as the number of boats increased, thus evasion (more erratic and sinuous movements) is a behavior used less by fin whales as the number of boats increases. Notwithstanding the fact that tourism development in the study area is small in scale, we found that WW generates adverse effects that are reflected in changes in the whales' movement patterns. This kind of information is valuable to the adjustment and/or design of management strategies for the species, which is fundamental for WW to continue to be a sustainable activity.

Keywords: traveling, resting, movement pattern analysis, land-based tracking, tourism effects, Chile

INTRODUCTION

Whale-watching (WW) is one of the fastest-growing tourism industries in a number of countries in recent decades, providing both economic and socioenvironmental benefits. WW has allowed the tourists who take part in it to gain increased knowledge of the biology and diversity of the species of whale seen and the environments in which they live (Filby et al., 2015; Pacheco et al., 2019). Local communities of artisanal fishers who participate in this economic activity benefit by diversifying from their traditional fishing activities, which allows them to increase their sources of income as fishing resources decrease (Parsons et al., 2003; Garrod and Wilson, 2004; Hoyt and Iñíguez, 2008; Guidino et al., 2020). One consequence of this is greater environmental consciousness, which stimulates interest in the conservation and protection of the marine fauna and their habitat (Higginbottom and Tribe, 2004; Zeppel and Muloin, 2008; Schuler and Pearson, 2019), both on the part of consumers (general public) and those who provide the services (e.g., fishers, researchers, businessmen) (Filby et al., 2015; Schuler and Pearson, 2019).

However, there is currently a strong concern over whether WW is an activity that really promotes the conservation of the subject species (Forestell, 2007). It has been widely reported in the literature that inadequate management of WW is an important source of perturbation for the animals, both in the short- and long-term (e.g., Corkeron, 2004; Bejder et al., 2006a; Argüelles et al., 2016; Sprogis et al., 2020b). Important sources of perturbation include a high number of boats in a confined area, very close proximity to the animals, the time and manner of approaching (and leaving) the animals, and lack of regulations or non-compliance with existing norms and regulations (Hoyt and Parsons, 2014). In the short-term, these sources may induce behavioral changes in the cetaceans, some of which may alter biologically important behavior such as feeding (Arcangeli and Crosti, 2009; Christiansen et al., 2013; Lesage et al., 2017) and resting (Avila et al., 2015; Sprogis et al., 2020a,b). Such behavioral variations may produce additional energy costs for the individuals (Williams et al., 2006; Christiansen et al., 2014), affecting their body condition in the medium and long-term, as well as the state of health and the reproductive success of the animals (Lusseau, 2005; Bejder et al., 2006b), which may eventually represent a threat to the conservation of the species exposed to WW (Corkeron, 2004; Lusseau and Bejder, 2007; Parsons, 2012). The other most frequent short-term effect reported is horizontal evasion, indicated by changes of direction in the movement patterns of the animals (Scheidat et al., 2004; Williams and Ashe, 2007; Williams et al., 2009; Schaffar et al., 2013; Schuler et al., 2019). Thus, in the presence of boats, movement patterns become less predictable as linearity decreases (the straight-line trajectory is lost) and reorientation increases (erratic trajectory) in order to evade the boats (Scheidat et al., 2004; Williams and Ashe, 2007; Schaffar et al., 2013). These evasion tactics vary depending on the number of boats and the approach distance (Williams et al., 2009; Schaffar et al., 2013). It has been shown that humpback whales (*Megaptera novaeangliae*) change their trajectory continuously when boats are close (Schaffar et al., 2013). It has been shown that the displacement trajectory of orcas (*Orcinus orca*) becomes more linear as the number of boats increases, indicating that the evasion tactic (increase in reorientation) may not be effective in the presence of a larger number of boats (Williams and Ashe, 2007; Williams et al., 2009). If evasive tactics are not effective, cetaceans must use strategies that are more energetically costly (Morete et al., 2007; Christiansen et al., 2014; Sprogis et al., 2020a,b), such as an increase in the velocity of displacement in the presence of boats (Christiansen et al., 2014; Schuler et al., 2019; Sprogis et al., 2020b). Another energetically expensive tactic used by cetaceans is vertical evasion, in which cetaceans increase their diving time (Stamation et al., 2010; Schaffar et al., 2013) and/or increase the rate of respiration (Christiansen et al., 2014; Schuler et al., 2019).

In Chile, tourism activities involving watching marine fauna and specifically WW are still incipient activities, growing by about 20% per year, with the potential for even greater development (Hoyt and Iñíguez, 2008). There are currently five localities in Chile where this activity is developed formally; Bahía de Mejillones in northern Chile, caleta Chañaral de Aceituno and Punta de Choros in north-central Chile, and caleta Puñihuil and the Francisco Coloane Marine Park in southern Chile (Hoyt and Iñíguez, 2008). Given the growth of the WW industry, the Undersecretary of Fisheries and Aquaculture (Subpesca) of the Chilean government published in 2011 the "General regulations for the observation of aquatic mammals, reptiles and birds and the recording of cetacean sighting" (D.S. No.38/2011; Subpesca, 2011). These regulations established the procedures and general requisites for the observation of these aquatic species, regulating among other aspects, observation distance, the method of approach of boats to the cetaceans and the behavior of tourists during the sightings (D.S. No.38/2011; Subpesca, 2011).

Caleta Chañaral de Aceituno is one of the favorite WW locations of tourists due to the high probability of sighting large cetaceans. This location is visited by a number of large cetacean species in the summer (e.g., blue, fin, humpback, and minke whales; Capella et al., 1999; Pérez et al., 2006; Toro et al., 2016; Sepúlveda et al., 2018). Fin whales are the most commonly observed species in the area (Pérez et al., 2006; Toro et al., 2016; Sepúlveda et al., 2018). The number of tourists visiting this location to participate in WW activities has increased exponentially in the last decade, from approximately 1,200 in the summer of 2010 to approximately 8,000 tourists in the summer of 2020 (Corporación Nacional Forestal, unpublished data). This location contains the Marine Protected Area "Isla Chañaral Marine Reserve" (D.S. No. 150-05; Subpesca, 2005), which has its own regulations for watching marine fauna.

Whale-watching is conducted by artisanal fishers of caleta Chañaral de Aceituno, which has provided an opportunity to expand and diversify their traditional activities (Sepúlveda et al., 2018). Due to the increase in the number of tourists and the importance of the species that visit the area, local authorities have introduced additional regulations in the marine reserve to those of the 2011 regulations, limiting the number of boats and the time they can stay with the animals (Res. Ex. No.655/2020; Sernapesca, 2020). However, in spite of these regulations, and considering the rapid increase of WW activity, to our knowledge, no study has addressed whether the cetaceans at this location are affected by WW and if so, to what degree. This study analyzed the behavioral responses of the fin whale to WW in this locality. The behavioral responses were evaluated using scenarios of WW "before", "during", and "after" the presence of WW boats. The number of boats and other factors such as year, month, group size, and distance from the observation point were also recorded. This study will provide an initial insight into the effects of WW on the fin whale in Chile, a species with known conservation issues.

MATERIALS AND METHODS

Study Area

The study area is located within the Humboldt Current System, in north-central Chile. This is a dynamic and productive coastal environment due to the presence of an important wind-driven coastal upwelling center (Montecino et al., 2006; Thiel et al., 2007). A high diversity of marine fauna has been reported in the area, including birds and marine mammals (Capella et al., 1999; Luna-Jorquera et al., 2003; Pérez et al., 2006; Sepúlveda et al., 2009, 2016), and it has been described as an important feeding area for the fin whale (*Balaenoptera physalus*) during the austral spring and summer (Pérez et al., 2006; Toro et al., 2016; Sepúlveda et al., 2018). These characteristics are what makes caleta Chañaral de Aceituno one of the favorite tourist places in Chile.

The land-based observation station was located on Chañaral Island (29°01′S, 71°36′W), at 52 m above sea level on the eastern edge of the island (**Figure 1**). The observation area includes a zone called "the channel," which is between the island and the continent (**Figure 1**). The largest concentration of tourist boats occurs in this zone as they see the cetaceans on their way to visit the fauna of the island. A portion of the Isla Chañaral Marine Reserve is also within the observation area (**Figure 1**); it has its own rules for WW (Res. Ex. No.655/2020; Sernapesca, 2020) in addition to those rules which apply to the whole country (D.S. No.38/2011; Subpesca, 2011).

Whale-watching is performed by artisanal fishers of caleta Chañaral de Aceituno, a small locality with about 100 inhabitants, located 9 km from the Chañaral island (**Figure 1**). Thirty-nine boats have formal permission to perform WW in the Marine Reserve, but in practice less than 20 boats perform these activities. The boats used are up to 10 m in length, with motors of up to 150 hp.

Data Collection

The study was carried out during the months of January and February annually, from 2015 to 2018. Observations were performed from 09:00 to 18:00 when weather conditions provided good visibility to ensure reliable data collection (Beaufort Sea state of 3 or less, with no coastal fog or rain). The viewing area covered approximately 180° and was scanned with either the naked eye or binoculars (10 × 42) (**Figure 1**).

Spatial movement patterns of fin whales were monitored using a Spectra Precision Model DET-2 digital theodolite with 30-power monocular magnification and 2 s precision. This method has been widely used to follow whales from land stations and has proven to be successful to estimate the position of a whale at a given time (e.g., Würsig et al., 1991; Scheidat et al., 2004; Schaffar et al., 2013; Pirotta et al., 2016). This also allowed the recording of changes in behavior of the animals in the presence and absence of tourist boats without the researchers interfering in the natural behavior of the whales (Würsig et al., 1991; Morete et al., 2018).

When an individual or a group of fin whales was sighted, scanning was suspended and a theodolite tracking session and a focal follow was initiated (i.e., tracking a single individual or group of fin whales at a time) (Altmann, 1974; Mann, 1999), both in the presence or absence of WW boats. A group was defined as two or more individuals that surfaced synchronously within 100 m of one another (Whitehead, 1983; Corkeron, 1995). Individuals or groups of whales were followed and sampled continuously using the description of the focal protocol given here. Focal follows were carried out by a team of three experienced observers: a theodolite operator, a spotter, and a data scorer. During the focal follow activities, the spotter announced the surfacing event of the focal group, the theodolite operator located its position, and the scoring observer recorded the time, the surface event, the behavior (traveling or resting, see below), the vertical and horizontal angles provided by the theodolite, the group size, the presence or absence of WW boats, and the number of WW boats. The whale's position (vertical and horizontal angles) was recorded every minute (or after the whale came to the surface) (Schaffar et al., 2010). To follow groups, the

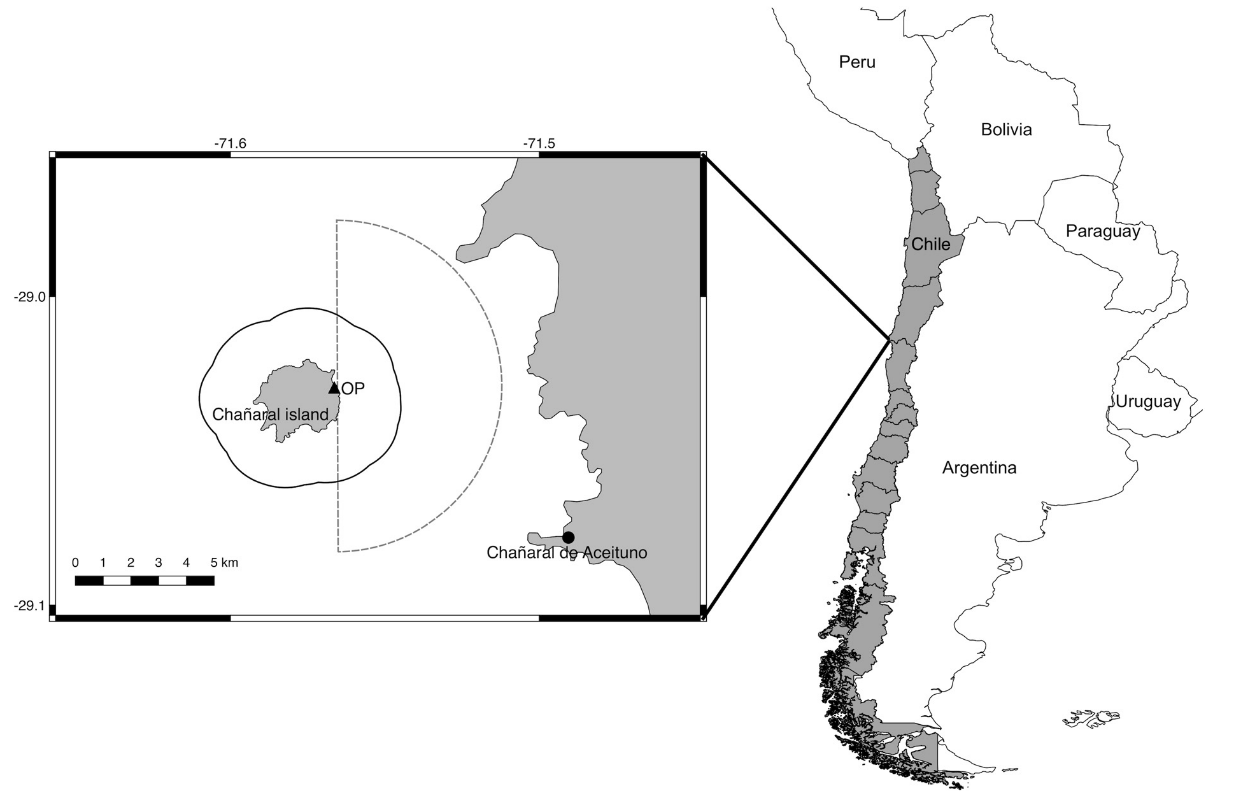

FIGURE 1 | Location of the study area. The black triangle indicates the land-based observation point (OP) and the black circle is the location of the caleta Chañaral de Aceituno. The black line indicates the limit of the Isla Chañaral Marine Reserve and the dashed line indicates the area of observation.

position of the first whale that came to the surface was recorded. Each whale or group of whales was tracked continuously until the animal was no longer visible, or environmental conditions prevented further tracking. WW boats were considered present and included in the analysis when they approached a whale in a straight line or parallel, according to the direction of the whale, at an estimated distance of 500 m from the animal. These methods are appropriate for fin whales since this species dives for short periods of time (<10 min) (Croll et al., 2001) being easy to follow. Also, in the study area fin whales occurred frequently, both singularly or in small groups (approximately three or four whales) (Toro et al., 2016), which reduce the risk of confusing individuals or groups.

The behavior of fin whales was classified into the categories of traveling or resting, based on specific behavioral events observed (Brown et al., 1994). The category of traveling was considered when an individual or group of whales were moving and oriented in the same direction, displaying a quasi-linear trajectory with sub-surface constant swimming without stopping (Brown et al., 1994), while resting was considered when an individual or group of whales was stationary and all members were oriented in the same direction (Brown et al., 1994). Although feeding behavior does occur in the study area (Pérez et al., 2006; Toro et al., 2016; Sepúlveda et al., 2018), this behavior was rarely recorded in the observation area, and therefore was not analyzed.

The information was digitized and entered into the VADAR software (Visual and Acoustic Detection and Ranging, developed by Eric Kniest). This software uses angles from the theodolite, together with the height of the station and the equipment to calculate the position of the focal individual or group. All observational information, including the exact time of each surfacing event and behavior, was imported to VADAR. From this process we obtained the behavioral response variables of: (1) swim speed, (2) reorientation, and (3) directness index (Harcourt et al., 2014). The swim speed (km h^{-1}) of a whale or group of whales was measured as the time (in hours) taken to cross the distance (in kilometers) between two consecutive sightings (Pirotta et al., 2016). Reorientation measures path predictability from one surfacing to the next, and it is defined as the change in the direction of movement of the individual or group (Williams et al., 2002). This measure is the angle between the path taken during a dive and the predicted straight-line path as indicated by the direction of the dive before it, ranging potentially from 0° to 180° (Williams et al., 2009). Low reorientation values indicate a smooth path, while high values indicate an erratic path (Williams et al., 2002). Finally, the directness index is defined as the path predictability of the whales over the length of the tracking session. This index is measured as the straight-line distance between the first and the last fix of a tracking session divided by the cumulative surface distance covered by the group (Williams et al., 2002), and it ranges from 0 (circular path) to 1 (straight line).

The three behavioral response variables were given by VADAR for each whale position fixed with the theodolite throughout a tracking session.

For statistical analyses, only theodolite tracking ≤6 km from the station was considered to ensure reliable data for analysis (see Würsig et al., 1991 for height-related errors). A follow event was only considered viable when an individual or group of whales was tracked for at least 15 min and/or at least five surfacing bouts (modified by Scheidat et al., 2004; Schaffar et al., 2010). These tracks allowed a representative sample of the whales' behavior (Schaffar et al., 2013).

Statistical Analyses

For the behaviors of traveling and resting, we modeled swim speed, reorientation, and directness index in response to the additive effects (i.e., no interactions) of: year (factor; 2015–2018), month (factor; January and February), distance from observation point (km), group size, and number of WW boats. In addition we included three levels of WW scenarios as a predictive variable; (1) "before" the arrival of the boats; (2) "during", when one or more boats were present with the whale(s); and (3) "after" the boats had left the area in which the whale(s) were located (Scheidat et al., 2004; Avila et al., 2015). For the response variable swim speed we used a normal distribution and for the variables of reorientation (i.e., proportion of 90° of reorientation) and directness index we used a beta distribution with a logit link. For all response variables we modeled only the location parameter of the chosen distribution (*mu*, i.e., mean). For model selection we used information-theoretic model comparison. Specifically, we carried out the selection of the best model in the set using stepwise model selection based on the generalized Akaike's information criterion (GAIC) with a penalty of $k = 3$ (>AIC and <BIC). The GAIC is a generalization of AIC to evaluate parsimony, which penalizes the deviance by a factor k (positive real number) the number of degrees of freedom in the model (i.e., GAIC = $k \times Df + D$), unlike AIC where k is fixed and equals two (Stasinopoulos et al., 2017). In addition, for all best models a Generalized (Pseudo) R-squared test was calculated (Nagelkerke, 1991). Models fitting, selection and diagnoses (based on residuals plots; Dunn and Smyth, 1996) were done using the gamlss package (Rigby and Stasinopoulos, 2005) of R (R Core Team, 2018). For multiple comparisons across factor levels, we used Tukey's *a posteriori* HSD test available in the emmeans package of R (Lenth et al., 2018). To avoid co-linearity problems during the modeling process we dropped variables with a variance inflation factor >2 (Zuur et al., 2010). Specifically, for the models of reorientation during traveling behavior and directness index during resting behavior we excluded the variable number of WW boats and for the model of reorientation during resting behavior we excluded the variable group size, due to the high level of collinearity that this variable presented with the variable of greatest interest, i.e., WW scenarios. Marginal effects from final models (i.e., predicted values for certain model terms by holding the non-focal variables constant) were also estimated using the emmeans package. We produced figures using the R package ggplot2 (Wickham, 2016).

RESULTS

Observation Effort

We spent a total of 94 days in the field, with a total of 684 h of observations. During that time, 34 effective focal follow events were usable, 24 for traveling and 10 for resting behaviors. We recorded 12 focal follows for traveling behavior that included the "before" WW scenario, 16 that included "during" WW scenario and eight that included the "after" WW scenario. For resting behavior, we recorded four focal follows "before" WW scenario and seven "during" WW scenario. Since the observed whales were no longer resting after WW, it was not possible to record data for this behavior in this instance.

More than half of the records for traveling and resting (57 and 55%, respectively) had boats present. Most of the observations were with the presence of a single boat (48% traveling, 68% resting), with smaller proportions in the presence of two (42% traveling, 17% resting) or three (10% traveling, 15% resting) boats.

Traveling Behavior

For swim speed during traveling behavior, the most parsimonious model contained the predictive variable of WW scenarios and accounted for 3% of the total variation (**Table 1**). There was a significant increase in swim speed in the "after" WW scenario (Tukey *post hoc*; $P < 0.05$, **Figure 2A**). The best model for reorientation included WW scenarios, year, and distance from observation point, and accounted for 32% of the total variation (**Table 1**). There was an increase in reorientation "during" and "after" WW scenarios compared to "before" (Tukey *post hoc*; $P < 0.001$, **Figure 2B**). The greatest values of reorientation were from 2016 (Tukey *post hoc*; $P < 0.05$, **Figure 2C**). Reorientation decreased as the distance from the observation point increased (slope and 95% CI in logit scale = -0.08 [–0.14, –0.01], $P < 0.05$, **Figure 2D**). The best model for the directness index included the predictive variable WW scenarios and accounted for 14% of the total variation (**Table 1**). The directness index decreased "during" and "after" WW compared to "before" WW (Tukey *post hoc*; $P < 0.001$, **Figure 2E**).

Resting Behavior

For swim speed during resting behavior, the most parsimonious model included distance from observation point and accounted for 8% of the total variance (**Table 1**). Swim speed increased together with the distance from the observation point (slope and 95% CI = 0.42 [0.12, 0.73], $P < 0.05$, **Figure 3A**). The best model for reorientation contained the predictive variables year, WW scenarios and number of WW boats, and accounted for 47% of the total variance (**Table 1**). The greatest values for reorientation occurred in 2017 (Tukey *post hoc*; $P < 0.05$, **Figure 3B**). There was significant higher reorientation "during" WW scenario than "before" ($P < 0.001$, **Figure 3C**). Also, reorientation decreased as the number of WW boats increased (slope and 95% CI in logit scale = –0.32 [–0.49, –0.16], $P < 0.001$, **Figure 3D**). The best model for the directness index included WW scenarios and group size, and accounted for 8% of the total variation (**Table 1**). There

TABLE 1 | Results from the backward stepwise model selection of swim speed, reorientation, and directness index for traveling and resting behaviors of fin whales.

Behavior	Response	Step	Df	Dev.	Resid.Df	Resid.Dev	GAIC
Traveling	Swim speed	Full model			193.00	830.72	863.72
		Distance	1	0.00	194.00	830.72	860.72
		Year	3	6.51	197.00	837.23	858.23
		Month	1	0.05	198.00	837.28	855.28
		Group size	1	0.04	199.00	837.32	852.32
		No. boats	1	0.63	200.00	837.95	849.95
	Reorientation	Full model			194.00	−720.86	−690.86
		Group size	1	0.02	195.00	−720.84	−693.84
		Month	1	0.05	196.00	−720.78	−696.78
	Directness index	Full model			193.00	−666.29	−633.29
		Year	3	2.58	196.00	−663.71	−639.71
		Group size	1	0.11	197.00	−663.60	−642.60
		No. boats	1	0.45	198.00	−663.15	−645.15
		Distance	1	0.99	199.00	−662.16	−647.16
		Month	1	2.48	200.00	−659.68	−647.68
Resting	Swim speed	Full model			75.00	295.95	325.95
		Year	3	2.04	78.00	297.98	318.98
		Group size	1	0.00	79.00	297.98	315.98
		WW scenarios	1	0.69	80.00	298.68	313.68
		No. boats	1	1.50	81.00	300.18	312.18
		Month	1	2.15	82.00	302.33	311.33
	Reorientation	Full model			76.00	−317.92	−290.92
		Month	1	0.32	77.00	−317.60	−293.60
		Distance	1	2.07	78.00	−315.53	−294.53
	Directness index	Full model			76.00	−191.23	−164.23
		Year	3	2.62	79.00	−188.61	−170.61
		Month	1	0.03	80.00	−188.58	−173.58
		Distance	1	0.08	81.00	−188.50	−176.50

It is shown an "anova" table corresponding to the steps taken in the search of the most parsimonious model (i.e., starting from the full model, each step shows the dropped variable). Df, degrees of freedom; Dev, deviance; Resid.Df, residual degrees of freedom; Resid. Dev, residual deviance; GAIC, Generalised Akaike's Information Criterion.

was a significant decrease in the directness index "during" WW compared to "before" ($P < 0.001$, **Figure 3E**). Directness index increased as the group size increased (slope and 95% CI in logit scale = 0.21 [0.01, 0.42], $P < 0.05$, **Figure 3F**).

DISCUSSION

The development and increase in WW has generated extensive discussion on the benefits and disturbance it produces. The economic and socio-environmental benefits have been widely recognized (e.g., Filby et al., 2015; Schuler and Pearson, 2019). However, there is growing evidence of the negative effects of tourism on the conservation of the species (Parsons, 2012; Higham et al., 2016). Considering the sustained increase in WW in the past few decades in a number of countries (Hoyt and Parsons, 2014; Schuler et al., 2019), monitoring of the effects of WW activity on subject species is fundamental to identify potential short-term perturbations with potential medium- and long-term consequences. Our study provides relevant information about the impact of WW on the behavior of the fin whale, a species poorly known in this topic, using a technique that does not interfere in the dynamics of tourism or in the behavioral response of the animals (Würsig et al., 1991; Morete et al., 2018; Piwetz et al., 2018).

