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Thailand's Missing Marine Fisheries Catch (1950–2014)

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Overexploitation of marine resources has led to declining catches in many countries worldwide, and often also leads to fishing effort being exported to waters of neighboring countries or high seas areas. Thailand is currently under pressure to curb illegal fishing and human rights violations within its distant water fleets or face a European Union import ban. Simultaneously, Thailand is attempting to reduce fishing effort within its Exclusive Economic Zone (EEZ). Crucial to these endeavors is a comprehensive knowledge of total fisheries catches over time. A reconstruction of fisheries catches within Thailand's EEZ and by Thailand's fleet in neighboring countries' EEZs was undertaken for 1950–2014 to derive a comprehensive historical time series of total catches. This includes landings and discards that were not accounted for in official, reported statistics. Reconstructed Thai catches from within Thailand's EEZ increased from approximately 400,000 t·year^{-1} in 1950 to a peak of 2.6 million t·year^{-1} in 1987, before declining to around 1.7 million t·year^{-1} in 2014. Catches taken by Thai vessels outside their own EEZ increased from 52,000 t·year^{-1} in 1965 to a peak of 7.6 million t·year^{-1} in 1996, before declining to around 3.7 million t·year^{-1} by 2014. In total, reconstructed catches were estimated to be nearly three times larger than data reported by Thailand to the Food and Agriculture Organization of the United Nations (FAO). Reconstructed Thai distant-water fleet catches were almost seven times higher than the comparable non-domestic catch deemed reported for Thailand. Thai landings from recreational fishing were conservatively estimated for the first time, and while they contributed less than 1% of current catch, they can be expected to grow in volume and importance with increasing tourism. As Thailand takes measures to reduce fishing effort within its EEZs and increases monitoring and enforcement of illegal and foreign fishing, it should take note of the present catch reconstruction as a comprehensive historical foundation that can point to needed improvements in data collection, policy development, and monitoring and enforcement.

Keywords: artisanal fisheries, catch reconstruction, industrial fisheries, large-scale fisheries, recreational fisheries, small-scale fisheries, subsistence fisheries, unreported catches

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INTRODUCTION

Catches from global fisheries have been declining since the mid-1990s due to global overfishing, mainly by industrial fleets, and resource depletion in many areas (Pauly and Zeller, 2016a,b, 2017a). As marine species respond to ocean warming, which will have severe impacts in tropical regions (Cheung et al., 2010), fisheries in ecosystems that are already under intense pressure will need to be managed in more precautionary manner in order to reduce overfishing, and have any hope of eventually turning toward sustainability (Pauly et al., 2002).

In many developing countries, fisheries catch data are often the only information available on their fisheries (Pauly, 2013), and can be used for first-order evaluation of stock status (Froese et al., 2012, 2013; Kleisner et al., 2013). Catch data can also be used for stock assessments, even in the absence of other fisheries and survey data (Martell and Froese, 2013). One method that can help countries to develop more comprehensive statistics for fisheries policy development and management is through a catch reconstruction approach, whereby components of catch that are not accounted for in official national statistics (e.g., due to resource limitations) are estimated using a variety of alternative information sources (Zeller et al., 2016). Most importantly, catch reconstructions of fisheries data can provide comprehensive historical time series foundation of fisheries catches, and thereby overcome the "presentist bias" unfortunately inherent in most official reported data time series (Zeller et al., 2007; Pauly and Zeller, 2017a).

Fisheries in Southeast Asia are expected to be most heavily impacted by ocean warming due to their tropical location (Cheung et al., 2009, 2010) and developing economies (Sumaila et al., 2011; Lam et al., 2012). Furthermore, populations in these and other tropical areas are most reliant on fish for food and essential micronutrient security (Golden et al., 2016). Unfortunately, many fisheries in Southeast Asia are facing substantial pressures due to human population pressures, overexploitation of marine resources and poor enforcement or lack of fishing regulations targeting stock sustainability. Considerable amounts of catch are frequently unreported in Southeast Asia (e.g., Philippines: Palomares and Pauly, 2014; Cambodia: Teh et al., 2014), and in recent years, some countries have adopted stricter policies to try and curb illegal fishing by closing their EEZs to foreign fishing entities or destroying illegal fishing vessels (Amindoni, 2015; DoF, 2015; Makur, 2016).

In Thailand, the introduction of trawlers in the early 1960s led to rapid expansion of commercial fisheries and subsequent overexploitation, stock depletion, and changes in ecosystem trophic functioning (Pauly, 1979; Christensen, 1998; Pimoljinda, 2002; Pauly and Chuenpagdee, 2003). Declining catch from local waters (now Thailand's EEZ) in the early 1970s led to Thai trawlers traveling further afield to fish in the waters of neighboring countries in the South China Sea, Indonesian archipelago, and Bay of Bengal under a series of official and private agreements as well as illegally (DoF, 1979; Butcher, 2004). For example, the majority of Thailand trawlers fished without permission in the waters of neighboring countries until the mid-1980s when authorities started to enact laws to restrict access to their EEZs and began seizing Thai vessels that were fishing without permission (Butcher, 2004). As a result, Thailand turned to a series of official and private agreements in the 1990s with Indonesia, Myanmar, Australia, India and others, with the majority of these agreements focusing on Indonesia and Myanmar (Butcher, 2004). However, Indonesia and Myanmar have tightened restrictions on foreign fishing access within their EEZs since 2000, leading to a decline in catches by Thai vessels in foreign waters (Butcher, 2004). Furthermore, despite attempts by the Thai government to establish a commercial trawl ban within 3 km (later extended to 3 nautical miles) off Thailand's shore, violations continued due to weak monitoring, control and surveillance (MCS) and poor enforcement (Pimoljinda, 2002). However, all commercial fishing vessels of more than 10 gross tones are currently prohibited by law to fish within 3 nautical miles, and more effective MCS is being devised and implemented (DoF, 2015).