Model results indicated that reorientation increased for both traveling and resting behaviors, while the directness index increased between the "before" and "during" WW scenarios. This means that in the presence of boats whales were making constant changes of direction and erratic movements, losing the movement linearity that they displayed before the boats arrived. These changes in the reorientation and directness index have been reported previously as responses of cetaceans to the presence of boats (e.g., Scheidat et al., 2004; Schaffar et al., 2013; Avila et al., 2015; Senigaglia et al., 2016; Sprogis et al., 2020a,b). Frid and Dill (2002) suggested that the alteration in the natural behavior of the animals in the presence of anthropogenic perturbation is produced because the animals perceive these perturbations similarly to a predation risk. For example, the minke whale (*Balaenoptera acutorostrata*) uses similar evasion tactics in response to the presence of tourist boats as in the presence of its natural predators orcas (Christiansen et al., 2013). This suggests that cetaceans could identify the presence of boats as a threat (Christiansen and Lusseau, 2014), resulting in the onset of avoidance behaviors.

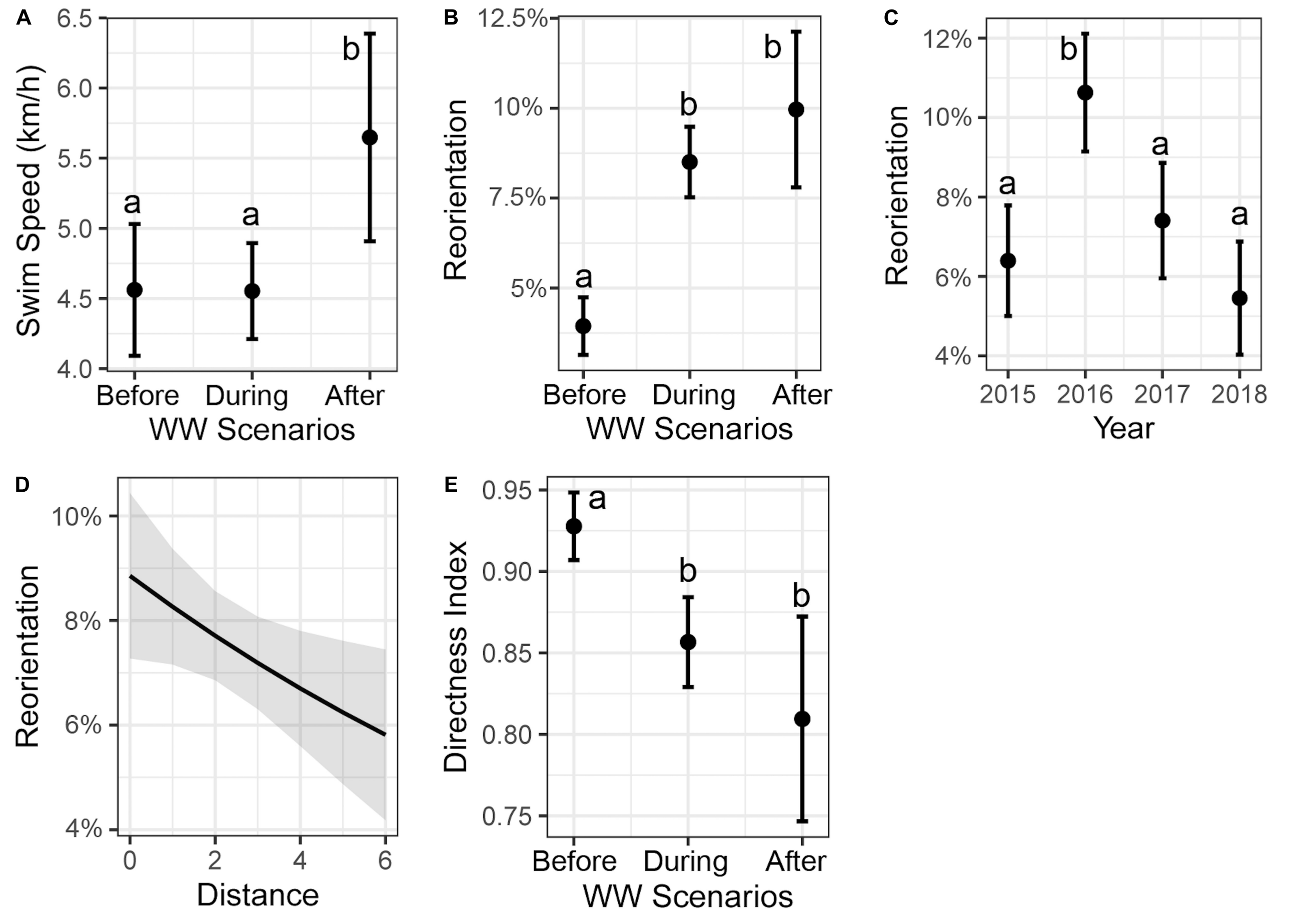

FIGURE 2 | Marginal effects (mean ± 95% confidence interval) from predictors of the best model for **(A)** swim speed, **(B–D)** reorientation, and **(E)** directness index during traveling behavior of fin whales. Different letters indicate significant differences between groups (Tukey *post hoc*; $P < 0.05$).

Although the model with the most support for swimming speed had low explicative power, it identified a significant increase in the "after" WW scenario during traveling behavior; i.e., the swim speed of the whales increased after the boats had left the area. An increase in the reorientation and a decrease in the directness index in the "after" WW scenario were also observed. In contrast to these results, different studies have indicated that once the boat visits had finished, the whales returned to their initial behavior after a short time (e.g., Scheidat et al., 2004; Avila et al., 2015). The persistence, and even accentuation of the perturbation of behavior when the boats had left may be related to the behavior of the boat operators after the sighting had finished. Our field observations indicate that the boats would leave the area at high speeds, and sometimes passing in front of the animal. These two factors may be affecting the whales even more than the presence of the boats, since the animals accentuate the evasion strategy, increasing their speed and following less predictable trajectories, after the boats leave. The negative effect of high-speed boats has previously been described, showing that this factor limits the ability of the whales to avoid them (Parsons, 2012). Additionally, considering that the noise of the boats generated by the propeller cavitation produces adverse reactions in whale behavior (Erbe et al., 2019), and that more noise is produced at higher speed (Walker et al., 2019), the behavioral change of the animals may be due to the increase in the boats speed. Although we did not use the speed and path direction of the boats moving away as predictive variables, there is evidence that these variables negatively impact the behavior of large cetaceans (Heckel et al., 2001; Argüelles et al., 2016; Fiori et al., 2019), since this avoidance strategy increases the energetic cost for the animals (Williams et al., 2009; Christiansen et al., 2014; Sprogis et al., 2020b). We recommend that future studies incorporate other variables to describe the boat behavior, such as speed and direction of arriving and departing boats, to identify other potentially relevant factors in the responses of fin whales to WW.

The only model that included the number of boats as a significant variable was reorientation during resting behavior, indicating that the trajectories of the fin whales in this behavior became more direct (decreasing reorientation) as the number of boats increased. The behavior of maximizing linear movement as the number of boats increased was described previously in orcas, indicating that evasion responses (erratic and more sinuous movements) are employed when there are few boats, and by

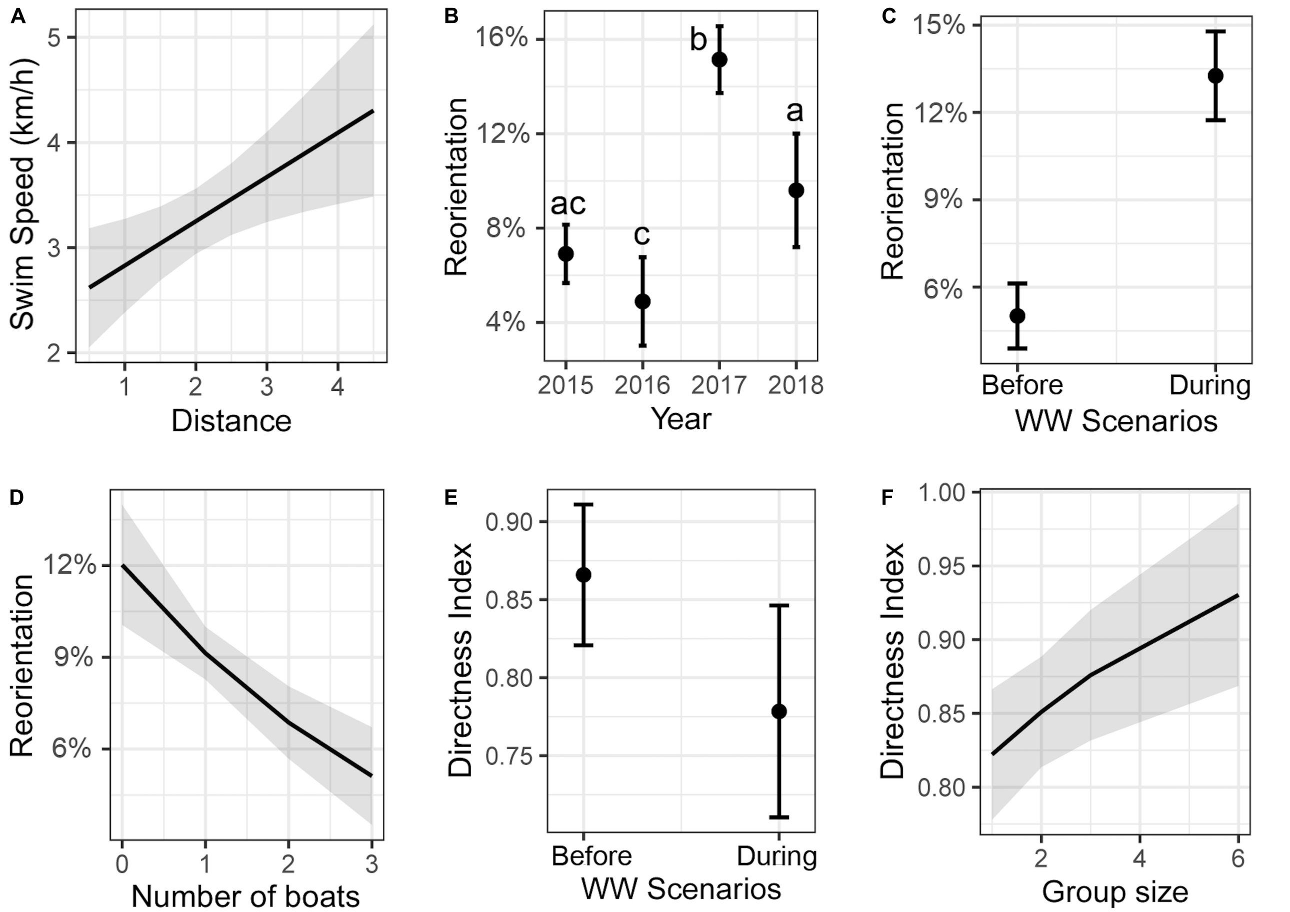

FIGURE 3 | Marginal effects (mean ± 95% confidence interval) from predictors of the best model for **(A)** swim speed, **(B–D)** reorientation, and **(E,F)** directness index during resting behavior of fin whales. Different letters indicate significant differences between groups (Tukey *post hoc*; $P < 0.05$).

contrast, when the number of boats increases the animals choose a more linear trajectory to move away (Williams et al., 2002, 2009). Although the maximum simultaneous number of boats near a whale or group of whales was considerably smaller in this study compared to the report of Williams et al. (2009) (3 versus 14 boats), our results suggest the effect was similar to that reported for a high number of boats. This suggests that maintaining a low number of boats near an individual or group of whales is crucial to avoid drastic changes in the behavioral responses of the fin whale. This is especially relevant and reinforces the current measures in the Isla Chañaral Marine Reserve, which permit a maximum of two boats per whale or group of whales.

Our study shows that the behavioral responses of the fin whales are directly influenced by the WW activities. However, it must be noted that environmental and/or social factors could also contribute to these responses (Yazvenko et al., 2007; Gailey et al., 2016; Kavanagh et al., 2017), and may be related to the low explicative power (less than 10%) of some of the models. These include environmental factors such as wind speed, depth, time of day, distance to the coast (Yazvenko et al., 2007; Williams et al., 2009; Kavanagh et al., 2017); intraspecific factors such as age, sex and group size (Williams et al., 2009; Kavanagh et al., 2017); and others associated with tourist activity, such as distance and speed of approach and departure and path of approaching (Williams et al., 2009; Schaffar et al., 2013), among others. For instance, our study found that reorientation during traveling behavior decreased as the distance between the observation point and the animals observed increases. This result may not be related to WW, but rather explained by the increase in depth in the study area farther from the coast (Gaymer et al., 2008). More direct movement by the whales may facilitate less energetically costly travel in deeper areas (Gailey et al., 2016). This demonstrates that the behavioral responses of cetaceans are difficult to analyze, since they are influenced by many variables, which are often not linear (Williams et al., 2009). Due to this complexity, it is important to evaluate how environmental and/or social factors affect the behavioral responses of the whales (without anthropogenic factors), in order to identify if these responses could be attributed to natural factors or to anthropogenic disturbances (Kavanagh et al., 2017). Some of the environmental parameters for this specific study would be the depth, swell height, and wind speed that have been reported as relevant variables in other studies of whales (Gailey et al., 2016; Kavanagh et al., 2017).

Tourist development in caleta Chañaral de Aceituno is still at a low scale compared to other WW areas, both national and international, due to the small number of visitors (although this is increasing), and the use of small boats (Sepúlveda et al., 2016). In spite of this, we showed that even in this stage of development WW generates adverse effects on fin whales. Although this study only considered short-term behavioral changes, it is important to consider that behavioral changes in the whales may also result in long-term negative effects (Parsons, 2012; Schuler et al., 2019). Alterations in essential behaviors such as resting, feeding, continuous changes in direction and increased swimming speed to avoid boats produce an increase in energetic costs (Bain et al., 2014; Christiansen et al., 2014), which may cause deterioration in the physical condition of the animals if prolonged over time (Beale, 2007). This study area is important for the fin whale, since it is a recognized feeding zone on the Chilean coast (Pérez et al., 2006; Toro et al., 2016; Sepúlveda et al., 2018). Photo-identification has shown that some individuals stay in the area for weeks and even months, and some individuals return in different years (Toro et al., 2016), thus the perturbation by WW may not only be momentary, but rather some animals may be exposed to these perturbations frequently and over an extended period of time. Although we do not know the extent of the exposure of individuals to the WW activities (e.g., maximal daily exposure of the whales to the boats, proportion of the fin whale population that is being affected by WW), and the potential long-term effect of the observed changes in the behavior of fin whales, we do encourage the use of precautionary principle for minimizing impacts by adopting the codes of best practices from the beginning. Future studies should evaluate the level of exposure by relating information regarding permanence pattern and habitat use by fin whales, together with data from tourism activity (e.g., area covered by a boat during a tourist trip, number of boats).

The study area of caleta Chañaral de Aceituno has unique characteristics that make it an optimal location for WW. It is a recognized feeding area for the fin whale and other small and large species of cetaceans, several of which face conservation issues (Capella et al., 1999; Pérez et al., 2006; Toro et al., 2016; Sepúlveda et al., 2018). It is a marine protected area which can implement its own regulations, and tourism is at a small scale performed by artisanal fishers who have important knowledge of the local fishing resources and tourism, as well as identity and sense of belonging to the area (Sepúlveda et al., 2016). The results obtained in this study should be considered in the adjustment of the existing management tools and in the design of new complementary conservation strategies, to increase the balance toward the positive aspects of WW, as has been demonstrated in other places (e.g., Península Valdez; Chalcobsky et al., 2017). Artisan fishers are key actors to include in the design of cetacean's conservation strategies. Given the importance of the conservation of the fin whale for their well-being, increasing the level of understanding is relevant to offer sustainable tourism services in the long term (Mace, 2014). Knowledge of whale behavior and responses to WW are critical to ensure the sustainability of tourism activity in this locality.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because the study was carried out through land-based observations, so there was no manipulation or any intervention in natural behavior of whales.

AUTHOR CONTRIBUTIONS

MS-C and MS wrote the manuscript text, while all authors wrote, reviewed and edited the manuscript text. MS-C, GP, and MS contributed to the project design and funding acquisition. MS-C, FB, and LG contributed to the investigation methodology, field work, and data processing. MP-A contributed to the investigation methodology and ethology. CC contributed to the conservation approach. HA and CA contributed to the formal analysis. All authors listed have made a substantial, direct and intellectual contribution to the work.

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Understanding Effects of Whale-Watching Vessel Noise on Humpback Whale Song in the North Pacific Coast of Colombia With Propagation Models of Masking and Acoustic Data Observations

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Soundscapes with minimal anthropogenic noise sources are key for the survival and effective communication of marine mammals. The Gulf of Tribugá is part of the breeding ground for humpback whale Stock G. Currently, no large-scale infrastructure exists on the Gulf's coastline, making it an area with high biodiversity and little anthropogenic noise. Whale-watching is one of the few human activities that contributes to the soundscape. By Morro Mico, on the southern limit of the Utría Natural National Park, an Ecological Acoustic Recorder (EAR, Oceanwide Science Institute) was deployed in the Gulf to record samples of acoustic activity from October to November 2018. It recorded for 10-min intervals with 20-min lapses for a duty cycle of 33.3%. One of the common peak frequencies of humpback whale song units from these recordings was used as input to an acoustic propagation model using the parabolic equation to simulate the communication space of a humpback whale when zero, one, and two boats are present. GPS positions of theodolite data from various whale watching scenarios in the Gulf were used to inform the models. Model results indicate that humpback whale song communication space could be reduced by as much as 63% in the presence of even one whale-watching boat. The boats traveling through the Gulf are the same as those used in whale-watching, and their engine noise while passing Morro Mico coincided with song structural and temporal changes observed in the acoustic data. Combining *in situ* data with acoustic models can advance the understanding of the spatio-temporal acoustic reactions of whales when their vocalizations are masked by boat noise. This project serves as an approximation of how humpback whale Stock G may respond to whale-watching vessel noise in the Gulf of Tribugá.

Keywords: Gulf of Tribugá, Colombia, inter-unit interval, whale-watching, humpback whale song, masking, propagation modeling

1. INTRODUCTION

Anthropogenic noise has increased in recent years as a result of human population growth, transportation network expansion, urbanization, and resource extraction (Shannon et al., 2016). In the ocean, anthropogenic noise has also increased as shipping lanes have expanded (McDonald et al., 2006; Hildebrand, 2009). Non-shipping human-generated noise sources such as seismic surveys, pile driving for off-shore construction, and military activities also contribute to underwater noise (Tougaard et al., 2009; Wright, 2014). As a result, human-generated noise often overlaps (masks) biological sounds in time and frequency, which could mean a loss of communication space for marine fauna (Cholewiak et al., 2018). For the purposes of this paper, masking is defined as a situation when noise interferes with an animal's ability to detect, interpret, and/or discriminate a sound (Fletcher and Munson, 1937). Because of masking release strategies (Erbe et al., 2016), this is not always <0 dB signal-to-noise ratio (SNR) over the same frequencies at the same time. However, we use "masked" as one of the SNR range labels in the model output and this will be discussed more thoroughly in section 3.2.

Acoustic signals are important for marine animals because they facilitate biological and ecological processes such as navigation, communication, and habitat selection (Haver et al., 2019). Marine mammals rely on the ability to detect meaningful signals from conspecifics, echoes from prey, or natural sounds that facilitate navigation, socializing, and foraging (McDonald et al., 2008). Since acoustic signals are the primary modality used by these animals, increasing noise pollution could affect their behavior, potentially reducing their access to important habitats, interfering with finding mates, reducing protective contact calling with offspring, or detecting prey. Furthermore, sustained acoustic pollution has been shown to increase stress hormone levels, causing harm by compromising the immune system and affecting an organism's health and reproductive success in the long term (Fair and Becker, 2000; McDonald et al., 2008; Rolland et al., 2012).

Humpback whales (*Megaptera novaeangliae*) are found in all major oceans and migrate long distances, depending on highly productive feeding grounds in high-latitude areas during the summer months for sustenance, and spending the winter months in low-latitude breeding grounds giving birth to their young and mating (Clapham, 1996, 2000). They are known for their evolving vocal display called "song," which is one of the most complex acoustic displays in the animal kingdom (Payne and McVay, 1971; Stimpert et al., 2012). Song is performed by males, predominantly on the breeding grounds (Stimpert et al., 2012), but also heard along migration routes and on the feeding grounds (Mattila et al., 1987; McSweeney et al., 1989; Clapham and Mattila, 1990; Clapham and Mead, 1999; Norris et al., 1999; Herman, 2017). Although the function of song is still a source of debate among experts, one possibility states that it could attract females to singers in a lekking arena or mediate interactions between males, making it particularly important for breeding functions (Herman, 2017).

Global humpback whale breeding areas have been impacted by noise pollution from human activities (Au and Green, 2000) like whale-watching tourism (Parsons, 2012) and shipping (Hildebrand, 2009; Tsujii et al., 2018). Boat noise has been found to reduce communication space, leading to chronic effects on populations (Putland et al., 2018). Marine shipping, particularly large ocean container ships, hydrocarbon transport, and cruise ships, is a recognized and persistent anthropogenic source of low-frequency ocean noise, contributing to the masking of essential sounds produced and heard by marine mammals and fish (Weilgart, 2007; Hatch et al., 2008; Hildebrand, 2009; Erbe, 2012; McKenna et al., 2012; Merchant et al., 2014; Williams et al., 2015). In this study's field site only small vessels that are commonly used in transport, artisanal fishing, and whale-watching are present (Rueda, 1997), so this manuscript will focus on masking effects from such vessels.

When vessel traffic noise and humpback whale song are both primary contributors to the soundscape, like in the Colombian Pacific during breeding season, overlap in time and frequency exists between the two sound sources (Heenehan et al., 2019). Humpback whales have been documented to decrease the number of bottom-feeding events per dive and reduce feeding dive descent rate as the intensity of ship noise increases, indicating that ship noise can impact foraging rates and efficiency (Blair et al., 2016). Furthermore, boat direction, speed, and passing frequency are correlated with changes in humpback whale behaviors like respiration rate, diving, swimming speed, communication, and social interaction (Bauer and Herman, 1986; Au and Green, 2000; Scheidat et al., 2004; Sousa-Lima and Clark, 2008; Stamation et al., 2010). Some animals respond to band-limited noise by changing the frequencies of their vocalizations to shift away from the potential effects of masking (Tyack, 2008; Kaplan and Mooney, 2015). In addition to correlating with detrimental behavioral changes and masking song, fishing and tourism-based whale-watching vessels have also been shown to mask the social sounds used by humpback whale competitive groups and mother and calf pairs (Cholewiak et al., 2018).

Along the coast of the Eastern Tropical Pacific Ocean, whale watching activities occur during the humpback whale breeding season because their exciting surface behaviors, like breaching, are easily visible for tourists to view (Darling and Berube, 2001). The effects of noise from whale-watching vessels have been researched in several areas of the world (Parsons, 2012). In South America, studies have found a variety of responses of humpback whales to whale-watching activity, but most are limited to visual observations of surface behaviors (Scheidat et al., 2004; Sousa-Lima and Clark, 2009; Avila et al., 2015). Other studies investigated the whales' interactions with noise generated by humans (Sousa-Lima and Clark, 2008). There is currently a lack of studies on acoustic reactions of humpback whales to whale-watching vessels on the South American Pacific Coast. More specifically, no acoustic studies of the effects of whale-watching on humpback whales have been conducted on the Pacific Coast of Colombia where the breeding ground is surrounded by a coastline not heavily populated by human infrastructure.

The region of Chocó, Colombia, is sparsely populated with small artisanal fishing villages and few roads. The only way to arrive to this Northwestern Colombian coastal area is by small

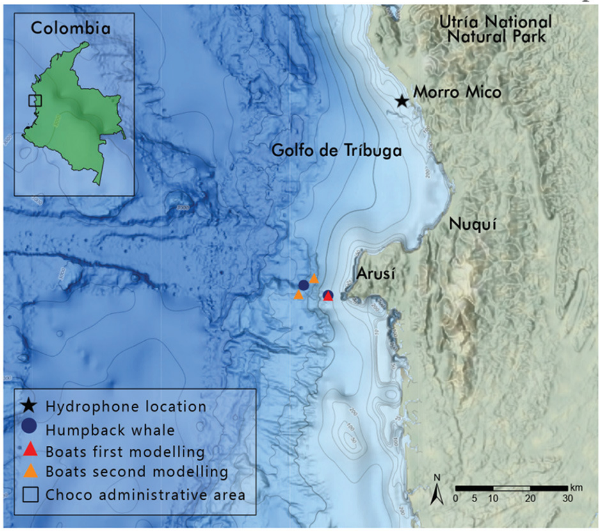

FIGURE 1 | Map of recording site: Morro Mico, Chocó, Colombia. Triangles mark the locations of boats in both models; circles mark the locations of humpback whales in both models. Boats and whales were the source locations in the models. A star marks the deployment location of the EAR (color online).

aircraft over an Andean Corridor from Medellín or Bogotá or by overnight boat from Buenaventura. This creates an ecotourism haven. The region is also void of shipping lanes. The Gulf of Tribugá, located in the northern Colombian Pacific, is part of the breeding grounds for humpback whales belonging to the breeding Stock G between the months of May and December (Avila et al., 2020) (**Figure 1**). It is an opportunistic location to study the effects of whale-watching boats since, compared to other coastal areas, it contains a small variety and a low density of motorized vessels. Families use either dug out canoes or small fiberglass boats with outboard motors to travel between villages, fish, and provide SCUBA and/or whale-watching tours. Once a week a fuel boat (about 40 m in length) transits the Gulf on Thursdays, and for a few months in the spring and summer a couple of shrimping boats sit off-shore harvesting. Aside from these few larger vessels, nearly all motorized vessel noise in the Gulf of Tribugá is from the same boats being used in whale-watching activities. Whale-watching is one of the primary ecotourism activities in Chocó, providing a large portion of available jobs to the surrounding communities (Hoyt and Iñíguez, 2008). Furthermore, the whale-watching industry in this area is offered by the community (Velandia and Díaz, 2016), and it is still in its infancy compared to many other areas where humpback whales breed. Despite the relatively small operational capacity, it is possible that noise from these whale-watching vessels still cause any of the aforementioned adverse effects on nearby humpback whales and negatively affect their singing behavior (Sousa-Lima and Clark, 2008).

The Gulf of Tribugá is one of the most biodiverse areas in the world and has complex climatic, geological, and biological history. The acoustic environment is relatively less intense than three other marine mammal sanctuary locations along the Pacific Coast: south of Cabo Pulmo, México (Seger, 2016), in Laguna San Ignacio, México (Seger et al., 2015), and in Glacier Bay, Alaska (Seger et al., 2012). Furthermore, artisanal fishing and whale-watching efforts are regulated and no shipping lanes are nearby. Acoustic data from these locations and the Gulf of Tribugá were processed in previous work using Ulysses software (written by Drs. Aaron Thode and Jit Sarkar) by calculating the hourly-averaged 1st percentile of sound pressure levels (SPLs) (dB re 1 μPa^2/Hz) in the 0–6250 Hz bandwidth. Comparing the 1st percentile minima, the Gulf of Tribugá was 26 dB re 1 μPa^2/Hz lower than south of Cabo Pulmo, 37 dB re 1 μPa^2/Hz lower than in Laguna San Ignacio, and 30 dB re 1 μPa^2/Hz lower than in Glacier Bay National Park (Seger, 2020; Seger et al., 2020). Sediment type, recording depth, and sound speed profiles are different among these locations, but boat activity and vessel sizes are similar in all of them. Whether a result of boat activity or propagation environments, the Gulf of Tribugá has less intense 1st percentile SPL minima than the other locations. The primary acoustic components in the Gulf of Tribugá's noise budget are snapping sounds from shrimp, seasonal humpback whale song, and noise produced by small boats (Rey et al., 2019). Therefore, Tribugá is an area where the primary source of acoustic disturbance is the noise from small boats that are used in whale-watching, artisanal fishing, and/or transportation for local families (Velandia and Díaz, 2016).

This could soon change because a mega marine port construction project has been proposed. It was denied permits once on Sept 29, 2020, but reapplication may occur. As a result, there is no set start date of construction. If constructed, the port would severely impact the local soundscape, raising underwater noise from relatively low levels to higher levels more like those around other large ports. The construction process and the resulting greater abundance of large vessels would increase noise disturbance quickly and permanently alter the acoustic environment. Since it is possible that humpback whales in the Gulf of Tribugá are accustomed to lower background noise and wider communication space than even the other sanctuary areas mentioned above, new transient vessel sounds from a shipping lane could have a larger impact on them in terms of increased SPLs than in other locations.

This project on the potential acoustic effects of whale-watching on humpback whale song is part of a larger effort (The PHySIColombia Project) to document the baseline soundscape in a place with relatively low levels of anthropogenic noise as a Before-After Control-Impact (BACI) study. Results from this project are representative of the effects whale-watching boats may have had on humpback whales in an earlier era when large vessel traffic was less expansive than it is in today's global shipping economy. Using acoustic propagation models to understand the effects of noise on marine mammals is not new, but is usually applied in the Northern Hemisphere for shipping lanes and pile driving (Chen et al., 2017; Heaney et al., 2020).

The specific goals for this paper were to (a) model and map a representative noise field from whale watching boats in the Gulf of Tribugá, (b) quantify communication space reduction of a typical humpback whale song caused by whale-watching boats and (c) analyze changes in acoustic features of humpback whale song in the presence of boat noise. It is intended for these results to serve two purposes. First, the mapped models of acoustic propagation will introduce the parabolic equation as a tool for visually understanding the sound levels that humpback whales receive from different configurations of whale watching boats in very specific acoustic environments in South America. Second, any effects on the singing behavior of humpback whales, or lack thereof, while in the presence of whale-watching boats can serve as a "baseline reference" for other studies where whale-watching activities occur more often, in higher densities, and/or in the presence of larger vessel activities.

2. MATERIALS AND METHODS

Methods included two components. The first was a preliminary acoustic field modeling component using source positions taken from theodolite data collected near Arusí (**Figure 1**) to fulfill goals (a) and (b). The second was a data-analysis component using acoustic data collected at Morro Mico to fulfill goal (c). The modeling component quantified how much the Stock G humpback whale's song could be experiencing acoustic masking from whale-watching boats and its methods will be discussed first. Validating the amount of area over which whales in Stock G would have to adapt to this whale-watching boat noise, the data-analysis component evaluated one structural and two temporal song changes when boat engines were present and will be discussed second. For this paper, "structural changes" are defined as large scale changes visible when viewing several minutes of a spectrogram, like unit changes or starting and stopping singing. "Temporal changes" are defined as changes in the length or spacing of units, and only units were considered in this analysis.

2.1. Theodolite Data Collection

A common whale-watching destination within the Gulf of Tribugá is off Arusí, toward Cabo Corrientes. Ecohotel Punta Brava is located on a cliff-side where R&E Ocean Community Conservation used a land-based theodolite station (5°29'1"N, 77°32'14"W). Theodolite observations were performed throughout the month of September 2019. Whale-watching activities were recorded for up to 10 h each day, weather permitting.

The theodolite station was positioned 23.5 m above sea level (a.s.l.), which allowed for long-range observations and monitoring of several whale groups simultaneously. The focal plane of the digital theodolite was measured as 25 m a.s.l. (including the height of the theodolite and tripod). Once a whale or group of whales entered the study area, they were tracked using the methods described in Würsig et al. (1991). The vertical and horizontal positions of whales and whale-watching boats were systematized using the open source theodolite tracking software Pythagoras (Gailey, 2002). The program converted the vertical and horizontal positions to GPS coordinates. Once the data were recorded, they were exported to an excel sheet.

2.2. Acoustic Propagation Modeling

Three general steps were used to model potential masking conditions of boat noise over humpback whale song. First, a model of the sound pressure level field of whale song was calculated from transmission loss (TL) fields computed with the acoustic source at the whale's location (from the theodolite data) and spreading over part of the Gulf of Tribugá. This and all following acoustic TL models were calculated for 350 Hz, which is a common peak frequency used in Stock G humpback whale song (Perazio and Mercado, 2018) and is also a peak frequency in whale watching boat noise. (These sound pressure level fields are most often called received levels (RL) in sonar literature.)

Second, noise fields were modeled for (1) a typical ambient noise level, and (2) a typical whale-watching boat traveling at a slow speed (Erbe, 2002). For the boat RL field, TL was computed over the same area of the Gulf with the source located at the boat(s) GPS location(s) in the theodolite data. This RL field for the boat was combined with the typical background noise level to complete a model of noise in the area. Third, the signal-to-noise ratio (SNR) between these whale communication and noise models were calculated for two scenarios: when one and two whale-watching boats were near a whale in the theodolite dataset. Planview (bird's-eye view) maps of these TL and SNR models illustrate the spatial variations of song and boat noise and depict how audible song could be throughout much of the Gulf of Tribugá when competing with noise from boat engines. The SNR planview maps for each scenario were brought into Esri's ArcGIS Pro for further analysis.

The acoustic propagation model used to compute TL given bathymetry, sound speed profile, sediment type, and source and receiver depths and positions was the parabolic equation (PE) formulation. The PE model solves the wave equation using a paraxial approximation and is well-suited for range-dependent environments at frequencies up to about 1 kHz (Heaney et al., 2020). A more detailed explanation of these models can be found in Heaney et al. (2020). The specific model implementation in use is Seahawk, a C language port of RAM (Collins, 1995) developed by Richard Campbell (RAM stands for "Range-dependent Acoustic Model"). It is based on the latest techniques in PE modeling such as the split step Padé solution which allows for large range steps and high angle acoustic propagation support.

Environmental inputs to the acoustic model were representative of the two scenarios being modeled for the Gulf of Tribugá. A common peak frequency of humpback whale song in the area (Perazio and Mercado, 2018) was used in the model: 350 Hz. This is also a common frequency in boat engine noise so masking in this frequency is highly likely. Whale song and boat noise were both assumed to be omnidirectional. Even though some research suggests that whale songs may have some level of directionality (Pack et al., 2003), a tested model to represent this is not yet available for input into the PE model. The source depth for modeled whales was 5 m and the source depth for modeled outboard motors of the boats was 2 m. The receiver depth for both the whale and boat models was 5 m (as if another whale near the surface was receiving song, or the whale being watched was receiving boat noise, respectively). The key differences between the whale and the boat models were their source positions in the Gulf of Tribugá and their source depths.

In the acoustic model, the ocean bottom was modeled as a sediment with mean grain size of 2ϕ (a coarse sandy sediment) on the Wentworth chart scale because the local SCUBA company said that the area is mostly sandy in their experience. By default, Seahawk uses a two layer model of the environment, consisting of separate water and sediment profiles defined independently. The sediment is treated as an acoustically thick halfspace, implemented as 20 wavelengths at the given frequency, containing an exponential absorptive sponge along the bottom of the sediment layer. The absorptive sponge layer ensures that sound will not reflect off the edge of the computational domain. The thickness of the water column is determined by the bathymetry and (optionally) sea surface height. The sediment was characterized by a single parameter, the log mean grain size, which is used along with the local sound speed at the water-sediment interface to determine the depth-dependent sound speed, density, and attenuation within the sediment layer (Hamilton, 1980). This single-parameter bottom characterization is useful because the log grain size parameter maps reasonably well (Wentworth, 1922) to the bottom types indicated on nautical charts. This model is an approximation of real-world conditions as the ocean bottom often contains multiple layers of sediments and is also inhomogeneous. However, if sediment data became available, the sediment model could be improved with more spatial dependence, both across the model domain and in depth.

TL fields for all the whale and boat positions were calculated over the same 150 km by 150 km area centered on the whales' GPS location from Sept 5, 2019, with computed 2,280 radials (azimuths) interpolated onto a output grid of 1,024 pixels in width. This area covers the north to south extent of the Gulf of Tribugá. TL is the pressure level field of an acoustic source with unit amplitude. The models of the whales' and boats' acoustic amplitudes will be explained in more detail during discussion of the SONAR equation.

Scenarios #1 and #2 from the theodolite data were on September 5, 2019 (10:20 a.m.), and September 20, 2019 (10:10 a.m.), respectively. On September 5th, a single whale was being watched by one boat; on September 20th, a single whale was being watched by two boats. Additionally, the Sept 5th sighting occurred closer to shore (by 10.5 km) over a water column depth of 139 m and the September 20th scenario was over a water column depth of 933 m.

The SONAR equation used to model these two scenarios was the passive version:

$$SNR = SL - TL - NL \tag{1}$$

where SNR is signal to noise ratio, SL is source level, TL is transmission loss, and NL is noise level. The threshold of SNR = 0 was selected to indicate a whale's song being audible over ambient sound levels (+SNR) or not (–SNR). Source levels chosen for the models were based on literature. Au et al. (2006) provided a range of SLs for each unit of humpback whale song in Hawaii. Their unit labeled E2 was noted as the most common unit in the songs in the Gulf of Tribugá data analyzed for this study, so the same SL_{rms} of 153 dB 1 μPa @ 1 m was used to represent Stock G song in our modeling. Erbe (2012) estimated the SLs of several types of whale-watching boats in Australia during whale-watching activities for orcas, and extrapolated their 10 knot and 20 knot SL measurements to other speeds. To keep our models conservative, the slowest speed in Erbe (2012) from a similar style vessel to those used in the Gulf was chosen for our model input: 145 dB re 1 μPa @ 1 m. All inputs to the PE model and planview map grids are summarized in **Table 1**.

NL was included in the models for both scenarios when boat(s) were present and absent. The NL for boats being present was the incoherent sum of the RL for the boat or boats and a background ambient noise level of 48 dB re 1 μPa (Huertas et al., 2019; Rey et al., 2019), taken from measurements with conditions which best matched conditions during the study period. In the case of boats being absent, the NL was only the background ambient noise level.

The RL grids were imported into Esri's ArcGIS Pro and transformed to an area preserving the projected coordinate system to minimize bias. For each of the two scenarios, the areas covered under three SNR intervals were computed: <0 dB (masked), 0–10 dB (unreliable audibility), and >10 dB (audible). The area (km^2) that these SNR intervals occupied in the models was calculated for both scenarios in the presence and absence of boats and compared.

Some assumptions needed to be made that these SNR planview maps of whale song, given surrounding boat noise from whale-watching vessels, provided evidence that a whale's communication space could have been reduced from engine noise throughout the Gulf of Tribugá. The following assumptions were made to validate the comparisons of modeling results in the area near Arusí with the data collection area near Morro Mico:

1. The acoustic propagation environment in both Arusí and Morro Mico are similar because they are in the same small Gulf, have similar bottom sediments, similar depths, similar bathymetries, and the boats and whales occupy similar distances to the coast. (Additional models from other projects have produced similar TL maps along the Gulf's coastline.)
2. The most common kind of boat used throughout the Gulf for whale-watching, transportation, and artisanal fishing are fiberglass hulls with outboard motors. Other types of vessels are relatively rare. Therefore, the boats passing by and milling around the recorder, if not engaged in whale-watching, would likely still be the same kind of boats used in whale-watching activities.
3. When boats engage in whale-watching activities, they have to approach the whales and usually do so at a typical travel speed. Sound from the approach will reach the whale and have masking effects before the boat reaches its watching point and slows down or stops.
4. Individual whales are able to, and do, traverse the distance between Morro Mico and Arusí in under a day's time. The whales whose songs have been analyzed from Morro Mico are capable of traveling to Arusí, so the whales used to generate our maps are from the same population (Stock G) as those recorded.

TABLE 1 | Inputs to the PE model for Gulf of Tribugá scenarios.

Variable	Assumption	Value
Propagating frequency	Song peak frequency from Perazio and Mercado (2018)	350 Hz
Receiver depth	Whale near surface while being watched	–5 m
Transmitter depth	Depth of outboard engine in water	–2 m
Sound speed profile	Dates of theodolite measurements	World Ocean Atlas 2018 Sept 5, 2019 10:20 a.m. Sept 20, 2019 10:10 a.m.
Pixels	Enough to show features in the planview maps	1,024
Range	Ensure range enough to capture most of the Gulf	150 x 150 km
Grain size (Wentworth Chart)	Muddy to rocky bottom types exist across the Gulf; sand granules are about in the middle	2ϕ
Bathymetry	Best known bathymetry in the region	GEBCO 2019
SL for boats	From Erbe (2012), slowest speed	145 dB re 1 μPa @1 m
SL for whales	From Au et al. (2006), unit E2's SL_{rms}	153 dB re 1 μPa @1 m

5. Acoustic data from 2018 would adequately represent boat noise in 2019. Boat traffic in the Gulf has no documented annual cycle and the artisanal fishing lifestyle (the main boat traffic contributor) has been consistent for decades.

2.3. Acoustic Data Collection

Acoustic data were collected at Morro Mico (**Figure 1**), from October to November 2018 (5°52.101'N, 77°19.007'W) with an Ecological Acoustic Recorder (EAR) from Oceanwide Science Institute. Morro Mico is an island in the region of Chocó that lies along the southern border of Utría National Natural Park. The EAR located there was programmed to record for 10 min at 30-min intervals for a duty cycle of 33.3%. The sampling rate was 15.625 kHz.

2.4. Acoustic Data Analysis

Acoustic data from the EAR at Morro Mico were downloaded and converted to .wav files using custom Matlab code (L. Munger). The hydrophones on the EARs had a sensitivity of –193.5 dB re 1 V/Pa with a 47.5 dB preamp. No additional gains were used. A total of 1681 10-min samples were obtained over 37 days. Data were manually analyzed every 3 h in Raven Pro 1.5 software, identifying times when acoustic sources fell into two groups: (1) small boat engine activity with whale song and (2) only humpback whale singing. A total of 67 files from the dataset were used: 33 of them contained humpback whale song and no boat activity and 34 contained both boat and song activity.

In only the 34-file set, humpback whale song structure before and after each full boat pass in a file was compared. Whether or not a qualitative difference in the song structure was observed between these two times was recorded "yes" or "no" to create a binary response variable. To consider something a qualitative change in song structure the criteria included: a different unit, a difference in bandwidth if the unit or phrase was the same, singing activity stopping, or singing activity starting. Unclassifiable changes occurred when boat noise was too loud to allow for unit identification, a boat pass continued beyond the end of the recording, or the sound of breathing whales replaced song.

For both sets of files, two quantitative measures were taken from the only or most apparent song in the file. In the set of files with boats, as many units as possible were measured even during the loudest boat activity to prevent large gaps accidentally being measured where units could be fully masked. The inability to separate boat noise frequency characteristics from song units they were superimposed on is the primary reason that only temporal features were measured and compared. These temporal measures were unit duration (time from the start to the end of a unit, in seconds) and inter-unit interval (IUI, time between consecutive song units, in seconds) (Mercado et al., 2005). All units found in each of the files were selected, for a total of 3,027 units from songs in files with boats present and 5,023 units from files without boats. Distributions of both temporal variables were then compared between when boats were and were not present to determinate changes on a larger time scale, as opposed to structural changes in which immediate pattern changes were observed.

2.5. Statistical Analysis

The null hypothesis that was tested for song structure stated that a whale would not change the structure of its song any more often than random (50% of the time) during a boat pass. The alternative hypothesis was that a whale would change the structure of its song more often than random (>50% of the time) during a boat pass.

The null hypothesis that was tested for temporal song features stated that there would be no significant difference in the length of song units or IUIs when boats were present vs. when boats were not present. The first alternative hypothesis was that average song unit length from files with boats present would be different (longer or shorter) than average song unit length from files without boats present. The second alternative hypothesis was that the average IUI length from files with boats present would be different (longer or shorter) than the average IUI length from files without boats present.

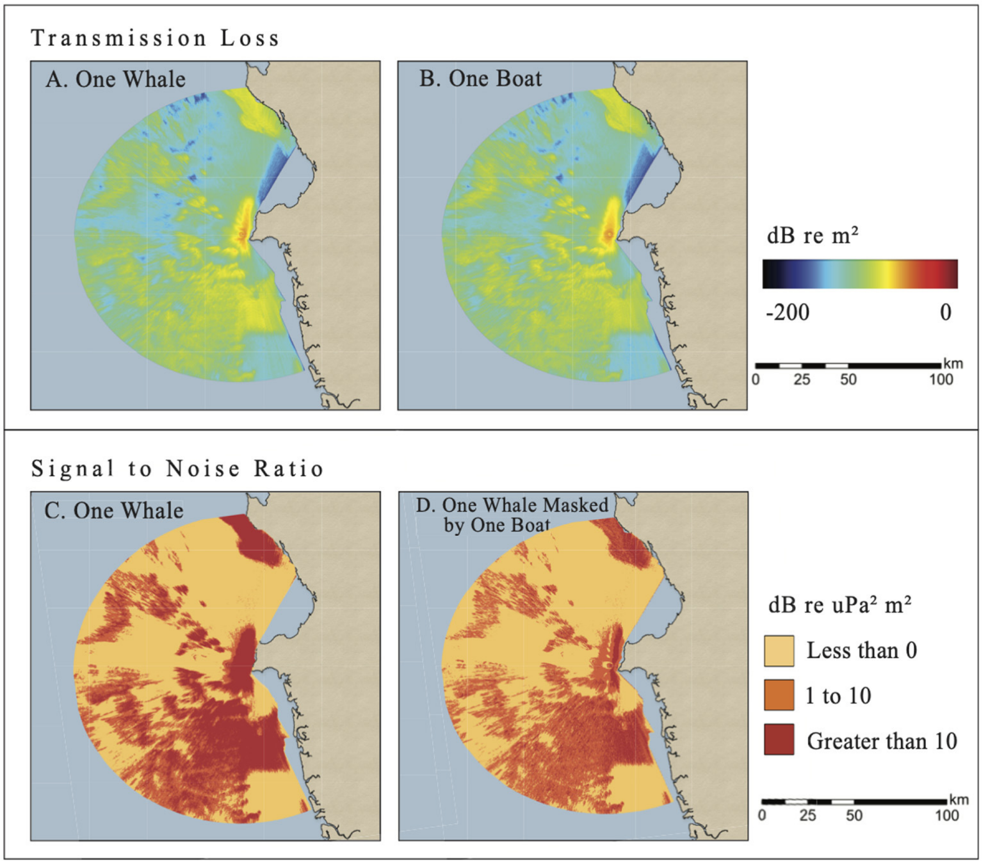

FIGURE 2 | Planview maps for the Sept 5, 2019, scenario #1 of continuous TL values of whale song **(top left)** and boat noise **(top right)** illustrate sound transmission loss near Arusí. Blue is less audible while red is more audible. Planview maps as binned SNR values better visualize the area of relatively higher SNR communication space when only ambient noise **(bottom left)** vs. one boat **(bottom right)** is present. Red indicates very audible areas of the whale song, orange indicates unreliably audible areas, and yellow indicates masked areas. Source level of the whale's hypothetical song was 153 dB re 1 μPa @ 1 m, which would be dark red in the top left map (color online).

Normality distributions of song unit length and IUI length boat/non-boat pairs were examined with the Shapiro-Wilk test and homogeneity of variances were examined with the *F*-test. They all exhibited non-normality even after data transformation. Therefore, the non-parametric Wilcoxon rank sum test was chosen to determine if there was a significant difference between song unit lengths and IUI lengths in the presence or absence of boats (Stewart-Oaten, 1995; Marques De Sá, 2007). The level of statistical significance was set as less than 5% ($p < 0.05$). All statistical analyses were conducted in R version 3.5.2.

3. RESULTS

3.1. Acoustic Propagation Modeling - SNR Planview Maps

RL (Received Level) and SNR (signal-to-noise ratio) planview maps of a hypothetically singing humpback whale from scenario #1 (1 whale, 1 boat) and scenario #2 (1 whale, 2 boats) illustrate key features about the acoustic environment of a humpback whale under undisturbed and whale-watching conditions. First, the propagation of sound emitted by any source, boat or whale, is shaped by different water depths and distances to shore (**Figures 2**, **4** top subplots). These observations about depth and coastal proximity match two of the three key parameters in environmental sensitivity analyses from pile driving propagation modeling along the east coast of the United States (Heaney et al., 2020), and temperature (the third parameter) in the Gulf of Tribugá would change less than at higher latitudes.

In scenario #1, the whale's communication space model without boat noise spread along-shore (solid orange-yellow oval, **Figure 2** top left) and spread more effectively to the south and west than to the north. The SNR model shows that in about half of the area, the song's sound energy would be masked (<0 dB, yellow, **Figure 2** bottom left) without competing boat noise but from natural transmission loss and ambient noise. Once noise from a single boat was included in the model (**Figure 2** top right), the whale's communication space was reduced further (**Figure 2** bottom right), particularly in the areas that were audible with just the presence of ambient noise (SNR >10 dB) (red, **Figure 2**, bottom subplots).

The change in area covered by these three SNR threshold ranges in the Gulf was calculated and compared between a hypothetical whale singing in ambient noise conditions to a hypothetical whale song competing with noise from a single boat (**Table 2** and **Figure 3**). Without boat noise the hypothetical whale song would have been very audible (SNR >10 dB) in 2,306 km^2 of the total 10,255 km^2 of the Gulf where sound energy propagated. By comparison, noise from one boat reduced the very audible area (>10 dB SNR) to 859 km^2, or a 63% reduction. With boat noise, the area of the Gulf where the whale's song was unreliably audible increased 35%, and 588 more square km were masked (an 11% increase). The presence of one boat did not mask much more communication space for the humpback whale song than just ambient noise, but it did decrease the very audible area by more than half.

In scenario #2, the whale's and boats' acoustic fields spread more evenly in all directions than in scenario #1 (**Figure 4** top subplots). The SNR-binned subplots for scenario #2 (**Figure 4** bottom subplots) showed that the regions where the whale song with only ambient noise was modeled as very audible (4,901 km^2) shrunk to 1,375 km^2 (a 72% decrease) in the presence of the two boats. The masked regions increased 79% in the presence of the two boats. Noise from two boats almost doubled the masked area as compared to just ambient noise, and only about one quarter of the very audible area remained. Percent changes in very audible, unreliably audible, and masked areas are presented for scenario #2 in **Table 3** and **Figure 5**).

A few comparisons to scenario #1 illustrate the effect of source positions and the extra boat. The source level position of the whale in scenario #1 was more affected by transmission loss and ambient noise, having more than twice the naturally masked area without any effect of boat noise than scenario #2 (5,526 km^2 compared to 2,582 km^2). Scenario #2's model results had 1.5 times more area of the Gulf where SNR is unreliably audible than in scenario #1 (5,077 km^2 compared to 3,282 km^2). Noise from two boats decreased the very audible area (>10 dB SNR) 9% more than the noise from just one boat. Finally, the scenario #2 model indicates that it would take more than two boats to mask (make SNR <0 dB) the entire communication space of a humpback whale song in the Gulf.

TABLE 2 | Area (km^2) that three SNR-binned audibility ranges occupy within the simulation for the September 5, 2019, scenario #1 (single whale alone with just ambient noise vs. single whale in close proximity to a single boat plus ambient noise).

SNR range	Whale + Ambient noise	Whale near one boat	Percent change
<0 dB (masked)	5,525.50	6,113.40	+11%
0–10 dB (unreliably audible)	2,423.74	3,282.82	+35%
>10 dB (very audible)	2,306.02	858.98	−63%

3.2. Effect of Noise From Boats on Structural Aspects of Humpback Whale Song

A total of 126 boat passes occurred within the set of 34 files with whale and boat activity. Qualitative analysis showed that song structure changed during a boat pass 58 times. Some of the song structure changes observed were: different unit used after a boat passed (often a different unit with a higher bandwidth than before), vocal activity stopped (**Figure 6**), and vocal activity started. However, song structure did not change 55 times during a

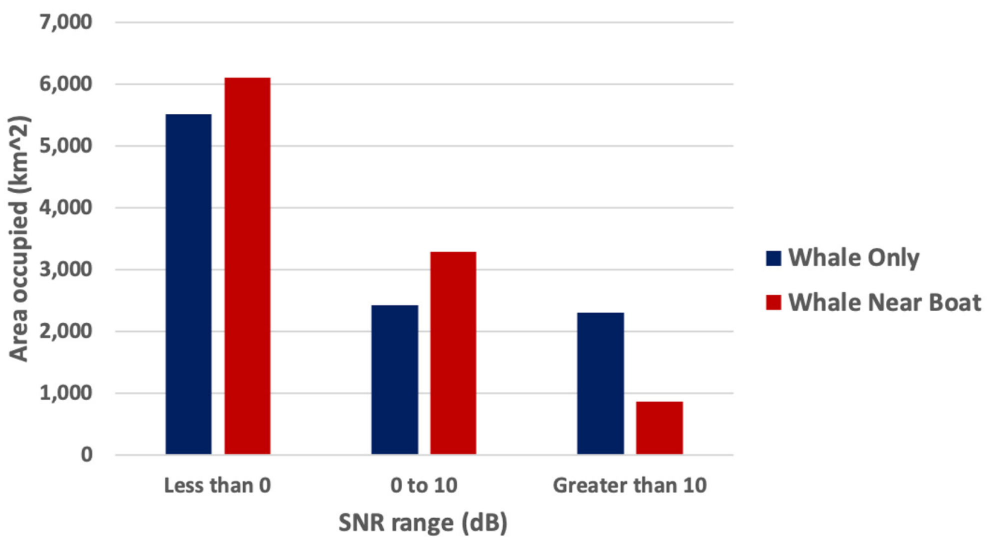

FIGURE 3 | Sept 5, 2019, scenario #1. Comparison bar plots of the area occupied by the three SNR bins of the hypothetical whale song when only ambient noise (blue/left bars) and one boat (red/right bars) was present (color online).

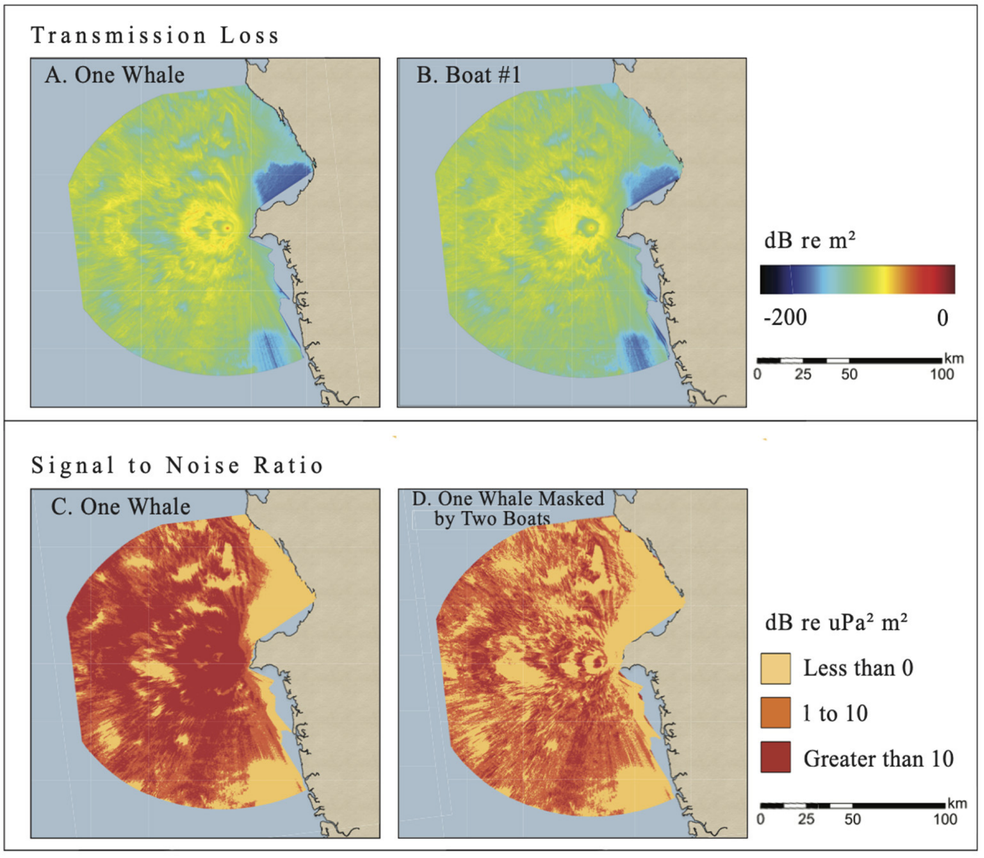

FIGURE 4 | Planview maps for the Sept 20, 2019, scenario #2 of continuous TL values of whale song **(top left)** and noise from one of the two boats **(top right)** near Arusá. Blue is less audible while red is more audible. In the bottom panels, planview maps of binned SNR values better visualize the area of relatively higher SNR communication space when only ambient noise **(bottom left)** vs. two boats **(bottom right)** are present. Red indicates very audible areas of the whale song, orange indicates unreliably audible areas, and yellow indicates masked areas(color online).

boat pass and 13 times the change could not be classified (n/a) as pertaining to song structure. Therefore, song structural changes did not occur significantly more often than random (50% of the time) when a boat passed.

3.3. Effect of Noise From Boats on Temporal Aspects of Humpback Whale Song

When distributions of song unit length in the presence and absence of boats (**Figures 7A,B**) were compared with a Wilcoxon rank sum test, there was a statistically significant difference between the ranks of their medians (p = 6.627e-06). The average song unit length and standard deviation was 1.1 ± 1.3 s with a median of 0.8 s when boats were present vs. 1.2 ± 1.1 s with a median of 0.9 s when they were absent. The presence of boat noise coincided with shorter and more variable song unit lengths in humpback whale songs in the Gulf of Tribugá.

When the distributions of the IUI length in the presence and absence of boats (**Figures 7C,D**) were compared with a Wilcoxon rank sum test the ranks of their medians were also significantly different (p = 2.2e-16). The average IUI length was 4.3 ± 9.1 s with a median of 2.4 s when boats were present vs. 2.6 ± 4.5 s with a median of 1.8 s when they were absent. The presence of boat noise coincided with longer and more variable IUIs in humpback whale songs in the Gulf of Tribugá.

TABLE 3 | Area (km^2) that three SNR-binned audibility ranges occupy within the simulation for the September 20, 2019, scenario #2 (single whale alone with ambient noise vs. single whale in close proximity to two boats plus ambient noise).

SNR range	Whale + Ambient noise	Whale near two boats	Percent change
<0 dB (masked)	2,582.30	4,634.00	+79%
0–10 dB (unreliably audible)	3,603.72	5,077.10	+41%
>10 dB (very audible)	4,900.80	1,374.94	−72%

The rate of the singing under boat presence and absence conditions was also calculated. There were 3,026 units sung in the 340 min of files with boats and 5,023 units sung in the 330 min of

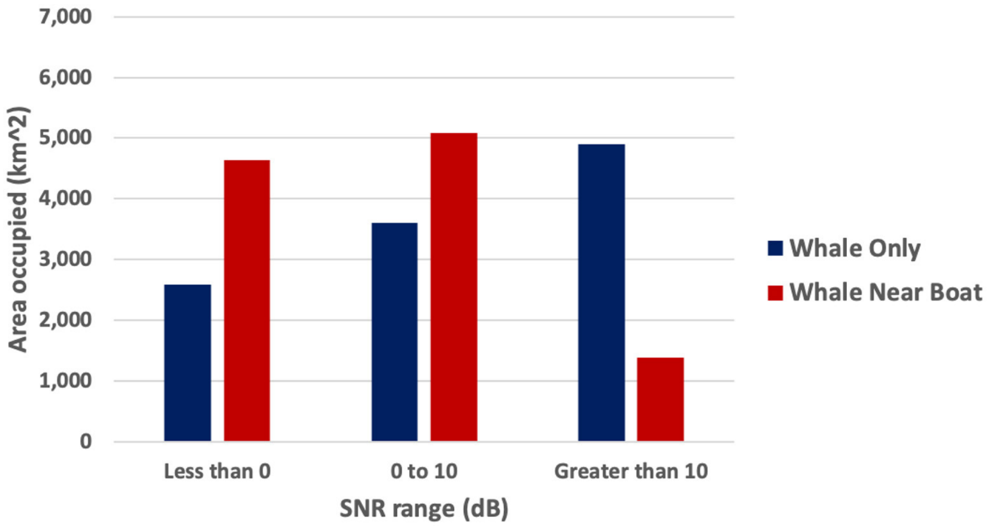

FIGURE 5 | Sept 20, 2019, scenario. #2, side-by-side bar plots of the area covered by each SNR bin of the hypothetical whale song when only ambient noise (blue/left bars) and two boats (red/right bars) were present (color online).

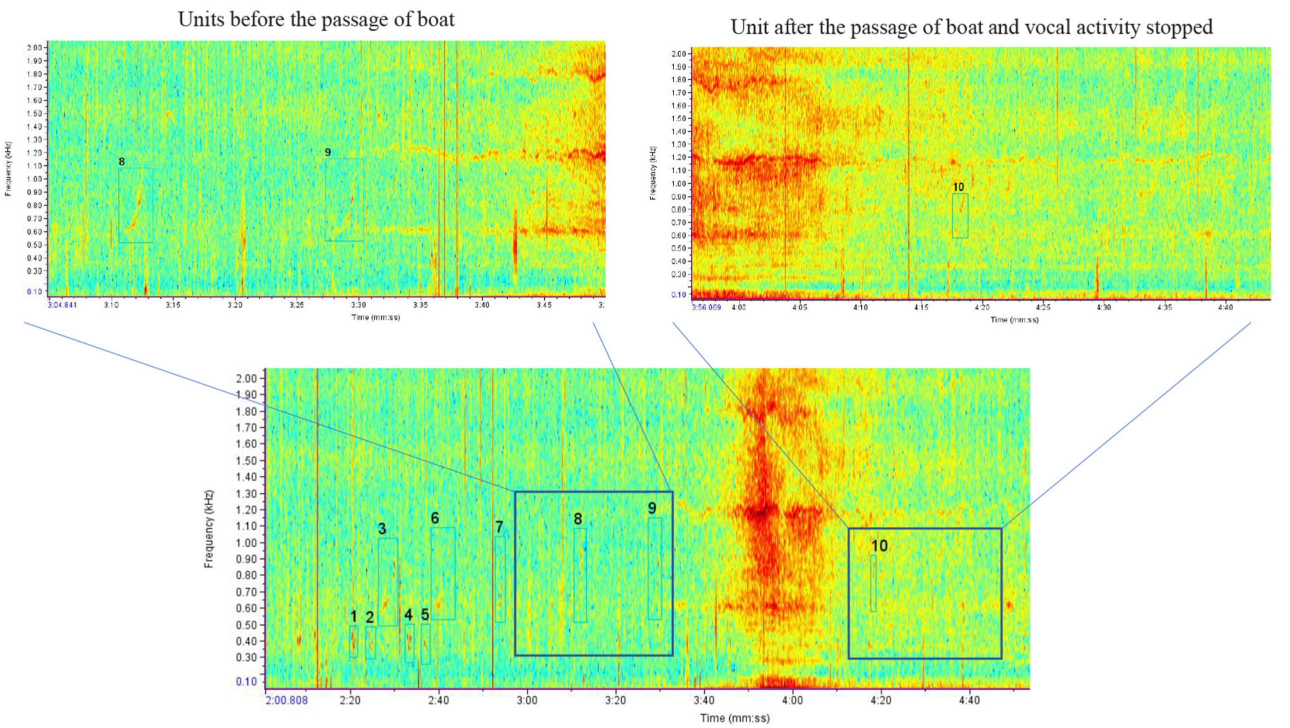

FIGURE 6 | Example of structural change in a song: stopped singing. At the beginning of the spectrogram, a phrase change happened to the song denoted by the 1, 2, and 3 (AAB) boxes (blue) until 3:40 when the boat pass began. During boat noise, units were difficult to identify. At 4:20 when the boat pass ended, the final unit able to be found (box 10) matched unit B of the phrase from before (boxes 3, 6, 7, 8, and 9). No more singing was heard/seen for the remainder of the 10-min recording (color online).

files without boats present. Dividing the total number of units by the total time yielded rates of 8.9 units/minute sung when boat noise was present compared to 15.2 units/minute sung when boat noise was absent. The apparent slower singing rate in the presence of boats is likely partially due to units being masked by boats, so fewer were able to be detected during manual analysis to be included in a rate calculation. This bias in this song rate metric will be discussed later.

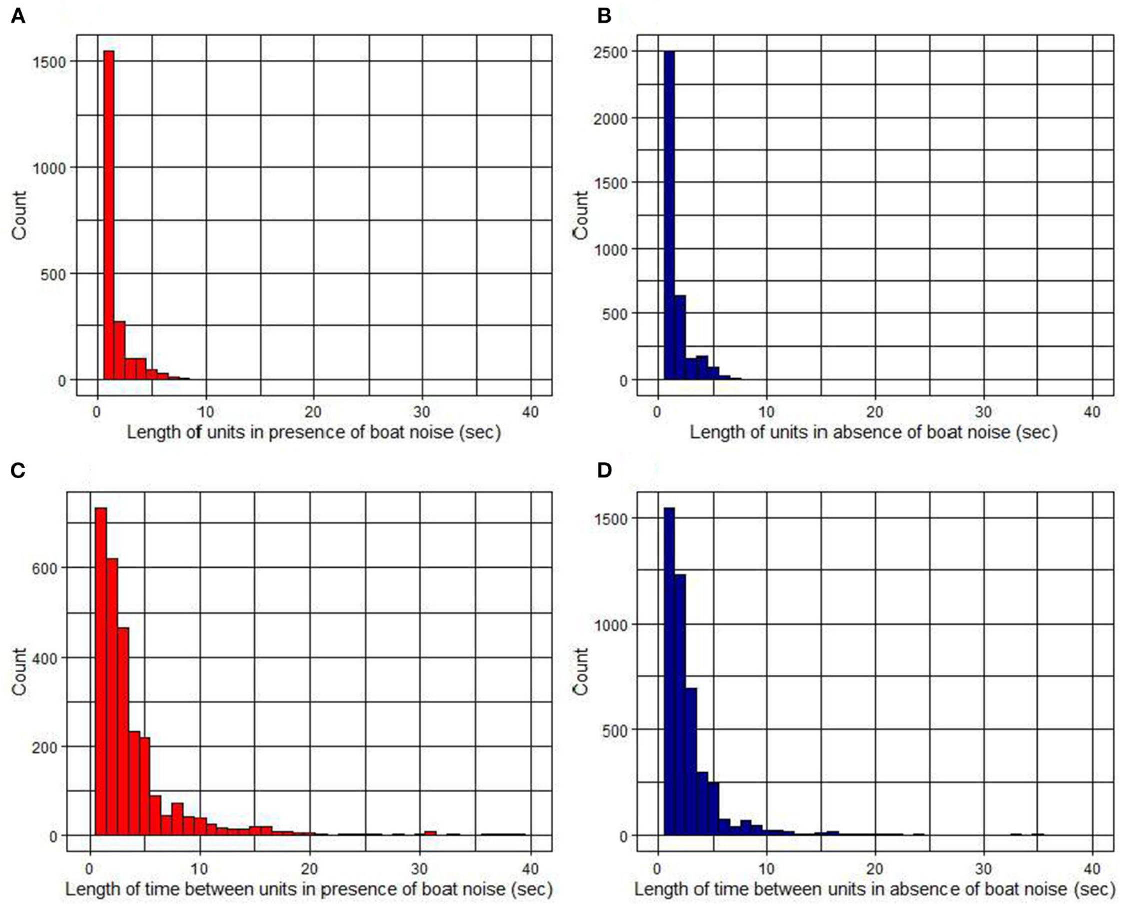

FIGURE 7 | Temporal difference in units and unit spacing in the presence and absence of boat noise: **(A)** length of song units in presence of boat noise and **(B)** absence of boat noise **(C)**; length of IUIs in the presence of boat noise and **(D)** absence of boat noise.

4. DISCUSSION

Boat-based whale-watching is one of the activities with the highest tourism demand in the Colombian Pacific. It has become very economically important in the last decade, especially in places like the Gulf of Tribugá where it is a stable seasonal job for local fishermen (Velandia and Díaz, 2016). It is reasonable to assume that boats within whale-watching distance of a humpback whale along the coast of the Gulf of Tribugá could mask the acoustic field of a whale if it is trying to sing or produce social calls. It is likely that masking of the song by the boat noise occurs not only when the whale-watching vessel is close, but also when it is farther away, like during an approach. Adaptive strategies to reduce the effects of this masking could be pursued by the whale, but at present there is an incomplete understanding of what these strategies are and how they are used.

The propagation modeling SNR planview maps, bar plots, and tables illustrate how far a hypothetical whale song could transmit through its habitat with only ambient noise as compared to in the presence of noise from one or two boats used in whale-watching activities. The audibility regions in the models were not meant to exactly represent song detectability, but rather serve as a visualization tool to capture two uncertainties. First, fine details of the environment such as the bottom sediment properties and the complete ocean temperature and salinity across the study area are not well known and lack *in situ* measurements. But if these details were known, the audibility results could shift. Second, these models do not include noise contributions due to wind and waves. If wind picks up or a storm passes, ambient noise levels would rise from more crashing waves and rain drops. A change in sea state from 1 to 5 can lead to an increase in background noise levels of 10 dB re 1μPa or more. It is possible that the unreliably audible areas would become masked under poor weather conditions.

While negative SNR represents masked space in our models, marine mammals do exhibit strategies to reduce the effects of this masking (Erbe et al., 2016), thus a 0 dB SNR threshold indicating masking is debatable. While we assume here that SNR values above 10 dB are loud enough for a signal to be heard over ambient noise under the typical variations in environmental and propagation conditions, a model validation study with higher resolution environmental inputs and a Monte Carlo estimate of

SNR variability would be better for establishing such thresholds. Such an estimate would be based on the uncertainties in the model input parameters such as diurnal and seasonal variations in the sound speed profile, fluctuating ambient noise levels, a variety of sediment types across the ocean floor, and/or frequency dependence of the humpback whale song and boat engine noise overlap.

Such sophisticated models, despite being in development for future work, were beyond the purpose of this project. The purpose of these models was to validate that (1) sound from boats and whales both travel many kilometers in the Gulf of Tribugá and (2) one or two whale-watching boats could reduce the communication space of a singing humpback whale. With this validation, it could be assumed that if the EAR deployed by Morro Mico recorded both whale song and boat noise, then the whale could likely detect the boat and the whale's communication space was likely reduced by the boat. Therefore, the whales that were recorded at Morro Mico likely experienced environmental pressure to change their acoustic behavior if deemed adaptive.

In a few areas of the models were the hypothetical whale songs masked by the noise from one or two whale-watching type boats, but more boat activity could create more expansive areas of masking. If the planned mega maritime port is built in the Gulf of Tribugá, boat noise will increase from more and larger vessels. It will be important to predict how much masking the noise from shipping lanes could have on humpback whale song. This project was the first step in understanding how one or two small vessels can reduce humpback whale communication space so the models can be further developed to predict the effects from more and larger vessels in the Gulf of Tribugá.

Since the recorded ambient sound levels here (Huertas et al., 2019; Rey et al., 2019), even with boats, are relatively lower than other humpback whale and gray whale breeding and feeding grounds in the Pacific Ocean (Seger, 2020), the Gulf of Tribugá is representative of a low disturbance "baseline" region. More heavily trafficked whale-watching areas in the world could mask whale song more and correlate with more extreme acoustic behavioral changes.

Despite this relatively low anthropogenic disturbance, two temporal aspects of singing activity were significantly different when boat noise was present compared to when it was absent. The fewer number of longer units sung in the presence of boats at longer IUIs could be a strategy to escape the masking. The longer IUIs during boat passes could also be a result of some units being completely masked in the spectrograms and therefore missed during analysis. We believe this happened rarely, but could have affected the results nonetheless.

The mean of the IUIs in the presence of boat noise was 4.3 s, but was 2.6 s (about half as long) in the absence of boat noise. Another study found average IUIs in humpback whale song ranging from 0.51 to 2.37 s (Handel et al., 2009). The IUIs in the songs recorded from the Gulf of Tribugá were longer than this range regardless of whether boat noise was present or absent. These results extend this previously published range of IUIs, but whether due to natural population differences or interruptions from boat noise is unclear.

The results also showed that (a) IUI length was more variable (larger standard deviation) than unit length regardless of whether boats were present or not and (b) the variability (standard deviation) in IUI length was larger in the presence of boat noise than in its absence. Singing tempo in the Gulf of Tribugá, therefore, was more governed by IUI length and was faster when boat noise was absent. This is contrary to previous work suggesting that humpback whales use unit length instead of IUI length to adjust song tempo (Schneider and Mercado, 2018) and that they use highly consistent unit and IUI durations for specific unit types in large-scale time (Mercado et al., 2005; Au et al., 2006). These more variable IUI and unit length results are plausible considering that songs have a naturally high level of intra-individual variability (Schneider and Mercado, 2018) are there were likely many individual whales' songs captured in our data. Or, comparing these results to previous work from other geographical regions simply documents natural differences across populations.

No common "boat-noise adapted" phrase was anecdotally noted during analyses, but doing a correlation test of which units and phrases were used during boat noise presence vs. absence would be an important next step. Not all song units are the same length. It is possible that the Stock G humpback whales are not lengthening units when boat noise is present, but rather are switching to a phrase which has naturally longer units in it. The whales could also be constantly morphing unit patterns in predictable ways (Mercado and Perazio, 2021) and these adjustments may happen more quickly in the presence of boat noise. The IUI and unit lengths in our results indicate that singing whales waited longer to sing each unit, and when they did sing, the unit was more likely to be longer. Certain phrases might be easier to use in this way than in others. This slowing down of song to possibly sing at more strategic intervals is limited, however. As the IUIs approach many seconds, and possibly minutes, long the song structure would break down. At some threshold this "slower tempo" strategy will no longer create a song, but rather a set of random calls without a phrasing or thematic structure, and a different strategy would need to be implemented. It is unclear whether the information contained in a quicker or slower song is as efficient or as comprehensible to the receiving individual as a song at "normal" speed.

Humpback whale song length as a whole is a summary of complex behavior that likely provides a relatively easy measure of response to potential disturbance (Fristrup et al., 2003). According to Fristrup et al. (2003) the increased duration of the songs might also be related to the density of the local whale population. If the local population and social activities increase, the duration of the song (and thus the duration of phrases and IUIs within that song) could also increase. This project only analyzed the clearest song in each file and did not analyze any background songs. Therefore it is possible that the longer IUIs observed during boat noise were actually a coincidental response to more nearby conspecifics.

Longer IUIs have one additional advantage in noisy conditions. They may cause the entire song to last long enough to still be present after a boat has passed. The whales could be conserving energy by singing less often while boat noise is present, under the assumption that eventually the boat will pass and then the song can return to a normal pace using a normal amount of metabolic energy. One study supports this interpretation. Miller et al. (2000) found that humpback whales sang longer songs during low frequency active sonar transmission to compensate for the acoustic interference (Miller et al., 2000).

Responding to boat noise is not the only thing that may alter humpback whale song, and some of the variability might be natural. Humpback whales tend to stop singing when they join another whale that is not singing (Tyack, 1981). Also, the location of the individual (either in deep or shallow waters) or the presence of predators could change the intensity of the vocalization, the frequencies, or the length of songs (Au et al., 2006; Guazzo et al., 2020). In these contexts, the consistency of performance may in turn be an indicator of fitness (Thompson, 1983) where it would be strategic to show high redundancy in call behavior under typical conditions as a strategy to increase detectability by congeners (Erbe et al., 2016). Furthermore, it has been found that humpback whales are capable of increasing the source levels of their song units (Guazzo et al., 2020). But even with several singers, the combined effort may not compensate for or supersede the same noise level as that in a very disturbed environment, which still results in a suboptimal communication space (Guazzo et al., 2020).

For future research, the examination of other variables is suggested, such as environmental or biological cycles, different types of noise sources like rain, wind, fish choruses, or natural physical drivers of ambient sound levels (Wenz, 1962; Clark et al., 2009). Natural or biological sounds could also create masking effects similar to that of boat noise. Furthermore, the analysis of the shipping lane masking models, currently ongoing as part of an undergraduate thesis project, and other effects such as stress levels (Rolland et al., 2012) of humpback whales that are exposed to boat noise would be informative. Since noise is a potential stressor, adapting one's song may not reduce or compensate for stress, but could exacerbate it, and prolonged stress could cause serious health problems (Erbe, 2012).

Another suggestion is to carry out a much more exhaustive estimate of the spatial overlap of boats and whales in the Gulf of Tribugá. Because the whale-watching type boats do not transmit AIS signals, there are no ship track data like those for larger ships to use as acoustic source locations in propagation models. But it is possible to place more hydrophones in several places around the Gulf of Tribugá to determine roughly where and how many boats are producing noise at several locations at any one time. Studies of temporal overlap with boat noise and whale song are also important. In this project, IUI and unit length metrics were more robust than singing rate in measuring temporal changes in humpback whale song since boat masking likely excluded units that the analysts could not see through boat noise. Therefore, future analysis should include denoising the data first if metrics like singing rate are included. For the time being, in the Gulf of Tribugá, whale watching activities occur between 8 a.m. and 5 p.m. and humpback whale singing peaks outside of these hours (Rey et al., 2019). Therefore boat noise overlaps less with song during peak singing activity and the humpback whales in Stock G still have relatively quieter night times during which to sing. If the port is built in Tribugá, though, this refuge time would no longer exist since merchant ships transit into and out of ports even in the night.

5. CONCLUSIONS

This project focused on the possible impacts that whale watching may have in one place with relatively low levels of anthropogenic noise (Gulf of Tribugá) in the world. For this, propagation models depicted and quantified the areas of the Gulf of Tribugá over which whale-watching boat noise could affect the song of humpback whales from Stock G. The statistical analyses of actual behavioral quantification in the absence and presence of noise from whale-watching type boats indicated that two of the three null hypotheses were rejected: song unit and IUI lengths were not the same when boat noise was and was not present. Rather, the presence of boat noise was coincident with longer and more variable song unit and IUI lengths in humpback whale songs.

This project did not attempt to control for all of the discussed potential behavioral and environmental variables that could have influenced song unit and IUI length instead of boat noise. This was partially because one hydrophone prevents much of the analysis, like source level determination, that would require an array of hydrophones. Mostly, however, this paper's goals were to (1) predict the masking potential of whale-watching boats in a relatively undisturbed breeding ground, (2) quantify the likely area of masking from whale-watching boat noise in the Gulf of Tribugá specifically, and (3) explore some fundamental observations about singing behavior changes in the presence of whale-watching boat noise that could be easily reproduced by students in remote field sites with access to only one hydrophone. The fact that singing behavior changed significantly over two temporal variables in the presence of boat noise in a place where anthropogenic noise is low means that even the places that may be assumed as good representations of baseline environments are not immune to the effects of disturbance. As the scientific community attempts to compare the effects of pollution on wildlife, seemingly pristine environments usually serve as controls. These results show that such control environments are not pure controls.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because no testing was done on humpback whales, nor were boats by the researchers used to approach the whales to sample acoustic and observational data.

AUTHOR CONTRIBUTIONS

KS, CP, and NB-A contributed to conception and design of the study and performed the fieldwork to collect the acoustic data. AV collected and processed the theodolite data. JB and KS performed the propagation modeling. SR analyzed and mapped the propagation modeling results. MR-B and LH-A analyzed the acoustic data, performed the statistical analyses, and maintained the shared database of results. MR-B and LH-A also wrote the first draft of the manuscript. KS, JB, SR, and AV wrote sections of the manuscript. AL-A served as main advisor to the two student authors and KS served as their topic advisor. All authors contributed to manuscript revision, read, and approved the submitted version.

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Challenges of Whale Watching and Swim With Dolphins in Mexico

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Mexico is one of the top 10 whale-watching destinations in the world. The target species for "whale watching" (WW) are the gray whale, blue whale, humpback whale, and fin whale; the target species for "swim with dolphins" (SWD) are the bottlenose dolphin, spotted dolphin, spinner dolphin, and killer whale. WW has an increment of 666% income, 94% of trips, and 51% in the jobs generated in the last 11 years. Although Mexican legislation to regulate WW appears to be well designed, the great challenge is applying this normative in the field. In particular, it has been observed that surveillance and enforcement of normative differ significantly whether WW has carried out within a Marine Protected Area (MPA) or area without such designation. WW of gray and blue whales in El Vizcaíno Biosphere Reserve and Bahía de Loreto National Park, respectively, is developed within the MPAs. They are considered examples of acceptable WW practices. In contrast, in places without protected status as Puerto Vallarta, Jal., and Los Cabos, Baja California Sur (BCS), the WW practices have different problems related to boats' presence without permission as sport fishing boats, private boats, and jet skis that do not respect WW guidelines. On the other hand, creating normativity or policies to regulate SWD in Mexico represents a current challenge. It is also a challenge to promote that local communities are involved in carrying out WW and SWD and are included in granting permits and the jobs and benefits of the economic spillover that these tourist activities generate.

Keywords: whales, dolphins, whale watching, normativity, Mexico, Turismo

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INTRODUCTION

Mexico is one of the top 10 whale-watching (WW) global destinations. It is the first in Latin America and the second in the American continent after the United States (Hoyt and Iñíguez, 2008). The first trips were in 1970 when ships filled with United States tourists departing from San Diego traveled on self-contained 7- to 10-day cruises down the Baja California coast to reach San Ignacio's lagoons Ojo de Liebre (Hoyt, 2008). In the late 1980s, the local communities around gray whales' breeding lagoons from the west coast of the Baja California Peninsula began to profit from WW using their boats. WW grew as a diverse industry. In the 1990s, it spread from the western to the eastern coast of the peninsula, from the lagoons to Loreto Bay, attracted by blue whales. The WW moved to the mainland coast, especially to Bahía de Banderas in Jalisco and Nayarit's states drawn by humpback whales. At the beginning of the century, it expanded north to Todos Santos Bay in front of Ensenada, taking advantage of gray whales' migration. It grew south to Los Cabos, in the southern end of the Baja California Peninsula to use humpback whales. In the last decade, on the mainland coast, it began north in the Upper Gulf of California, taking advantage of fin whales' resident population (DOF, 2019) and started south in Guerrero and Oaxaca states to use humpback whales (DOF, 2015). Besides WW, another interaction with cetaceans was implemented as a tourist attraction: the "dolphins watching" (DW) and "swim with dolphins" (SWD). Both activities began in Jalisco in 2000, taking advantage of bottlenose dolphins. In Sinaloa, since 2015 on bottlenose, spotted, and spinner dolphins, and recently in Baja California Sur, in 2018 using killer whales.

In Mexico, WW of baleen whales and sperm whales is regulated by the 131 Official Mexican Standard, which was implemented in 1998 (NOM-131-SEMARNAT, 1998; DOF, 2011). Its objective is to minimize human activity's negative impact, following scientific reports and experiences in other countries. Cetaceans modify their behavior in the short term in the presence of tourist boats. For example, the actions record them spending less time on the surface, increase their diving time (Nowacek et al., 2001), swim faster (Williams et al., 2002; Lundquist et al., 2013), or show erratic movements (Senigaglia et al., 2016). Also, it is proposed that the noise generated by the engines of the boats can affect the vocalization patterns (Jensen et al., 2009), among other potential effects.

Even though WW in Mexico has grown explosively as in the rest of the world (Finkler and Higham, 2020), there are few systematic studies about WW. These papers are reduced to analyze WW on gray whales that arrive in Laguna de San Ignacio, Ojo de libre (Brenner et al., 2016), and Bahía Magdalena (Paredes-Lozano, 2016; Schwoerer et al., 2016). On the other hand, it should be noted that despite the adverse effects of WW being recorded in odontocetes (Bejder et al., 2006, IWC, 2007, Senigaglia et al., 2011), there is still no law to regulate the observation of dolphins in Mexico. There is also no regulation for swimming with whales or dolphins, despite the evidence on behavioral changes in this activity (Lundquist et al., 2013; Sprogis et al., 2020). This document aims to present an overview of WW in Mexico, based on published information, data provided by tour operators, non-governmental organizations, and our field experience since 1980.

WW TARGET SPECIES

There are records of eight species of mysticetes in the Mexican Pacific, including the Gulf of California. Of those, three migratory—gray whale (*Eschrichtius robustus*), humpback whale (*Megaptera novaeangliae*), and blue whale (*Balaenoptera musculus*)—and one with a resident population within the Gulf of California, the fin whale (*Balaenoptera physalus*), is the target of WW in Mexico (**Table 1** and **Figure 1**).

Gray Whale, *Eschrichtius robustus*

Gray whales occur most frequently in shallow coastal waters in the North Pacific. Two populations are recognized: the endangered western population of about 300 individuals that summer in the Okhotsk Sea in Russia; and the eastern population of more than 21,000 individuals that summer in the Bering, Chukchi, and Western Beaufort Seas (Swartz, 2018). Individuals from both populations migrate from their summer feeding grounds to their winter breeding and calving areas off the Baja California peninsula (Weller et al., 2012). The main wintering areas on the peninsula are the Ojo de Liebre Lagoon, San Ignacio Lagoon, and Magdalena Bay Lagoon complex (Urbán et al., 2003).

Humpback Whale, *Megaptera novaeangliae*

Humpback whales are distributed in all the world's oceans. It is a highly migratory species. It is distributed in its feeding areas during the spring–autumn, located in waters of middle or high latitudes. Later in winter, it goes to its delivery areas in the tropics (Clapham, 2018). Of the North Pacific population, an abundance of 21,808 (CV = 0.04) has been estimated (Barlow et al., 2011). Although the structure of this population is not clear, some migratory connections have been established. The reproductive groups distributed in the coasts of Japan, Hawaii, and the north of the Mexican Pacific (Baja California-Nayarit) feed mainly on the Kamchatka Peninsula, the Bering Sea, and the Gulf of Alaska. In the winter nursery areas of southern Mexico and Central America, they feed in Canada and the United States (Calambokidis et al., 2008; Baker et al., 2013). In the Mexican Pacific, humpback whales aggregate at the southern tip of the Baja California peninsula, particularly between Cabo Pulmo and Cabo San Lucas, around the Tres Marías Islands and Isla Isabel, and off the mainland coast from Mazatlán to Chiapas (Central America) (Urbán et al., 2000).

Blue Whale, *Balaenoptera* Musculus

The blue whale is a wide-ranging species distributed throughout the world's oceans in the coastal, shelf, and oceanic waters (Sears and Perrin, 2018). The blue whales from the Eastern North Pacific population are summering in California and Oregon and migrate to the southwest coast of the Gulf of California from Loreto to Los Cabos during winter and spring (Urbán, 2010). Nevertheless, there are records of blue whales during all seasons as north as the Midriff Islands (SEMARNAT, 2018). Gendron and Gerrodette (2003) estimate the population size of 362 individuals (CI = 47.5%) in the Gulf of California.

Fin Whale, *Balaenoptera physalus*

Fin whales are found in all the world's oceans from the equator to polar regions; the largest concentrations are temperate and cold waters (Aguilar and García-Vernet, 2018). There is a resident population of fin whales in the Gulf of California (Bérubé et al., 2002; Urbán et al., 2005) with a generalized pattern of distribution: in the northern Gulf and from Canal de Ballenas to Bahía de La Paz in winter and spring; and in the Midriff Islands and Bahía de La Paz in summer and fall. The fin whale population size in the Gulf of California has been estimated at 656 individuals (95% CI 374–938) (Díaz-Guzmán, 2006).

TABLE 1 | Sites, species, and periods of WW and SWD in Mexico.

State	Site	Period	Activity	Species
Baja California	Bahía de Todo Santos	December 15–April 15	WW	Gray whale
Baja California Sur	Pto. Adolfo López M., Pto San Carlos, Bahía Magdalena Bahía de Santa Maria, Pto. Cancún, Pto. Chale	January 01–April 30	WW	Gray whale
	Bahía de Loreto National Park*	January 01–April 30	WW	Blue whale Fin whale
	El Vizcaino Biosphere Reserve*	December 15–30 April	WW	Gray whale
	Cabo San Lucas, San José del Cabo, Cabo Pulmo National Park*	December 15–30 April	WW	Humpback whale Gray whale
	Los Frailes-Bahía de La Paz	June–August	SWD	Killer whales
Sonora	Puerto Peñasco	January 01–April 30	WW	Fin whales
Sinaloa	Mazatlán-Teacapán	December 08–March 31	WW	Humpback whales
		April–December	SWD	Bottlenose dolphin Spotted dolphin Spinner dolphin
Nayarit	Bahía de Banderas	December 08–March 23	WW	Humpback whales
		April–December	SWD	Bottlenose dolphin
	Compostela	December 01–March 23	WW	Humpback whale
	San Blas-Isla Isabel	December 01–March 23	WW	Humpback whale
Jalisco	Bahía de Banderas	December 01–March 23	WW	Humpback whale
	Bahía de Tenacatita	December 08–March 23	WW	Humpback whale
Guerrero	Playa La Majahua	December 15–March 20	WW	Humpback whale
	Barra de Potosí	December 15–March 20	WW	Humpback whale
	Zihuatanejo de Azueta y Petatlán	December 15–March 20	WW	Humpback whale
Oaxaca	Puerto Angel-Mazunte	December 05–March 21	WW	Humpback whale
	Puerto Escondido-Bahía Principal-Puerto Angelito	December 15–March 21	WW	Humpback whale

**Marine protected area.*

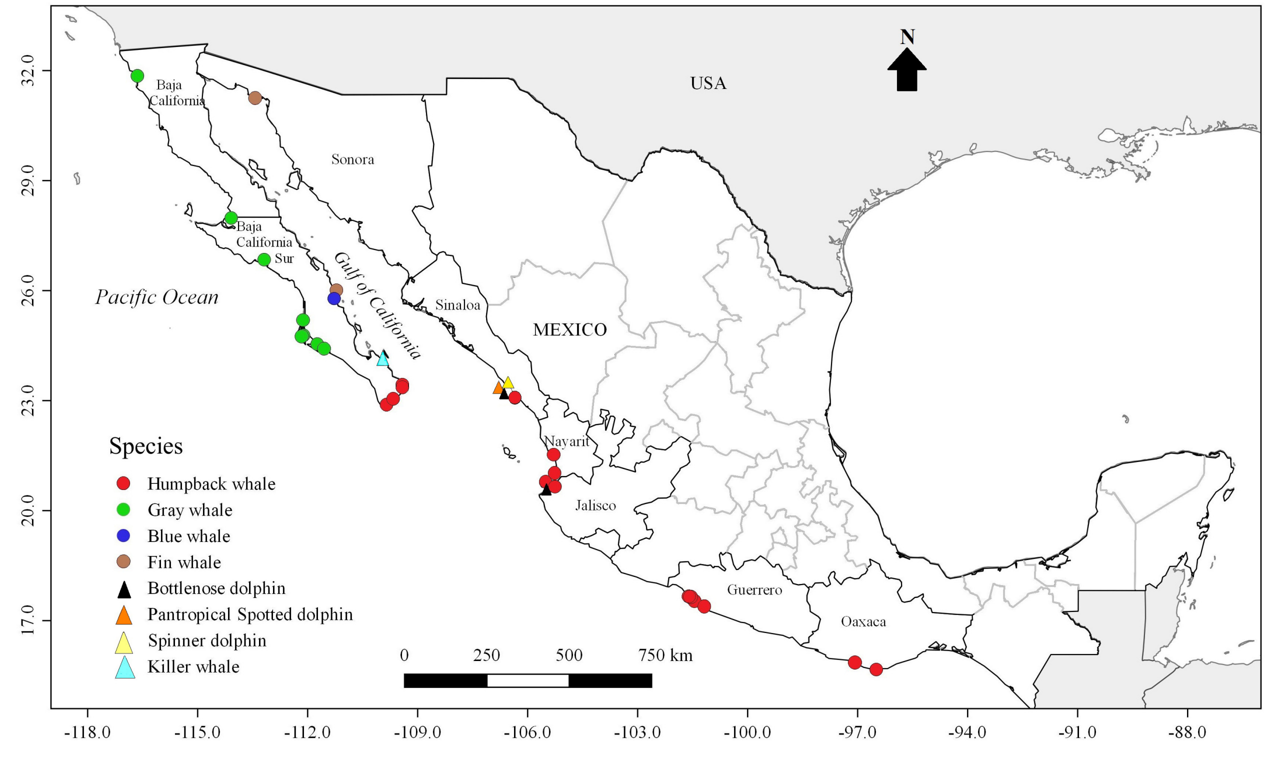

FIGURE 1 | WW and SWD sites in México.

SWD AND DW AND TARGET SPECIES

Regarding the odontocetes, of the 25 species distributed in the Mexican Pacific (Medrano and Urbán, 2018), four species are targeted to SWD: the bottlenose dolphin (*Tursiops truncatus*), the spotted dolphin (*Stenella attenuata*), the spinner dolphin (*Stenella longirostris*), and the killer whales (*Orcinus orca*) (**Table 1** and **Figure 1**). There are no DW companies with specific target species. The DW is complimentary during WW or SWD trips.

Bottlenose Dolphin, *Tursiops truncatus*

Bottlenose dolphins exist worldwide in temperate and tropical waters, with populations occurring in coastal waters, around islands and atolls, and over shallow banks and offshore in deep water (Wells and Scott, 2018). Differences in morphology, feeding habits, and parasite loads suggest at least two distinctive forms, coastal and offshore, in the eastern North Pacific and the Gulf of California (Walker, 1981; Díaz-Gamboa, 2003). This species is one of the most frequently seen dolphins. The bottlenose dolphins related to the DW and SWD belong to the coast. There is an estimated 33,799 (95% CI = 20,500–58,358) to the Gulf of California (Gerrodette and Palacios, 1996).

Pantropical Spotted Dolphin, *Stenella attenuata*

Pantropical spotted dolphins are found throughout the world's tropical and subtropical regions, between about 40°N and 40°S (Jefferson et al., 2015). It is the most-abundant dolphin in the Gulf of California and southern Mexico, especially off the coasts from Sinaloa to Chiapas. Two subspecies of the pantropical spotted dolphin (the offshore species, *S. attenuata attenuata*, and the coastal *S. attenuata graffmani*) have been identified in the Eastern Tropical Pacific (Perrin and Hohn, 1994). Although the coastal species is most common, both species' records have been documented on Mexico's coasts. The spotted dolphins related to the DW and SWD belong to the subspecies *S. attenuata graffmani*. The abundance estimation of this species in the Eastern Tropical Pacific is around 640,000 individuals (Perrin, 2018a).

Spinner Dolphin, *Stenella longirostris*

Spinner dolphins are found around the world in tropical waters (Jefferson et al., 2015). The observations of this species in the Mexican Pacific, including the Gulf of California, belong to the subspecies *S. longirostris orientalis*, and possible *S. longirostris centroamericana* described in the Eastern Tropical Pacific (Perrin and Gilpatrick, 1994). The spinner dolphins related to the DW and SWD belong to the subspecies *S. longirostris orientalis*. Abundance estimates of this species in the Eastern Tropical Pacific are around 800,000 individuals (Perrin, 2018b).

Killer Whale, *Orcinus orca*

Killer whales, or orcas, are the world's most widespread mammal, found from the tropics to high latitudes in both hemispheres and oceanic and coastal areas (Ford, 2018). Between 1973 and 2013, 246 sightings were reported, including 246 individuals photo-identified throughout the Gulf of California. Group size ranged from 1 to 45 animals, with an average of 5.6 individuals per group (Guerrero-Ruiz, 2013). Five resident "pods" of killer whales have been documented in the Gulf of California (González-Ruelas, 2016). Recently, it was proposed that the killer whales from the Mexican Pacific belong to the ecotype "Eastern Tropical Pacific" (Vargas-Bravo et al., 2020).

WW AND SWD PLACES AND SEASONS

The Environment and Natural Resources Ministry from Mexico (SEMARNAT) publishes every year the places and periods where WW is permitted (e.g., DOF, 2020). The timing of the WW season depends on the time of the arrival of the migratory species and the latitude of the WW place (**Figure 1** and **Table 1**).

The humpback whale is the species with more WW official sites (21), including Baja California Sur, Sinaloa, Jalisco, Nayarit, Guerrero, and Oaxaca. This species' sighting is carried out from boats of different sizes, that is, from small ships of 23 ft to catamarans of 75 ft. The second species with more WW official sites is the gray whale (9), including Baja California and Baja California Sur. WW is performing during the migration in the open sea to and from the breeding lagoons. While in Ensenada, Baja California, medium-sized boats are permitted, in the breeding lagoons, BCS, only small ships of 22–27 ft. named "pangas" are allowed. There are two WW official sites for the fin whale: Loreto on the east coast of BCS and in the Upper Gulf of California on Sonora's coast, where pangas and medium-sized boats are permitted. Finally, the blue whale has only one WW official site in Loreto on the east coast of BCS, and only pangas are allowed.

On the other hand, there are no official observation sites for SWD. The swim with bottlenose dolphins is done in Sinaloa and Jalisco, using pangas from May to December. The swim with spotted and spinner dolphins is done in Sinaloa, using pangas and farther from the shore than the bottlenose dolphins. The swim with orcas is done on the southeast coast of BCS, using small airplanes to localize the orcas and pangas to approach and swim with them. The activity is done in summer when the mobulas (*Mobula mobular*) arrive in this area, and the orcas feed on them.

DEVELOPMENT OF WW IN MEXICO IN THE LAST 10 YEARS

The SEMARNAT (2020) reported that WW activity increased in the last 10 years (2009–2019), by 666% in income, 94% in the number of trips, and 51% in the jobs generated. WW targeting humpback whales is the one that caused the most revenue, travels, and employment in 2019. For example, of the total profits (US $ 7,782,602) with the three species (humpback, gray, and blue whale), 81% corresponds to the WW with the humpback whale, as well as 68% of the trips and 74% of the work (**Figure 2**).

Such a growth rate suggests that this tourism industry has growth potential in the current decade. At the same time, it

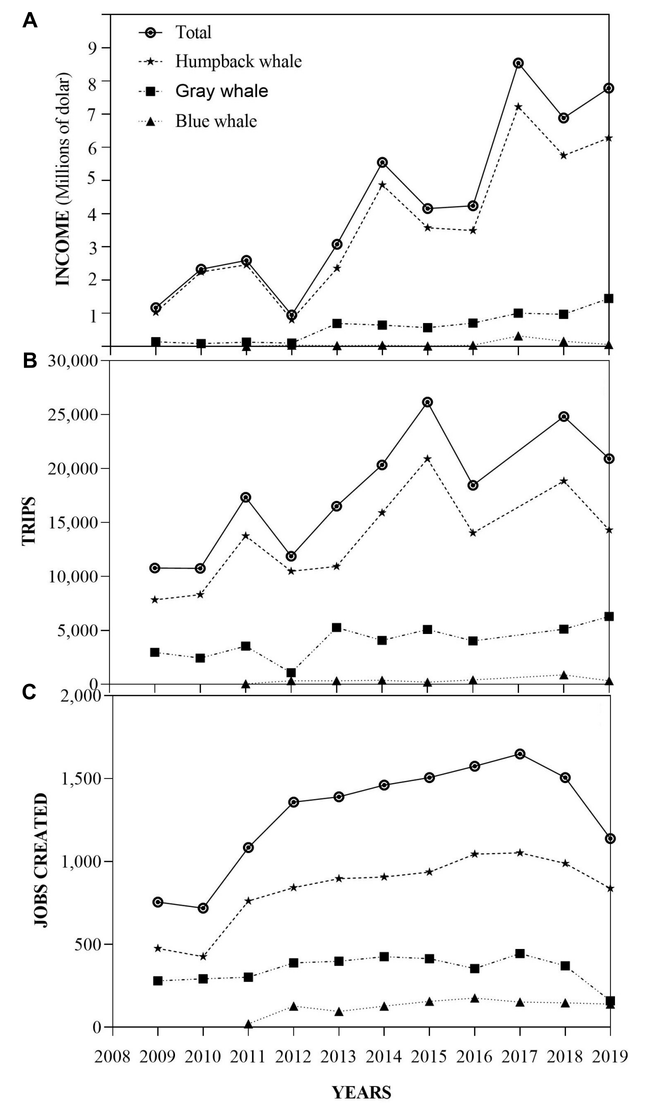

FIGURE 2 | Growth indicators for WW in Mexico 2009–2019, for humpback whales (*Megaptera novaeangliae*), gray whales (*Eschrichtius robustus*), and blue whales (*Balaenoptera musculus*): **(A)** income, **(B)** trips, and **(C)** jobs created. Data from SEMARNAT (2020).

represents a potential increase in the number of boats and people seeking to access the whales' environment and get closer to the whales themselves. Unfortunately, there are no systematic records or studies that help in the modeling of upcoming scenarios. It is discouraging to think of excessive growth in the whale resource's use and the inappropriate use of the marine environment in the current context.

Remarkably, the economic gains generated by WW of the humpback whale can be attributed to its biological characteristics. This species mainly shows high activity on the surface, displaying showy movements. The whales' widest distribution has led to numerous sighting points in different locations in the Mexican Pacific. Such development of the WW industry around this species supposes major pressure, so it also demands scientific studies that record WW's effects.

LEGAL MEXICAN FRAMEWORK

In Mexico, all marine mammals are protected by the Official Mexican Standard 059 (DOF, 2002a), which includes the risk category and promotes conservation actions for each species. In 2002, Mexico signed a decree that establishes a refuge for great whales in all the Mexican territory's marine areas and the waters where Mexico exercises its sovereignty and jurisdiction (DOF, 2002b). That same year, the General Wildlife Law prohibited the extractive use of any marine mammal. It began to promote non-extractive use to conserving marine mammals and favoring the sustainable development of the population and regional economies (LGVS, 2002).

The Official Mexican Standard 131 (DOF, 2011) establishes guidelines and specifications for developing WW activities (mysticetes and sperm whales) to protect and conserve the whales and their habitat. Depending on the species, vessels must respect the minimum distances established (between 60 and 100 m) and maintain speeds below 9 km/h when entering the whale or dolphin watching area and 4 km/h during the WW. Boats should also avoid sudden changes in direction and speed. A maximum of four ships can approach a single whale or group of whales at a time, among other specifications.

In the Mexican legislation, there are no regulations for DW or swimming with whales or dolphins. In the dolphins' case, more and more tourism service providers advertise these tours on their internet pages. In swimming with humpback whales, so far, there are no announcements about these types of tours, but it is known that "opportunistic" events occur with increasing frequency.

CONCLUSIONS

The Mexican Pacific encompasses subtropical and tropical waters from the Northeast Pacific and are the migratory destination of three of the most attractive whales in WW: the blue whale, the gray whale, and humpback whale. The distribution area for the resident population of fin whales is in the Gulf of California all year. The regular presence of whales, proximity to shore, and good weather have been essential in developing WW in this country.

Legislation to regulate WW in Mexico is considered well designed and aims to minimize tourist activity. In Mexico, no specific investigations have been carried out to know the short-, medium-, and long-term impact of this activity. However, the current legislation is governed by the precautionary principle and the results of other countries' investigations (Nowacek et al., 2001; Williams et al., 2002; Jensen et al., 2009; Lundquist et al., 2013).

Although the Mexican legislation about the marine mammals, and specifically with the WW in Mexico, is good, the great challenge is to apply the normativity in the field. Since the MPAs responsibilities are to monitor and evaluate WW activities, there is a significant difference in WW surveillance degree depending on if they are happening an MPA or not. In the case of gray whales in the Ojo de Liebre and San Ignacio Lagoons, which are part of the El Vizcaíno Biosphere Reserve, they are considered examples of good WW practices in the world (Hoyt, 2011; IWC, 2018). The only official WW site for blue whales is located in another MPA, the Bahía de Loreto National Park. Another example of good practices, where passive observation is conducted, is a novel way of approaching and observing whales (IWC, 2018).

On the other hand, the remaining official WW sites for humpback whales (20 sites, **Table 1**) are not within MPAs, except Cabo Pulmo National Park. In the case of Puerto Vallarta, Jal., and Los Cabos, BCS—the two most important tourist destinations WW with humpback whales in Mexico—tour operators with a WW permit must take a training course to follow all the guidelines of NOM-131. But the problem is with boats that are not licensed and do WW activities, such as sport fishing boats, private yachts, and jet skis.

These site situations become complex since low or no surveillance, economic interest, and low respect for nature make these sites dangerous for people and humpback whales. To mitigate this situation, civil associations give training workshops to WW tour operators and activate campaigns such as "Sail with caution in whale season" by Whale Ecology and Conservation (ECOBAC AC) in Puerto Vallarta. Our research group PRIMMA (Marine Mammal Research Program) has given courses on good WW practices aimed at the local communities and tourism service providers (in Puerto Chale, Puerto Peñasco, Bahía Magdalena, Los Cabos, among others). Despite the efforts, the results have not yet been perceived, which is why an intense campaign to raise awareness about the impact of WW's bad practices is necessary. In this campaign, all key stakeholders (authorities, tour operators, tourists, scientists, fishermen, etc.) should be involved and act in consequence.

Another strategy on a larger scale in time and space is to create more MPAs covering areas with high WW activity, such as the Los Cabos region. We elaborated the proposals of three priority areas for the conservation and management of great whales. One on the west coast of the Baja California Peninsula from Laguna San Ignacio to Bahía Magdalena focused on gray whales (Viloria-Gomora et al., in press). Another around the tip of the Baja California Peninsula from Cabo San Lucas to Cabo Pulmo focused on humpback whales (Urbán et al., in press-a). And in the east coast from Loreto to Cabo Pulmo with an emphasis on blue whales, fin whales, humpback whales, and killer whales (Urbán et al., in press-b). The next steps for these documents will be to submit them to the Mexican government to consider their eventual acceptance.

There is a need for SWD regulations that establish rules to make the activity safe, both for humans and dolphins. The companies that currently offer SWD in Mexico adopted laws that are followed in other countries, including no touching dolphins, not feeding them, not swimming in groups of feeding dolphins, and not swimming in groups where more than 50% are calves, among others (Lewis and Walker, 2018). It is to standardize procedures for the different species and sites where SWD is performed. Today there is a consensus among the SWD stakeholders to create an Official Mexican Standard with the normativity and policies of the SWD appropriate to Mexico. Finally, another challenge in Latin America, Mexico included, is promoting WW and SWD acceptable practices, involving the local communities in these tourism activities to include them in the permits granted, jobs generated, and benefits of the increasing income.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: http://dgeiawf.semarnat.gob.mx:8080/ibi_apps/WFServlet?IBIF_ex=D3_BIODIV03_15&IBIC_user=dgeia_mce&IBIC_pass=dgeia_mce&NOMBREENTIDAD=*.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because it is not necessary, the study is about a tourism activity related to whales.

AUTHOR CONTRIBUTIONS

Both authors: conceptualization, funding acquisition, writing—original draft, and writing—review and editing.

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Tourist Knowledge, Pro-Conservation Intentions, and Tourist Concern for the Impacts of Whale-Watching in Las Perlas Archipelago, Panama

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Whale watching has become an important economic activity for many coastal areas where whales aggregate at certain times of year. Las Perlas Archipelago in Panama is a breeding ground for humpback whales, where the numbers of both visitors and tour operators have increased in recent years with little compliance and enforcement of regulations. Nevertheless, there is potential to improve whale-watching management at this site and its use as a tool for education and conservation awareness. Our objective was to assess tourist knowledge, perceptions and pro-conservation attitudes related to whale watching and how this activity is managed in Las Perlas. One hundred and eleven tourists were surveyed in the summer of 2019 after they participated in whale–watching tours. Overall, respondents had little knowledge about whales and their conservation before a whale-watching trip. However, after the excursion, tourists felt they had learned more about whale biology and the regulations for whale-watching. Trip satisfaction after whale-watching activities was higher when whale behaviors, including breaching and tail slaps, were observed. Respondents expressed low satisfaction when there was an excessive number of boats around a whale-sighting. Concern for lack of compliance seemed to be associated with whale-watching operations that onboard tour guides. This study highlights the importance of whale watching as a tool for promoting whale conservation through education and the need to improve the enforcement of existing regulations and visitor monitoring to reduce potential negative impacts of whale-watching.

Keywords: whale-watching, tourist knowledge, satisfaction, management measures, conservation attitudes and behaviors

INTRODUCTION

Whale watching has become a significant sector of the nature-based tourism industry (Higginbottom, 2004). Commercial whale watching started in the 1980s and is categorized as an ecotourism activity because it can be ecologically sustainable while simultaneously fostering cultural and environmental appreciation for the marine environment

(O'Connor et al., 2009; Wearing et al., 2014). Whale watching is considered a viable alternative to whaling (Einarsson, 2009; Cunningham et al., 2012), as it also supports coastal communities and offers them a sense of identity and pride (Hoyt, 2001; Rossing, 2006; Hoyt and Iñíguez, 2008; Peake et al., 2009; Cisneros-Montemayor et al., 2010; Schwoerer et al., 2016; Guidino et al., 2020).

However, there are growing concerns about the negative impacts the whale-watching industry may exert on cetacean populations (Orams, 2004; Parsons, 2012; Cressey, 2014; Sitar et al., 2016; Kassamali-Fox et al., 2020). Direct impacts, such as vessel collisions can injure whales (Nielson et al., 2012; Guzman et al., 2013). Vessel presence and overcrowding can induce short-term behavioral changes, including movement and speed changes (Morete et al., 2007; Scarpaci and Parsons, 2015; García-Cegarra et al., 2019), path changes to avoid vessels (Williams et al., 2002; Stamation et al., 2010; Schaffar et al., 2013; Fiori et al., 2019; Amrein et al., 2020) and changes in activity budget like resting less (Senigaglia et al., 2016). Additionally, noise pollution from whale watching boats can induce changes in call duration and impair cetacean communication (Foote et al., 2004; Rossi-Santos, 2016). Therefore, effective whale-watching management is pivotal to ensure the sustainability of this activity and protect the cetacean populations on which the industry depends (Gleason and Parsons, 2019).

Furthermore, the whale-watching experience can influence tourists' positive attitudes and encourage them to appreciate and protect cetaceans (Finkler and Higham, 2004; Wearing et al., 2014; Hoberg et al., 2020). Marine wildlife tours have the potential of providing educational benefits as many of them include on-site environmental interpretation (Orams, 1995a,b; Schanzel, 2004; Zeppel and Muloin, 2008). Environmental interpretation is defined as an on-site educational activity that typically takes place during visitors' leisure time, and consists of information being provided by a tour guide to a voluntary audience (Orams, 1995b; Ham and Weiler, 2002; Lück, 2003). In the context of whale watching, tourists can learn about whale and dolphin biology, ecology, and conservation (Birtles et al., 2002; Lück, 2003; Stamation et al., 2007; Lopez and Pearson, 2017), which can potentially shape their beliefs and attitudes toward cetacean conservation. This could then influence pro-conservation intentions and behaviors in the future, such as intention to join responsible tours, and donations to environmental organizations or volunteer work, respectively (Mayes et al., 2004; Andersen and Miller, 2006; Filby et al., 2015; Cheng et al., 2018; Clark et al., 2019). Although conservation intentions do not necessarily transform into behavior, they could influence behavior over time if there are strong motivations, facilitating conditions, opportunities and guidance to perform the behavior (Ajzen et al., 2009; Jacobs and Harms, 2014).

While previous studies have emphasized the importance of environmental interpretation and how it influences tourist satisfaction and pro-conservation intentions, Latin American countries have been largely overlooked, with one exception in Peru, where García-Cegarra and Pacheco (2017) found a significant improvement in tourists' knowledge on whale ecology, conservation and the impacts of whale watching by testing their responses before and after whale-watching tours.

Whale-watching activities were established in Panama in the late 1990s (Sitar and Parsons, 2019). Since then, the whale-watching industry in Panama has grown and it is especially developed in Bocas del Toro, where dolphin watching is the main activity (Hoyt and Iñíguez, 2008). In 2017, the Panamanian government issued whale-watching regulations that included vessel speed limits, maximum observation times and the maximum number of vessels observing a group of cetaceans at the same time (Ministry of the Environment, Republic of Panama, 2017). However, the International Whaling Commission (IWC) has recently raised concerns over the sustainability of dolphin-watching tours in Bocas del Toro [International Whaling Commission (IWC), 2019], where the levels of non-compliance to the national whale-watching regulations are consistently high (Sitar et al., 2016; Sitar and Parsons, 2019). These frequent violations have influenced tourists' negative attitudes and low satisfaction with the dolphin-watching operations (Sitar et al., 2017). Similarly, whale-watching regulations are not being strictly followed in the Marine Protected Area of Las Perlas Archipelago (Amrein et al., 2020), which is an important breeding and calving area for humpback whales in Panama (Guzman et al., 2014). Although the whale-watching industry in Las Perlas developed later than in Bocas del Toro (Hoyt and Iñíguez, 2008), currently, at least four private tour operators and an unknown number of informal tours operating without licenses offer whale-watching trips. This increasing tourism activity, together with the lack of regulation enforcement and visitor monitoring, is causing changes in the behavior of humpback whales related to increased vessel presence (Amrein et al., 2020).

In this paper we present a preliminary assessment of tourist knowledge, perceptions, motivation, satisfaction, and pro-conservation attitudes related to whale watching and how this activity is managed in Las Perlas. This study aims to gain knowledge of the tourists' perspectives of the type of outcomes resulting after a whale-watching experience. We expect that tourism opinions and perspectives will help to refine the current management actions of the activity.

MATERIALS AND METHODS

Study Area

Las Perlas Archipelago includes over 200 islands and islets 60 km southeast of Panama City in the Gulf of Panama, Pacific Ocean (8°25′N, 7°91′W; see map in **Figure 1**). The archipelago encompasses an area of 168,771 ha, of which 135,618 ha are waters surrounding the islands, and it was declared a Marine Protected Area in 2007. The entire area is shallow, averaging 15 m depth and not exceeding 50 m. Here, the population of humpback whales is identified as Breeding Stock G [International Whaling Commission (IWC), 1998], which is one of the seven "stocks" inhabiting oceans in the southern hemisphere. The humpback whale population of this archipelago is estimated to be around 1,000 individuals, with about 25–50 calves born annually

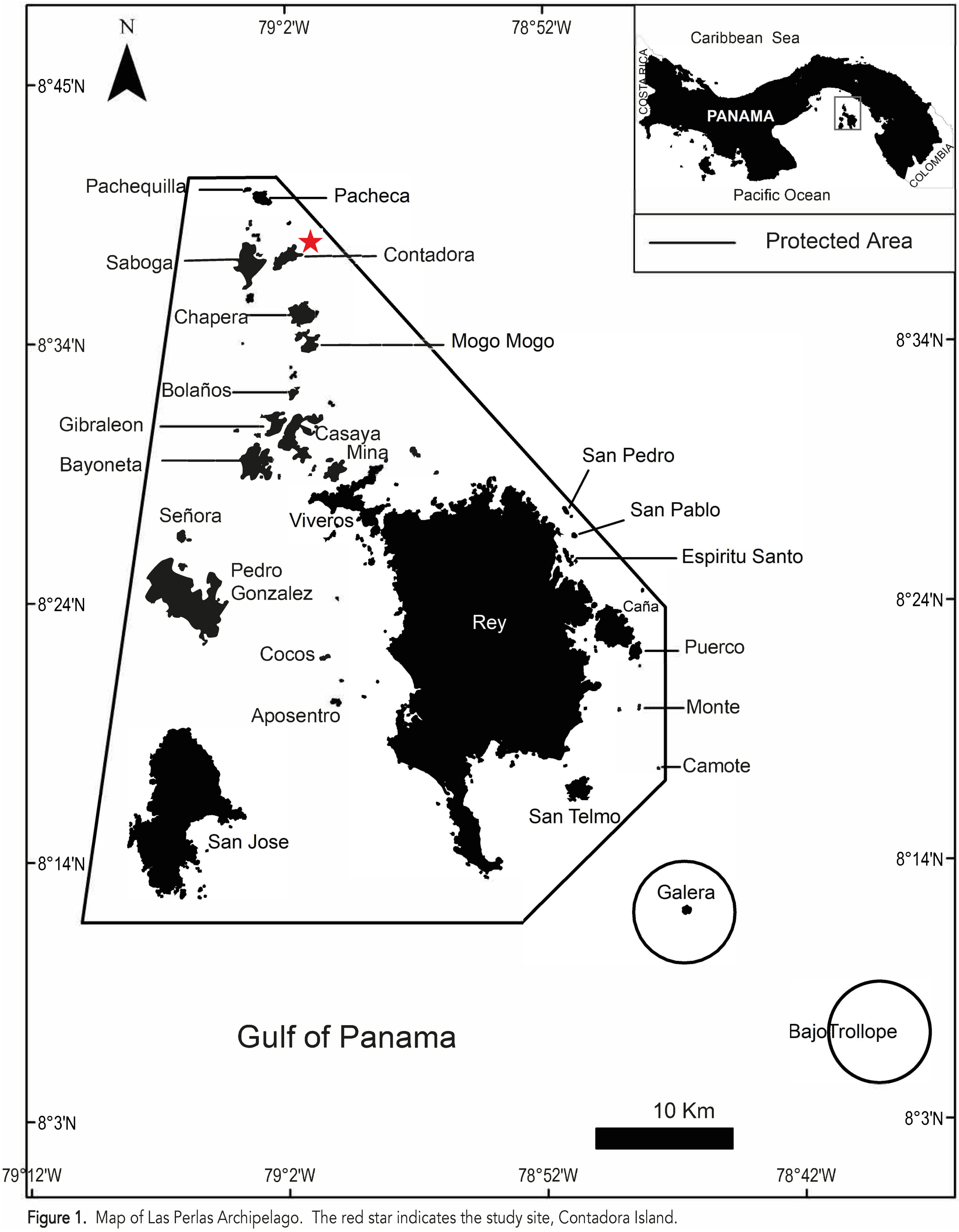

FIGURE 1 | Map of Las Perlas Archipelago. The red star indicates the study site, Contadora Island.

(Guzman et al., 2015). Breeding lasts from June to December, with peaks in August and September. The largest island within the archipelago is Contadora, with an estimated population of 300 inhabitants. Our study focused on this island because it is the main growing tourist destination in the area, and it is known for its remote location and secluded beaches. At the time of the study, two main tour boats offered whale watching from this island, each with a capacity for 20 passengers and often included a tour guide. Local fishermen also provide informal whale-watching tours, operating without licenses from the main beaches located in the island. Whale—watching trips last for 3 h on average, and they can be organized for any time during the day.

Survey

Data for the analysis were obtained from a survey of tourists visiting Contadora Island. In the first section of the survey, respondents were asked about their knowledge about whale behavior, threats and conservation, before and after their whale-watching experience. The second section addressed their motivations and expectations, including the importance they placed on observing different whale behaviors. Finally, they were asked to rate their satisfaction with the experience, observations, and trip conditions (number of boats present, distance to the whales and boat speed). The survey also collected personal information from respondents about their attitudes, perceptions and beliefs toward whale conservation and socio-economic and demographic variables.

Surveys were implemented during August 2019 and were distributed to tourists who either took a formal whale-watching tour or an informal tour with a local fisherman. Based on the best available data[1] on tourists visiting Contadora, an estimate of at least 1000 tourists arrived to this island in summer 2019, of which 150 tourists were invited to participate in this study and 111 of them completed the survey[2] (response rate 74%). The survey was a self-administered intercept survey, where every third tourist leaving Contadora Island was intercepted and asked to fill out the survey on their own and return it to the interceptor upon completion. Tourists were approached at the waiting area in Contadora's main dock prior to boarding the boat to leave the island, and at the main beaches. The questionnaires were available both in English and Spanish for the purpose of covering both foreign and local tourists. The survey was conducted under approval from the Arizona State University Institutional Review Board.

Analytical Approach

Among socio demographic aspects, gender was recorded, nationality and residency status grouped into three main regions: North America, Latin America, and Europe & Asia. Age groups were classified according to human development stages (Erikson, 1968): teenagers (13 to 19 years), young adults (20 to 40 years), middle—age adult (41 to 64 years), older—adults (65 years and older). Contingency tables were used for descriptions of socio—demographic aspects. We used 5-point Likert—scales to score the following: knowledge gains after the trip, motivation, satisfaction, and agreement with whale conservation statements. To assess how much respondents knew about whales and their conservation, they were asked to rate on a 5-point Likert scale their knowledge before and after the trip. Four knowledge categories were considered: whale behavior, threats to whales, whale conservation and whale-watching regulations. We used a non-parametric Mann-Whitney test to evaluate differences between knowledge prior to and after the experience.

Satisfaction was analyzed from two different angles. An importance- performance (IP) analysis was performed to assess satisfaction compared to expectations (Martilla and James, 1977; Sever, 2015). In the survey, participants were asked to indicate "how important was seeing X behaviors" as a motivation for the trip, using a 5-point Likert-scale from 1 = not at all important to 5 = extremely important. Whale behaviors include breaching, blow, tail slap, head slap, pectoral fin slap, fins exposure, fluke dive, and spy hop. The importance per respondent (I) was then compared to the satisfaction rating of seeing these behaviors (P). The difference between I and P indicates whether expectations were met (negative values) or if they were not (positive values). In addition to the IP analysis, we used regression analysis to determine which factors related to whale observations and trip conditions influenced visitor satisfaction. All statistical analyses and tests were performed using the software Stata 16.

RESULTS

Socio—Demographic Characteristics

Of the 111 respondents who completed the survey, 51% were women. The average age of respondents was 43 years (see **Table 1**). Approximately 95% were foreigners and 5% from Panama. Respondents from Europe and Asia, particularly the Netherlands and Spain, accounted for 53% of all respondents. Latin American respondents accounted for another 27%, while the other 20% were tourists from the United States. Eighty six percent of the respondents had at least a 4-year university degree or higher, and more than 75% indicated having full-time employment. A mean of $91,000 USD with a standard deviation of $72,300 USD of household income was estimated from all respondents.

Knowledge Gains From the Whale-Watching Experience

Before taking a whale-watching tour, only 14.3% of survey respondents had a good or excellent knowledge about whale behavior, threats affecting whales and their conservation measures. After the whale-watching experience, respondents reported a significant 1-point median increase in knowledge about whales after their trip (see **Table 2**, $P < 0.01$). When comparing knowledge gains from the two type of whale-watching operations, we found significant differences between tour operators (mean = 0.81, median = 0.75, n = 39) and local fishermen (mean = 0.36, median = 0.25, n = 34, $P < 0.05$).

When asked about the new topics learned during the whale-watching tour, respondents emphasized whale behavior, including parental care, breeding, and communication behaviors, and migration patterns in the region. Most respondents were also aware of the threats affecting whales and indicated that ocean

[1]Records of passengers transported from Panama City to Las Perlas Archipelago from main maritime and air transportation companies, information, however, is incomplete.

[2]This sample size is small and it corresponds to 8.77% margin of error; however, results are still informative considering that it is a preliminary assessment.

TABLE 1 | Socio-demographic variables.

Socioeconomic variable	N = 111
Gender (%)	
Female	51%
Male	49%
Education Category (%)	
High school	10%
Some university	4%
Undergraduate degree	31%
Graduate work/degree	55%
Employment Category (%)	
Full-time employed	79%
Part-time employed	6%
Student	8%
Retired	5%
Unemployed/Unpaid	2%
Region of Origin (%)	
Europe & Asia	53%
Latin America	27%
North America	20%
Age Category (%)	
Middle-age adults	53%
Young adults	42%
Older adults	3%
Teenagers	2%
Income (2018 thousand $US dollars)*	
Median Income	55,0
Mean Income	91,1

**Income results are based on a sample of 75% of the population who answered the income question.*

pollution, climate change and improperly managed tourism are currently the most pressing threats requiring immediate action.

Motivations, Observations, and Satisfaction

Table 3 summarizes the main motivations and key observations of respondents. The results indicate that whale-watching is one of the main motivations to visit Contadora Island. Almost half of the respondents have seen whales in the past. During the study period, 99% of tourists surveyed saw whales exhibiting at least one behavior, with a median of four individual whales and five whale behaviors seen across the sample. Both the median motivation to see whale behaviors and the satisfaction to see these behaviors was "very important."

The IP analysis showed that most of the whale-watching experiences, 68%, meet or exceeded respondents expectations (**Figure 2**). In all these cases, the satisfaction of seeing whale behavior as part of the tour was the same or higher compared to initial motivation to see them. For 30 respondents, however, satisfaction levels were low. The main reasons indicated by respondents include not being able to see whales breaching, whales being too far away, not having enough time, lack of explanations, or desire for more interpretation, and bad weather conditions.

Results indicated that the median overall satisfaction for the whale-watching experience was rated high (4 out of 5, see **Table 3**). Regression results showed that this outcome is mostly driven by four variables: satisfaction of seeing whale behaviors ($t = 15.55$, $p < 0.001$); number of whale behaviors observed ($t = 1.69$, $p < 0.10$); proximity to the whales ($t = 2.30$, $p < 0.05$); and age ($t = 3.20$, $p < 0.01$). Other variables including: boats at high speed; whether respondents had observed whales prior to the trip; and gender did not have a significant effect on overall satisfaction (**Table 4**).

Respondent Reactions to Potential Impacts of Whale-Watching

Half of respondents did observe boats in close proximity to whales (55%) and boats going at high speed (52%) around the areas were whales are observed in Las Perlas Archipelago (**Table 3**). The vast majority of respondents, 87%, felt comfortable and excited to be close to the whales. A small number had safety concerns about being too close or about the potential impacts to whales. Our results showed a median of three additional boats at the same time in places where respondents watch whales, and in some cases up to six additional boats. Respondents were asked to indicate how comfortable they felt with the number of boats present at each place where they observed whales. Although comfort levels (as a satisfaction indicator) varied across the sample, median satisfaction represented in **Figure 3** with red diamonds showed a decrease with increasing boats at a same place. In fact, with six boats at the same time, most respondents under this circumstance felt a little comfortable (mean = 1.77, median = 2). On average, the maximum number of boats

TABLE 2 | Differences in knowledge about whales before and after the whale-watching experience.

Knowledge about. . .[a]	Before Trip			After Trip			Mann-Whitney test[b]	
	Mean	Median	SD	Mean	Median	SD		
Whale behavior	2,25	2,00	1,00	3,00	3,00	0,93	5,69	***
Threats to whales	2,51	2,00	1,07	2,94	3,00	1,07	2,76	***
Whale conservation	2,45	2,00	1,03	2,90	3,00	0,99	3,26	***
Whale-watching regulations	2,10	2,00	1,09	2,10	3,00	1,09	4,33	***

[a]*Knowledge measured in a 5-point likert scale: 1 = None to 5 = Excellent.* [b]*Significance of the Mann-Whitney test; statistically significant differences between distributions are indicated at the 1% (***).*

TABLE 3 | Summary of motivations, observations, and satisfaction related to the whale-watching experience.

	% Respondents		Mean	Median	SD
Motivation general		**Motivation (scale 1 to 5)**			
Whale-watching	45%	See whale behaviors	4,14	4,00	0,84
Enjoy beaches	21%	**Satisfaction (scale 1 to 5)**			
Recreational activities	9%	See whale behaviors	4,13	4,00	0,82
Other	26%	Overall (trip)	3,99	4,00	0,86
Observations					
Whales before	48%	**Observations**			
Whale behaviors (at least 1)	99%	Whale behaviors	5,12	5,00	2,39
Boats high speed	52%	Individual whales	7,00	4,00	6,00
Boats close to individual whales	55%	Mother & calf	1,80	1,00	1,20
Boats close to mother/calf	35%	Boats at same time	2,90	3,00	1,70

that respondents found acceptable at one location for a whale-watching experience was three.

Attitudes, Perceptions, and Intentions Toward Whale Conservation

Respondents showed strong positive attitudes and beliefs toward whale conservation (**Figure 4**). Approximately 75% of respondents agreed that whale conservation is important for society, that actions to protect whales should be implemented globally and that more education is required to reduce threats on whales. However, at least 53% of respondents were not sure that whale watching is an activity that promotes whale conservation. This may be explained by concerns expressed about tourism impacts or by negative tour experiences. Almost 80% of respondents felt a strong responsibility toward protecting whales. In addition, most respondents (72%) indicated a potential intention to not participate in whale-watching activities that would cause stress on whales. In addition to these attitude and belief statements, respondents were asked whether they would be willing to pay a fee to implement additional actions to conserve whales in this area. Although the sample size was too small for a comprehensive and statistically significant analysis of willingness to pay, the results gave some indication as to the potential for this initiative. Eighty percent (80%) of respondents stated that would be willing to pay a fee for this purpose with an average amount of 26.50 USD.

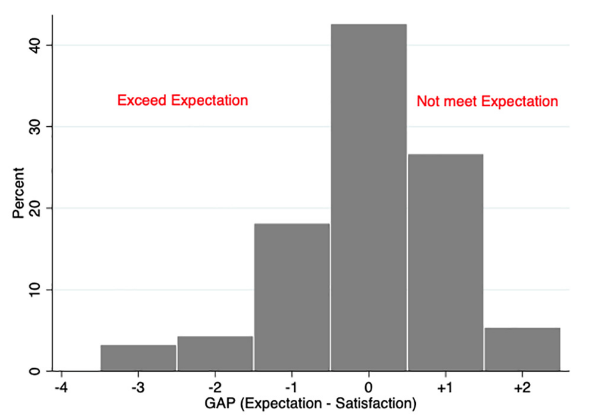

FIGURE 2 | Results of the Expectation-Satisfaction Gap Analysis.

TABLE 4 | Regression results: Factors influencing tourist satisfaction.

Explanatory variable	Coefficient	SD	
Constant	0,49	0,31	
Satisfaction and observations			
Satisfaction (see whale behaviors)	0,89	0,06	***
Whale behaviors observed	0,03	0,02	*
Observed whales before	0,02	0,09	
Observed boats high speed	-0,01	0,10	
Observed boats close to whales	0,24	0,10	**
Demographics			
Age	-0,01	0,00	***
Female	-0,03	0,09	

*Statistical significance: * = 10% level, ** = 5% level, *** = 1% level.*

DISCUSSION

Here, we provide the first qualitative analysis of some of the social aspects regarding a growing whale-watching activity in Las Perlas Archipelago in Panama. Our results suggest that during whale

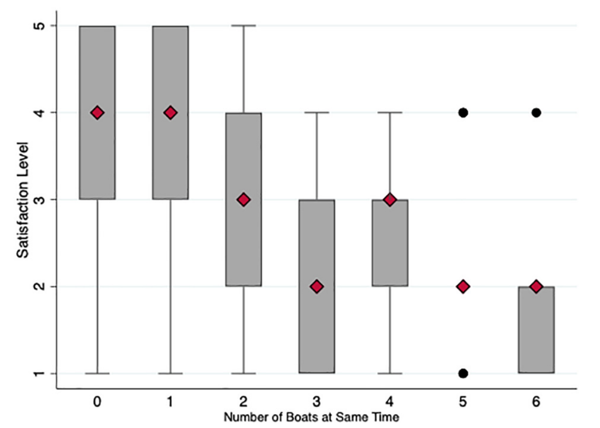

FIGURE 3 | Changes in respondents' satisfaction level with number of whale-watching boats present at a same time and location.

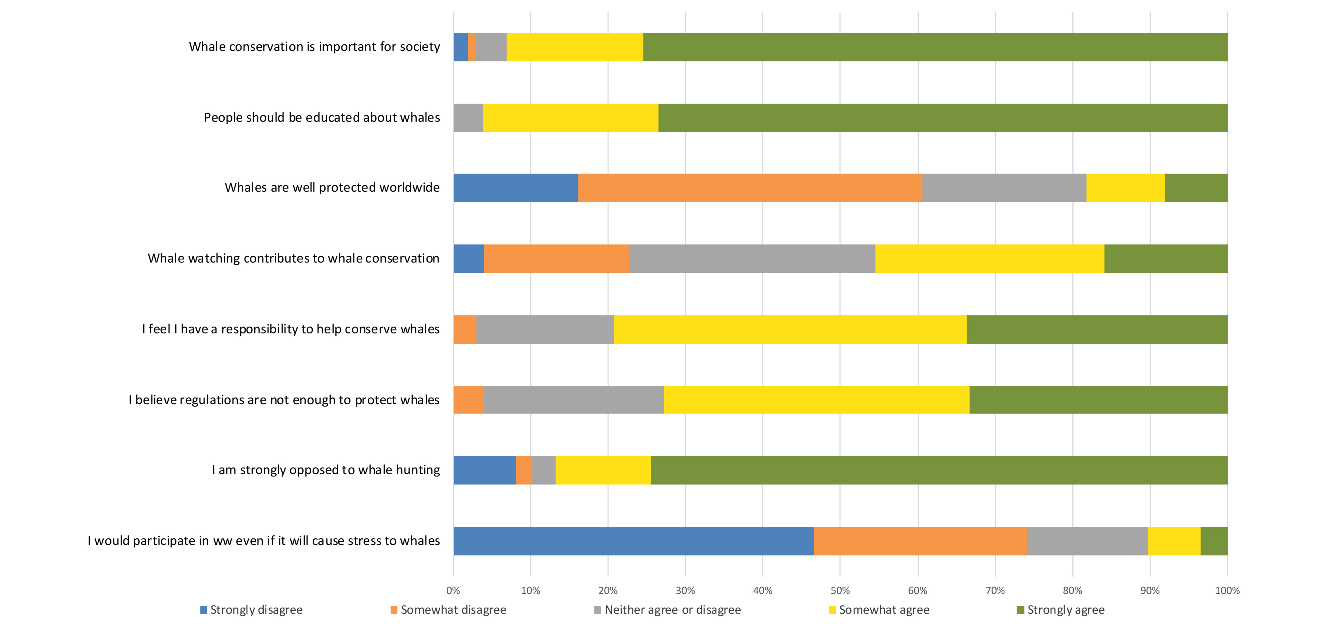

FIGURE 4 | Level of agreement with statements about whale conservation.

watching visitors gained new knowledge and awareness about whales and their conservation. In addition, we found overall high satisfaction levels after the nature-based experience, largely influenced by the positive impact of observing whale behaviors. Both outcomes highlight the role of whale-watching as a potential tool for enhancing knowledge about whales and connection with wildlife; for increasing awareness of whale conservation; and potentially for fostering pro-conservation attitudes and intentions. However, we also identified areas for improvement where these positive aspects can be further enhanced, and where whale-watching activities in this region can be better managed and enforced.

Enhancing the Learning Experience From Whale-Watching

Of the respondents who participated in a whale-watching tour during the study, 63% gained new knowledge about whales. This shows that 37% of the respondents did not learn something new after the trip. This may be partly explained by the large percentage of respondents with either undergraduate (31%) or graduate (55%) university degrees, who likely have a higher baseline knowledge than the general population. This high-level of education among whale-watchers has been found in other studies (Lück, 2003; Parsons et al., 2003; García-Cegarra and Pacheco, 2017). However, even well-educated tourists may lack specific knowledge about wildlife and conservation issues at this site. Therefore, there is room to increase the level of interpretation and knowledge-based activities during whale-watching experiences.

The involvement of all the agents offering whale-watching activities is also key to increasing the educational benefits from this activity. In Las Perlas, whale-watching tours are carried out by tour operators and by local fishermen from different islands within the archipelago. Our results suggest that knowledge gains are significantly higher for the more formal tour operations that have operated for longer time in the area. The interpretation role of the tour guide in these tours is crucial for the learning experience of participants (Stronza and Durham, 2008; Zeppel and Muloin, 2008). However, trips organized by local fishermen, which have increased in recent years, do not have a tour guide nor do they include interpretation material, and there is frequently a language barrier. This emphasizes the need to complement and increase training efforts oriented to local stakeholders who are joining this venture. Under current Panamanian regulations, there are specific articles that mandate actions that, if implemented, will promote a better overall educational experience. These include: (a) that all operators must have a certified tour guide or captain specialized in cetaceans and the current regulations; (b) the guide or the captain must pass a training course validated by the Ministry of Environment that includes learning about whale biology, behavior, identification, but also group management techniques, safety standards, first-aid, and emergency protocols; (c) all certified guides and captains should update their record every 2 years (Ministry of the Environment, Republic of Panama, 2017).

Linking Satisfaction and Whale Conservation

Satisfaction is a key social indicator for evaluating psychological benefits from tourism and recreational activities. In the case of wildlife tourism, one of the main goals is to balance potential impacts or disturbances to the target species with a high level of satisfaction and enjoyment from the tourist (Orams, 1995b, 2000). Generally, tourists are attracted to seeing cetaceans in the wild, and their satisfaction with whale-watching operations is largely related to the presence of whales and being able to observe their behaviors (e.g., Orams, 2000; Lopez and Pearson, 2017). Whales exhibit fascinating behaviors, including breaching, fin exposure and tail slaps, which motivate people to participate in whale encounters. This study showed that respondent satisfaction after a whale-watching experience is high on average and significantly correlated with the number and frequency of whales and behaviors observed.

In order to allow tourists to better appreciate whale behaviors, tour operators may be inclined to get as close as possible to the whales (Orams, 2000; Shapiro, 2006; Whitt and Read, 2006; Kessler et al., 2014). Our results suggest that tourist satisfaction is also positively correlated with proximity to whales. Only 10 respondents (9.17% of the sample) commented that they did not feel comfortable with proximity and expressed safety concerns. Tourists tend to be highly satisfied when operators follow best practices and guidelines to reduce potential impacts to whales (Lück, 2003; Draheim et al., 2010; Kessler et al., 2014). In the case of whale watching at Las Perlas, more work may be required to educate visitors on best practices for whale watching, with a special emphasis on the importance of complying with speed levels and minimum acceptable distances to guarantee both whales' and tourists' safety.

Unsustainable whale-watching practices can also have negative impacts on the tourism industry itself. Some studies have shown that tourist satisfaction and intention to return go beyond whale-watching observations, and are also influenced by perceptions of their own safety and the sustainability of whale-watching practices (e.g., García-Cegarra and Pacheco, 2017). For example, low levels of satisfaction have been recorded in tours with vessel overcrowding and failure to maintain a prudent distance between the boats and the whales (Ávila-Foucat et al., 2013; Bentz et al., 2016). This does not seem to be the case at present in Las Perlas. Nevertheless, enforcement of sustainable and lower-impact measures should be implemented so as not to jeopardize the long-term benefits to both the community and the visitors.

Opportunities to Improve Compliance of Whale-Watching Regulations

Countries where whale-watching tourism has been growing in recent years have been developing regulations and following guidelines for best practices to minimize impacts on whales. In 2017, the Government of Panama passed Regulation Number 0530-2017 on rules and management measures for dolphin and whale-watching activities in Panamanian waters. The regulation defines a detailed set of rules referring to both administrative, interpretation and technical procedures. Among technical mandates the most important are (a) vessels must keep a minimal distance of 250 meters from the whales, (b) there is a maximum speed of 4 knots or 7 kilometers per hour in the whale-watching area, (c) an maximum observation time of 30 min in a single location, and (d) a maximum of 2 boats (keeping a parallel distance of at least 200 m between them) are permitted at the same time with the same group of whales (Ministry of the Environment, Republic of Panama, 2017). Our results suggest a low compliance of all these regulations in Las Perlas Archipelago. Approximately 50% of respondents expressed a perception of boats navigating at high speed, boats at close proximity to whales and even calves, and observed on average three additional boats at the same time in one specific location, with some sites reaching as many as seven boats in total. Regarding the latter, median satisfaction levels showed a decrease with additional number of boats (**Figure 3**). This is an important argument to improve the quality of the experience in the area by complying with the rule of maximum two boats at the same time. In addition, when evaluating attitudes and beliefs toward whale conservation, the majority of respondents indicated a high level of agreement with actions to protect whales. Managers and tour operators can consider these positive attitudes together with a strong interpretation about regulations and conservation measures on-board to ensure that tourists are active promoters of best practices on-site. It is clear that despite a comprehensive set of regulations that includes fines for non-compliance, there is an urgent need to improve their enforcement, and to implement a well-defined visitor monitoring program to guarantee the long-term benefits of whale watching in Panama.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Arizona State University Office of Research Integrity and Assurance. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

SC, KS, HG, and LG conceptualized the idea for research. KS and AA implemented the research in the field. SC and MG-F analyzed the data and wrote the manuscript. All co-authors provided valuable input during the drafting of the manuscript.

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Spatial and Temporal Effects of Whale Watching on a Tourism-Naive Resident Population of Bottlenose Dolphins (*Tursiops truncatus*) in the Humboldt Penguin National Reserve, Chile

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Standardized measures of behavior can be powerful tools for assessing the impact of whale watching activities on natural populations of cetaceans. To determine the possible impact of tourism on dolphins between a period without whale watching (1989–1992) (T1) and a period with whale watching (2010–2020) (T2), we examined the changes in the rate of surface behaviors, the group size of long-time resident bottlenose dolphins living in the waters of the Humboldt Current off Chile, and for T2 alone, we compared these differences between two localities, the Punta de Choros and Chañaral de Aceituno coves. We observed a significant decrease in the group size of the resident population and in the frequency of surface events associated with the absence and presence of tourism. For T2, we observed significant differences for the frequency of surface events between the Chañaral de Aceituno and Punta de Choros coves and differences in the frequency of surface events at different hours of the day. This was associated with the number of vessels at the time of the encounter. In addition, we observed for T2 that the most observed instantaneous response of the dolphins to the presence of tourist vessels was to avoid the boats, while approaching the boats was the least observed response. The number of vessels present in each dolphin encounter was the most important variable for our model as it explains these differences. These results show that tourism vessels have a significant impact on dolphin behavior and sociability, while the same population of dolphins have different spatial and temporal responses to different impacts of tourism. Further studies are needed to establish whether changes in the rate of surface behaviors are associated with higher levels of stress in dolphins and with effects on their health and reproductive success in the long term.

Keywords: behavior, bottlenose dolphins (*Tursiops truncatus*), whale-watching, space effect, Chile, time scale

INTRODUCTION

Over the last two decades, commercial boat-based whale watching has exponentially increased in the coastal areas of the world (Hoyt, 2001; Weir and Pierce, 2012; Hoyt and Parsons, 2014; Silva, 2015). Consequently, it has raised concerns about the potential negative impact these activities might have on cetaceans (Richardson et al., 1995; Nowacek et al., 2007). Some studies have shown changes in the behavior of resident dolphin populations depending on the species and the type and number of vessels present (Ford et al., 1996; Bejder et al., 2006; La Manna et al., 2013; Pirotta et al., 2015; New et al., 2020). These changes can be reflected as shifts in distribution (Mattson et al., 2005; Lemon et al., 2006) and feeding sites (Stockin et al., 2008), differences in vocal behavior, and in the frequency of surface behaviors, such as body posture and leaping (Lusseau, 2003a).

In Chile, boat-based whale watching was first developed in the mid-1990s in Chañaral de Aceituno cove, and focused on a school of 40–45 bottlenose dolphins discovered in 1987 next to the west coast of Chañaral Island (29° 01′S, 71° 37′W) (González et al., 1989). These dolphins have been studied with photo-identification comparisons for about 30 years (González et al., 1989; Gibbons, 1992; Capella et al., 1999; Thomas, 2005; Molina, 2006; Cruz, 2011; Toro, 2011). By means of photo-ID, Gibbons (1992) established the residence of these dolphins in this area, where they remained at least until 1995 (Capella et al., 1999). Subsequently, the dolphins moved 28 km to the south coast of Choros Island (29° 15′S, 71° 33′W) (Capella et al., 1999; Sanino and Yáñez, 2001) and between 2000 and 2020 (Perez-Alvarez et al., 2018; Santos-Carvallo et al., 2018), the school has been seen at both sites, keeping the individual composition unchanged for a significant number of members (Thomas, 2005; Molina, 2006; Cruz, 2011).

Even though whale watching was developed in Chañaral de Aceituno cove in the mid-1990s, it extended to Punta de Choros cove at the end of 90s, in response to the shift in distribution of the bottlenose dolphins (Hanshing, 2001). The regular presence of these resident bottlenose dolphins (Gibbons, 1992; Sanino and Yáñez, 2001; Thomas, 2005; Molina, 2006; Cruz, 2011; Toro, 2011) and co-occurrence of a high diversity of marine mammals (Capella et al., 1999, Capella et al., Unpublished data), and also the growth of tourism in the city of La Serena, which is a city 117 km south of Punta de Choros, led to an explosive growth in local whale watching over the last decade. The number of visitors and vessels registered in the area of Punta de Choros–Chañaral de Aceituno coves, shows an increase from just one vessel and a hundred visitors in 1995, 72 vessels and over 51,000 visitors in 2016 (Hanshing, 2001; Toro, 2011, P. Arrospide, pers. comm., March 2017), and up to receiving over 29,000 visitors in the 2020 whale watching season (Hanshing, 2001; Toro, 2011, P. Arrospide, com. Pers.).

In this article, we assess the impact of whale-watching vessels off the Punta de Choros–Chañaral de Aceituno coves on the surface behavior and group size of resident bottlenose dolphins in Chañaral Island and Choros and Damas Island, respectively, between 2010 and 2020 (T2). We compare the rates of surface behavior observed in a first period from 1989 to 1992 (T1) without whale-watching vessels to a second period from 2010 to 2020 (T2) when whale-watching vessels were present and the differences in the rates of surface behavior between the morning and afternoon for both periods. We also compared dolphin behavior and responses to boats during T2 with varying numbers of vessels present during sightings, with a low number of vessels in the morning and a higher number in the afternoon.

MATERIALS AND METHODS

Study Area

The study area located in the northern limit of the upwelling zone of Coquimbo Bay in the cold waters of the Humboldt Current off a 10 km stretch of mainland coast includes the waters around three coastal islands belonging to the Humboldt Penguin National Reserve (**Figure 1**). Chañaral Island located further north only offers whale watching from Chañaral de Aceituno cove, and Choros and Damas islands, the other two southern islands offer whale watching from the Punta de Choros cove (29° 15′S).

The focus group studied corresponds to a small resident population of 45–50 bottlenose dolphins. At least 50% of the individuals have been living in the area from 1987 to 2020 (Capella et al., unpublished data; Vilina et al., 1995) and moving among the coastal waters of the three islands.

During the spring–summer seasons of 1989–1990 years (T1), surface behaviors of a single group of bottlenose dolphins were monitored by at least two observers using binoculars (8 × 30) from a cliff 30 masl on the south-west coast of Chañaral Island. A total of 10 surface behaviors (**Table 1**; Gibbons, 1992; Bearzi et al., 1999; Würsig and Whitehead, 2009) were continuously observed by recording all events (Bearzi et al., 1999; Mann, 1999; Bearzi et al., 2005; Williams et al., 2006) from 8:00 to 17:00 h (n = 78 days, 508.2 h) between December and February (Gibbons, 1992). Group size was determined by maximum counts every 5 min.

During 10 successive years between 2011 and 2020 (T2), the dolphins moved in a more scattered and unpredictable way throughout the study area, making it impossible to monitor

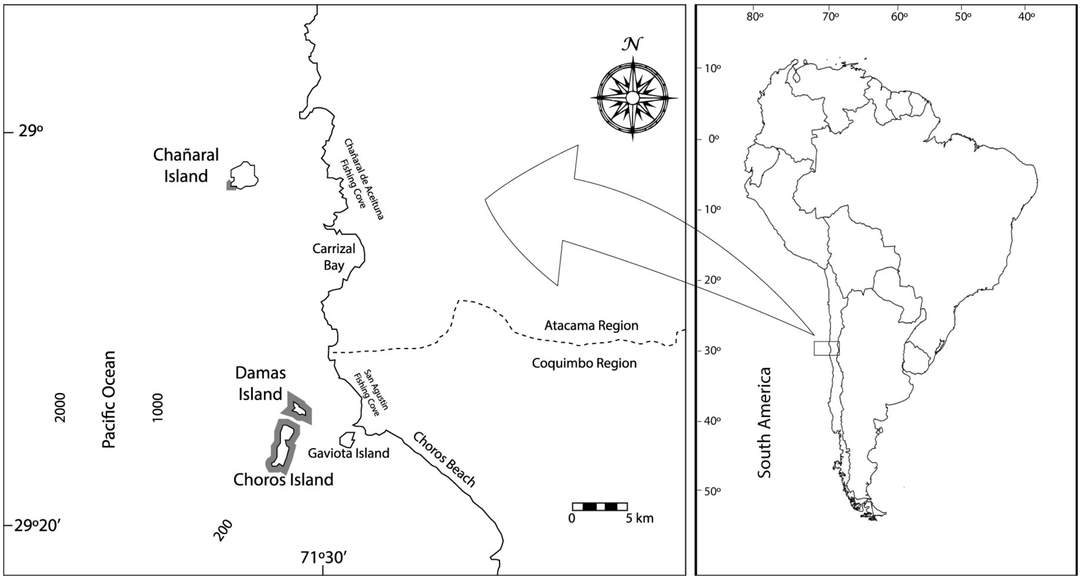

FIGURE 1 | Map of the study area in coastal waters of the Humboldt Current, northern Chile. The gray shaded area at Southwest of Chañaral Island shows the study area for the T1 period without whale watching (1989–1992) and around Chañaral and Damas, Gaviotas, and Choros Islands for T2 with whale watching (2010–2020). In both areas, at least 50% of dolphins were the same individuals.

TABLE 1 | Details of definitions of surface behavior and the response to boat disturbance for bottlenose dolphins (*Tursiops truncatus*) (Bearzi et al., 1999 and Bearzi et al., 2005 modified).

States		Definition
Surface behavior		
1	Leap	Airborne forward progress of at least one body length while in the dorsal position.
2	Lateral bow	Bow performed in lateral position.
3	Back bow	Airborne forward progress of at least one body length while in the ventral position
4	High bow	Bow higher than one body length.
5	Head slap	Side of head makes sharp, noisy contact with surface.
6	Spy hop	Brief vertical or near-vertical elevation of body and head – up exposure of the fore section followed by sinking return to the water.
7	Tail slap	Flat and noisy contact of caudal section on water surface.
8	Back breach	Fore section elevated above surface with the ventrum uppermost and dropped backward, landing noisily on the dorsum.
9	Breach	Animal elevates portion of fore section above surface and drops flatly and noisily on the lateral side.
10	Flukes up	Dolphin arches back and exposes flukes as dives.
Response to the boat		
1	Avoidance	When an individual or focal group of dolphins moves away, changes direction, increases speed, or dives with the arrival of a tourism boat.
2	No response	The individual or focal group of dolphins do not show any behavioral response relative to the arrival and presence of the tourist vessel.
3	Approach	The individual or focal group of dolphins move toward the sightseeing boat for at least part of the observation period.
4	Bowride/accompany	Special response where the animals follow the waves left by the tourist boat/when the individual dolphins swim in the same direction of the tour boat during the encounter.

their behavior and group size systematically from land. Data about the occurrence of surface behaviors and group size were collected during 357 brief encounters (16-min average for each effective encounter) from whale-watching vessels (11 m in length, four-stroke 100 HP engine) in the coastal waters off Chañaral island and the Choros–Damas islands (**Figure 1**) between 8:00 and 17:00 h (n = 421 days; 3,723 h), on trips lasting 2–3 h between January and February, with two observers.

In addition, during T2, instantaneous responses from each individual dolphin alerted to the presence of tourist vessels from Chañaral de Aceituno cove and Punta de Choros cove were recorded for Chañaral island and the Choros–Damas islands, respectively. The four instantaneous responses are described in **Table 1**. For all measurements, between 8:00 and 12:00 was classified as AM and between 12:00 and 17:00 was classified as PM.

Analysis

For statistical comparisons of behavioral events, we used a ratio for behavioral events to group sizes for each encounter (number of events/group size). Statistical analyses were performed in R v 4.0.2 and R studio v 1.3.1073 and plotted with the R base options and the ggplot2 package. To determine the normality of the sighting and effort variables, we performed a Shapiro–Wilk normality test. To determine the differences between group size with the presence and absence of tourist vessels, we used a Kruskal–Wallis rank sum test and pairwise comparisons using a Wilcoxon rank sum test with continuity correction.

A generalized linear model (GLM) with normal distribution was built to verify the association between the frequency of surface behaviors and the presence of whale-watching vessels (T1 and T2); time of the day; month, year, and number of vessels. Generalized linear models (GLM) were built using the "glm" function for the package stats, with the argument family = "binomial" and a p-value threshold of <0.05 for significant predictors. All the models were plotted using the package effects and residuals were analyzed for normality and homoscedasticity. One-way ANOVA was used to compare the AM and PM frequency of behaviors to T1 and T2 and for the number of vessels for T2, followed by the *post hoc* Tukey multiple comparison test to compare the number of surface behaviors in different numbers of vessels, using the package "multcomp" V1.4-10 in the R statistical language (Westfall et al., 1999).

To establish a relationship between the number of vessels and the response of bottlenose dolphins, we made decision trees using the caret and randomForest packages with a split of the observations into 70% training and 30% testing datasets.

RESULTS

In T1, we had a total of 58 days of observation of dolphins from land. Observations were made in morning and afternoon. The observation time varied between 130 and 235 min in the morning and 200 and 355 min in the afternoon. For T2, 357 encounters with groups of resident dolphins were recorded. Of these encounters, 279 were in Punta de Choros and 78 in Chañaral de Aceituno. Of the total number of encounters, 175 correspond to AM hours (146 Punta de Choros and 29 Chañaral de Aceituno) and 182 correspond (133 Punta de Choros and 49 Chañaral de Aceituno) to PM hours. For T2, effective encounters had an average duration of 16 min (max: 31 min; min: 4 min).

The average group size in T1 was 42 individuals (median = 43, range: 40–45) for only one distinguished cohesive group (Gibbons, 1992). During T2, between one to five groups (median = 8, range: 1–15) were seen in both areas during a working day (**Figure 2**). No significant differences were observed in the group size, neither between the coves and hours of the day nor among encounters with different numbers of whale-watching vessels.

In T1, a total of 5,708 surface behaviors (rate: 4 surface behaviors per individual) were recorded during 6,963 min of dedicated observations at the coast of Chañaral Island. Of these observations, 2,880 min were dedicated to AM hours, registering 2,983 (rate: 2.8 surface behaviors per individual) surface behaviors. In the PM hours, there were 4,083 min of observations and 2,725 (rate: 4.9 surface behaviors per individual) surface behaviors recorded (**Figure 3A**).

In T2, a total of 2,465 (rate 0.8) surface behaviors were counted in 5,282 min of observations. Surface behaviors were observed in 61.2% of all encounters with dolphins; 57.7% of the meetings in Punta de Choros and 74.6% in Chañaral de Aceituno (**Figure 3B**). For both T1 and T2 periods, the most observed surface behavior was leaping, however, the proportion of this event increased significantly for T2 (p-value = 0.00134).

For T1, significant differences (p-value = 0.001) were observed in the surface behaviors between AM and PM, with PM being the period with more surface events (**Figure 3A**). At T2, significant differences between AM and PM were observed, with most surface behaviors for both the Punta de Choros and Chañaral de Aceituno coves occurring in the AM hours (**Figure 3B**). We found a significant difference in the frequency of surface events in T2 with the presence of tourism and T1 with the absence of tourism (p-value $<$ 3.312e-17) for the Kruskal–Wallis test.

As for the results of the GLM analysis, we found a significant effect for the variables presence of tourism, cove, and years (p-value = 0.05), AM–PM (in T1 and T2), and presence and number of vessels (p-value $<$ 0.0001). For the month variable (January–February), no significant effect was observed on surface events (**Figure 3**). For T2, we observed significant differences between the frequency of surface behaviors and the presence of whale-watching vessels (ANOVA, $p > 0.001$) for the Chañaral de Aceituno (**Figure 4A**) and Punta de Choros coves (**Figure 4B**). For the *post hoc* Tukey analysis, we found a significant difference when the number of whale-watching vessels was more than two.

In T2, out of a total 2,883 instantaneous responses to vessels' disturbance, 51.1% corresponded to avoidance, 30.3% resulted in no response, 13.7% attempted to bowride, and 4.9% approached the boat. From that total, it was found that in Punta de Choros, 63.2% of the responses corresponded to avoidance and it increased for the PM hours, and the least observed response was approaching with 0.3%. Whereas in the Chañaral de Aceituno waters, with fewer whale-watching vessels than Punta de Choros, no response (45.1%) was the most frequent, followed by bowride at 25.8% (**Figure 5**).

We made a decision tree between the instantaneous responses to the tourist vessels, considering only the data in which the whole group of dolphins responded to the encounter with the vessels. For Punta de Choros, the group of dolphins had a 65% probability of avoidance of the site in the presence of three or more whale-watching vessels, but when the number of vessels was less than three, the group of dolphins had a 35% probability of no response (**Figure 6A**). For Chañaral de Aceituno, the group of dolphins

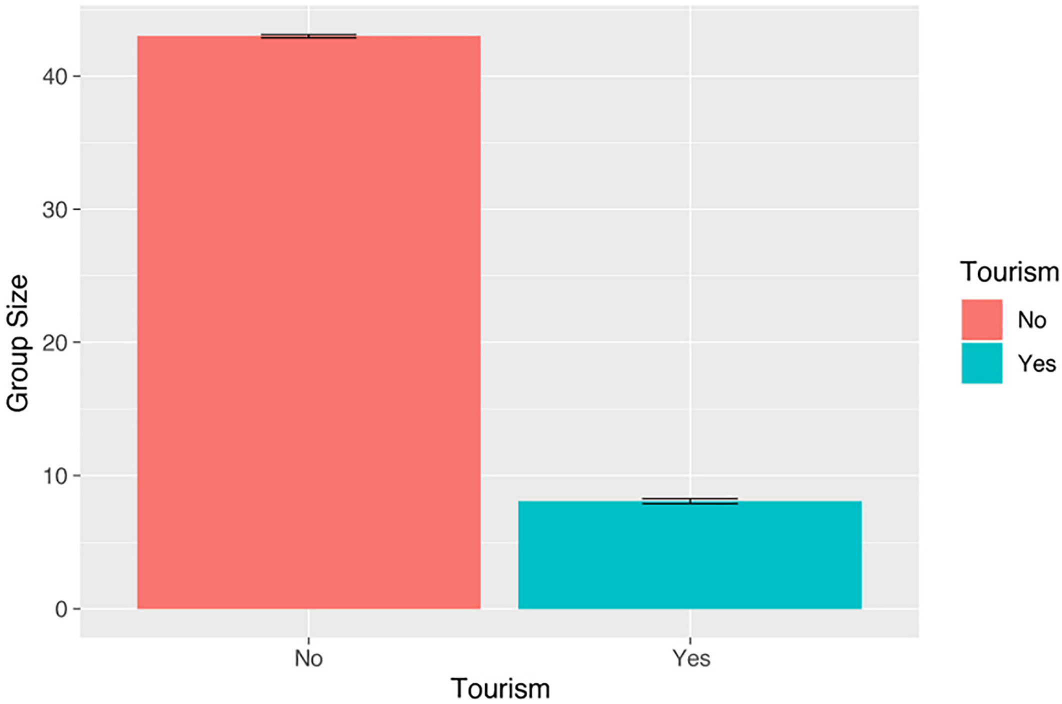

FIGURE 2 | Bottlenose dolphin group sizes in T1 (without whale watching) and T2 (with whale watching) in the study area. The horizontal line in the box represents the mean and the limits in the percentiles 25 and 75. The error bar indicates the maximum and minimum values.

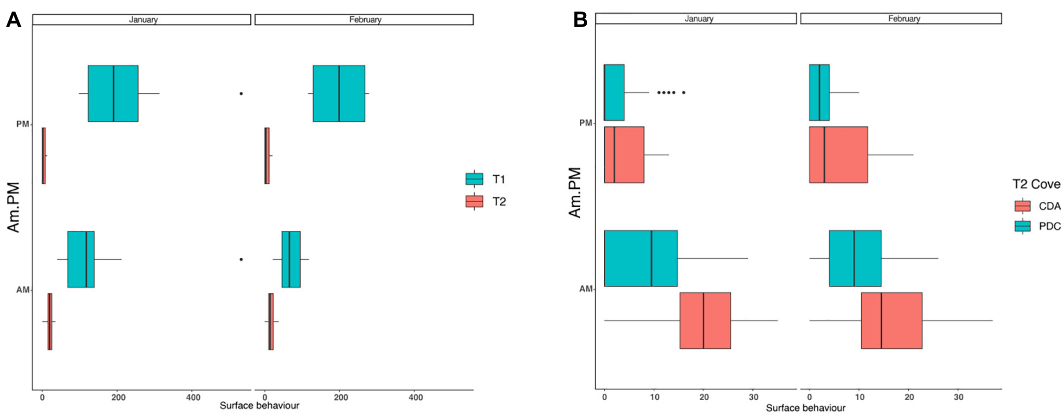

FIGURE 3 | Frequency of occurrence of the ten surface behaviors by bottlenose dolphins in the study area. Without whale watching and with whale watching for the morning (AM) and afternoon (PM) and for January and February **(A)**. Frequency of occurrence of the ten surface behaviors by bottlenose dolphins in the study area in T2 for the Chañaral de Aceituno (CDA) and Punta de Choros (PDC) coves, for the morning (AM) and afternoon (PM) and for January and February **(B)**.

had a 17% probability of avoidance of the site in the presence of two tourism vessels (**Figure 6B**).

We found significant differences in the number of vessels at the time between AM and PM for T2 in Punta de Choros (*p*-value = 0.000234) in the Kruskal–Wallis test. In Punta de Choros, we found an average of five vessels present at each encounter (AM: four vessels; PM: six vessels) and for Chañaral de Aceituno, we found an average of two vessels present per encounter (AM: one vessel; PM: two vessels). Also, it was observed that the high number of vessels present in each encounter was accentuated during the months of February, especially in Punta de Choros cove (**Figure 7**).

DISCUSSION

Although there are numerous studies of bottlenose dolphins worldwide, there are a limited number of studies on the introduction of whale-watching vessels on the same individuals across time and space, as we describe here for the Chañaral de

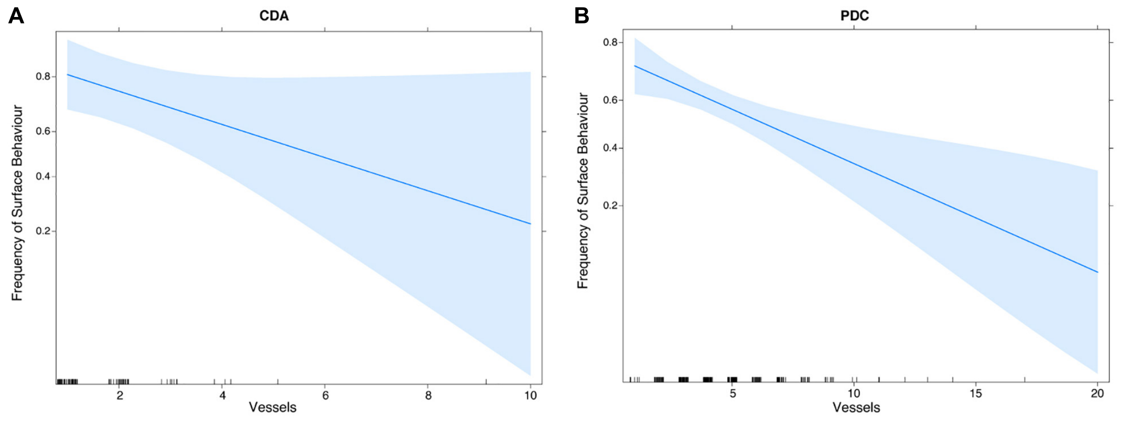

FIGURE 4 | Effect plot of the prediction model based on the data for the frequency of surface behavior and number of vessels present in each encounter with bottlenose dolphins, for the **(A)** Chañaral de Aceituno (CDA) and **(B)** Punta de Choros (PDC) coves.

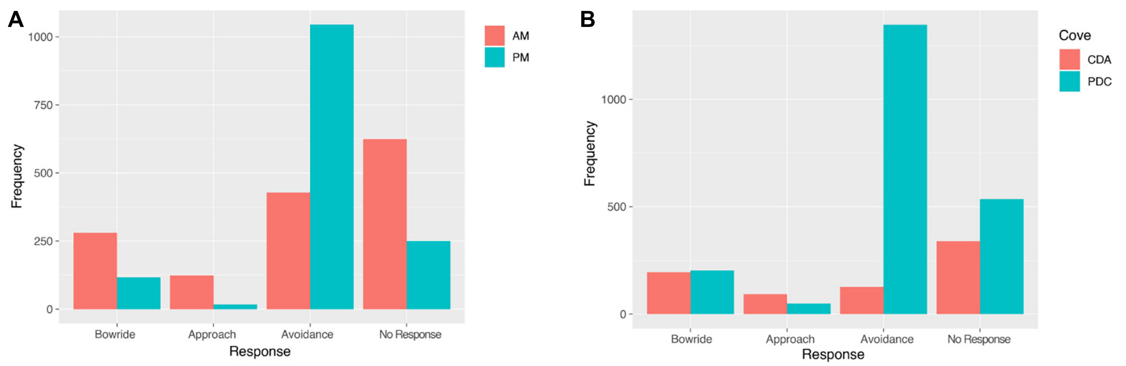

FIGURE 5 | Individual response to the vessels for the morning (AM) and afternoon (PM) **(A)**. Frequency of an individual response to vessel disturbance for the dolphins. Individual responses for the Chañaral de Aceituno (CDA) and Punta de Choros (PDC) cove in T2 **(B)**.

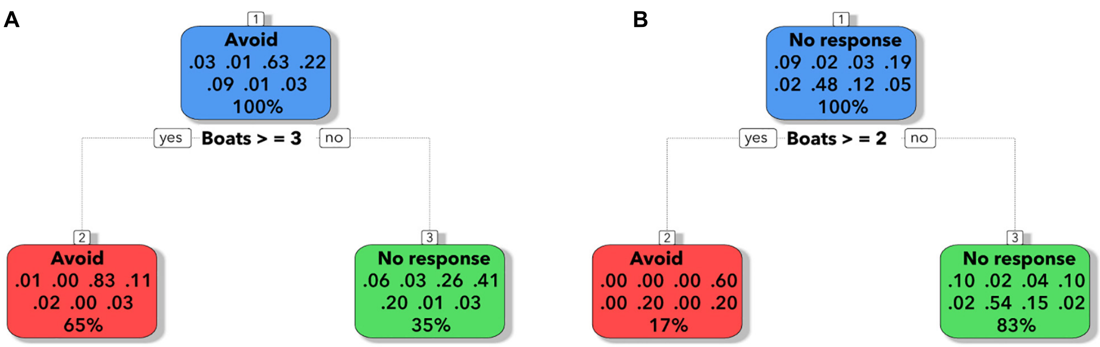

FIGURE 6 | The decision trees show the predicted probability of avoidance or no response for the Punta de Choros dolphin encounters groups **(A)** and Chañaral de Aceituno dolphin encounters groups **(B)**. Note that the two probabilities add to 100%. The proportion is 100% for the root node.

Aceituno and Punta de Choros coves. The superficial behaviors of dolphins have been associated with different contexts such as levels of alertness, social behaviors, or collaborative foraging behavior (Constantine et al., 2004; Lusseau, 2006). It is in this context that we wanted to verify if whale watching causes some effect on these behaviors.

We demonstrate the impact of whale-watching vessels on resident bottlenose dolphins in northern Chile by lines of complementary evidence. We found a significant decrease in the rate of dolphin surface behaviors associated with the number of whale-watching vessels visits, for the different sites studied. The differences in the rate of dolphin surface behaviors between

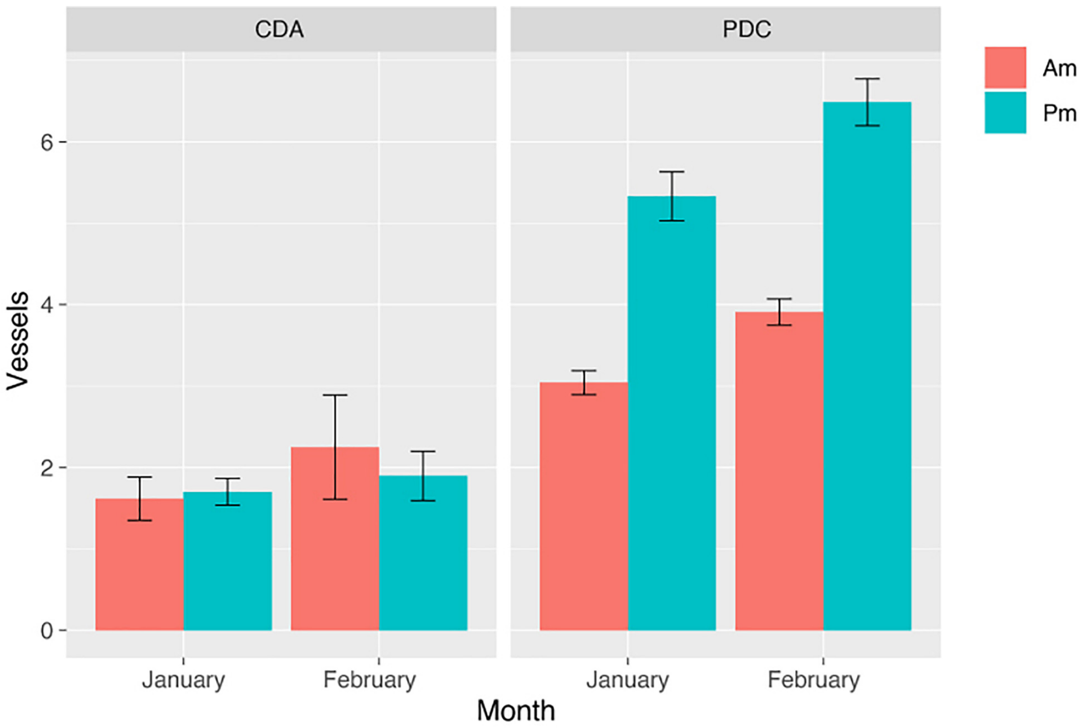

FIGURE 7 | Number of vessels present at each encounter with the dolphins in T2 for both the Chañaral de Aceituno (CDA) and Punta de Choros (PDC) coves, time of day (AM and PM), and January and February. The error bar indicates the standard deviation.

islands were associated or coincided with the differences in the numbers of whale-watching vessels that visited them.

The same was true for the differences in the rate of behaviors between the morning and afternoon. We ruled out that this daily pattern of surface activities was a consequence of the natural circadian cycle, because during T1 (without whale-watching vessels), we observed more surface events in the afternoon, which differed from T2, when we found a significant decrease in the rate of the dolphins' surface activity during afternoons with significantly more vessels present compared to mornings. We also considered a possible cumulative daily effect of whale watching on the dolphins' behavior from morning to afternoon. More frequencies of surface events were recorded in the afternoon in a population of bottlenose dolphins in North America (Henderson, 2004) as well as that observed in the spinner dolphin (*Stenella longirostris*) in Hawaii (Norris and Dohl, 1980), these studies were in the absence of tourist vessels.

It complements the abovementioned response to boat disturbance, we found that the avoidance response (51.1%) was the most observed, especially in Punta de Choros increasing toward the afternoon (63.2%), whereas in Chañaral de Aceituno, no response was the most observed (45.1%). Our results match with those observed in Guiana dolphins and river dolphins in the Amazon, where in the presence of more than one vessel, the dolphins tend to avoid the vessel or show no response to its presence (Acosta, 2002). This response to the presence of vessels has also been described in bottlenose dolphins (Constantine, 2001; Steckenreuter et al., 2012; Pérez-Jorge et al., 2017), even observing differences in the ways of escape between males and females in New Zealand bottlenose dolphins (Lusseau, 2003b, 2007). Differences in the relative frequency of "leap forward" behavior with and without the presence of tour vessels has already been described in a resident population of bottlenose dolphins in New Zealand (Lusseau, 2003a). It has been speculated that these behaviors would be cost effective methods for visual and acoustic communication (Whitehead and Waters, 1990; Lusseau, 2003b, 2006, 2007; Williams et al., 2006; Lusseau et al., 2009), especially in noisy environments (Erbe, 2002). The frequent withdrawal of dolphins from whale-watching vessels and the increase in the rate of "leap forward" with more vessels could be associated with avoiding the source of disturbance, aggressiveness, or it could be a starting behavior for a set of other responses (Williams et al., 2002; Lusseau, 2006).

The decrease in the surface behavior of bottlenose dolphins associated with the presence of vessels observed in our study is similar to that described for other populations of this species that reside in whale-watching vessel activity areas, such as in Cispatá Bay, Colombia (Ávila, 1995), Sarasota, FL, United States (Nowacek et al., 2001), and Doubtful Sound, New Zealand (Lusseau, 2003a); and also for other dolphin species, such as Hector's dolphins, *Cephalorhynchus hectori*, in Porpoise Bay, New Zealand (Bejder et al., 1999).

Our results suggest that whale-watching vessels produce short-term changes in surface behavior. Nevertheless, it is necessary to study whether changes in the rate of surface events are associated with greater stress and whether whale-watching vessel activities could have long-term implications such as health, energy budget, reproduction, and dynamics of this resident population of bottlenose dolphins, and could be addressed by application of the PCoD approach (Williams et al., 1992; New et al., 2015, 2020).

For this resident population of bottlenose dolphins, we have observed that, in the last 3 years, at least one stable group of individuals has decreased (unpublished data). In addition, they have been found in a higher proportion in the same area that we describe for T1. This could be associated with a recolonization of the area in response to the high number of tourism vessels in Punta de Choros cove. This type of response has been described in Panama, Croatia, and Australia, where the high number of tourist vessels causes dolphin populations to avoid these areas in the long term, moving toward areas with less pressure from vessels (Lusseau, 2005; Steckenreuter et al., 2012; Rako et al., 2013).

Comprehensive assessment of the impact of whale-watching vessels on this local bottlenose dolphin population is a basic requirement in the establishment of policies of conservation, environmental education, and regulatory standards. The establishment of these policies is a condition *sine qua non* for the conservation of the local bottlenose population and also for the economic sustainability of the local community. We hope this work will contribute to these objectives.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because it is an observational study, where data were taken from tourist boats, so with or without the study the animals would have the presence of the boats.

AUTHOR CONTRIBUTIONS

FT, JC, JG, and YV led the project and designed the work. FT, JC, JG, YV, BT-B, GM, CU-Y, and PA collected the data and field work. FT, JA, CP, MA-R, BT-B, GM, JG, and JC wrote the manuscript. FT, JA, NL, and MA-R contributed to the statistic analysis, visualization, and plotting results. CP, NL, and FC helped to improve the manuscript. All authors contributed to the article and approved the submitted version.

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