In addition to attempting to rebuild fisheries stocks within its EEZ, Thailand is currently under considerable pressure to assert stronger control over its fishing fleets in order to address rampant illegal fishing and serious accusations of labor abuses occurring on its vessels (McDowell et al., 2015). For example, the European Union (EU) issued a "yellow card" status to Thailand's marine fisheries in April 2015 as a warning to strengthen laws against illegal fishing, improve monitoring, control and surveillance systems (MCS) and traceability of landings, or face a ban of Thai exports into the EU market (Neslen, 2015). As Thailand is considered the fourth largest seafood exporter in the world, such a ban could be very damaging to the economy of Thailand (Anon, 2015; FAO, 2016). One action Thailand has taken to address human rights violations (Walk Free Foundation, 2016; see also https://www.globalslaveryindex.org/country/thailand/) was to impose a temporary ban of at-sea transshipments within and outside of its EEZ, and require all Thai vessels to return to port within 30 days at sea (Anon, 2017). Furthermore, Thai Union, one of the world's largest seafood producers, has committed itself in 2014 to refrain from purchasing seafood from vessels involved in transshipments in Thailand's EEZ (Anon, 2016). At the time of writing the present contribution, Thailand remains on the "yellow card" status despite improvements to its legal framework (DoF, 2015; Hodal, 2016). While these changes have led to multiple arrests for illegal fishing, some reports suggest that significant levels of illegal activity continue, with vessels responding by traveling further distances to fish rather than comply with strict new measures (Greenpeace, 2016; Hodal, 2016). However, as demanded by Thailand's current fisheries law, fishing vessels of over 30 gross tones (including transshipment vessels) must be equipped with a Vessel Monitor System (VMS) and every port-entry and port-exit must be reported to one of the 32 "Port-In and Port-Out Control Centers," which perform inspection at port, at sea, and on land to ensure that fishing vessels are operating legally[1] (DoF, 2015).

[1]http://www.europetouch.in.th/FileFishery/File/File1/F160202155948.pdf
http://www.iotc.org/sites/default/files/documents/2016/06/IOTC-2016-WPNT06-13_-_Thailand.pdf
http://thaiembdc.org/2016/03/07/thailands-fisheries-reform/

One component that can help inform general fisheries policy development is the historical context as provided through comprehensive historical baselines of data. Catch reconstructions (Zeller et al., 2016) can provide such baselines, by illustrating the best available picture of total catch trends over the last 60+ years. For example, through careful consideration of such data and associated trends, Thailand can evaluate the substantial social, economic as well as nutritional benefits obtained by their domestic small-scale and recreational fisheries sectors that are significantly under-represented in both national data systems as well as policy/management frameworks (Pauly and Zeller, 2016a, 2017a,b). Knowledge of the extent of unreported catches both by their domestic as well as their distant-water fleets (due to flag-state responsibilities) can help Thailand develop monitoring and enforcement protocols to better cover all sectors in order to make its fisheries more accountable as well as sustainable.

Our aim in this study was to reconstruct total Thai catches from marine fisheries for 1950–2014 by complementing official reported data with conservative estimates of unreported landings and discards taken by Thailand's fleets from within Thailand's EEZs (**Figure 1**) and the EEZs of neighboring countries, including Indonesia, Malaysia, Cambodia, Myanmar, Viet Nam, Bangladesh and Somalia. We view such reconstructions as living documents that are open to improvements and refinement, and we welcome input and feedback from interested parties to strengthen and improve on the existing data, as well as correct any potential errors.

METHODS

Total marine fisheries catches from 1950 to 2014 were estimated using the well-established catch reconstruction approach of Zeller et al. (2016), which was initially applied in Zeller et al. (2006) and first described in Zeller et al. (2007). The present contribution is an update of the original catch reconstruction of Thailand's marine fisheries from 1950-2010 which is detailed in Teh et al. (2015)[2]. Landings of large pelagic taxa such as tunas, billfishes and pelagic sharks by targeted industrial fisheries were excluded from the present dataset as they were estimated by a separate *Sea Around Us* study (Le Manach et al., 2016), but are integrated in the data available for Thailand at www.seaaroundus.org.

Reported Data

FAO FishStatJ data were compared to national reports produced by Thailand's Department of Fisheries (DoF) and found to provide a more comprehensive estimate of total reported catch for 1950–2014 for Indian and Pacific Ocean waters accessed by Thai fishing fleets, likely due to FAO's harmonization of multiple data sources in addition to national data (Garibaldi, 2012). National logbook survey data from DoF's Information Technology Centre were available from 1998 to 2009, and were used to derive estimates of reported industrial (i.e., large-scale sector) landings for each FAO statistical area during this period. Industrial fishing was assumed to have started in 1962 with the introduction of otter trawls in Thailand, and is thought to have increased to account for approximately 57% of reported landings by the mid-1960s (Butcher, 1999). Linear interpolation was used to estimate reported industrial landings between 1962–1965 and 1967–1997. An average ratio of industrial catch reported by the DoF logbook survey to total catch reported by FAO was determined for 1998–2009. This proportion was held constant and applied to the total FAO reported landings for 2010–2014 to determine industrial reported catch. Small-scale reported landings were calculated as the difference between total reported catch and industrial reported catch for 1950–2014.

Fishing in Other Countries

Trawling by Thai vessels expanded outside of Thailand's domestic waters (later being declared as Thailand's Exclusive Economic Zone, EEZ in 1981[3] in 1968 (Phasuk, 1987). The percentage of reported catch outside of Thailand's EEZ was interpolated to the 1998 level from zero in 1967 and was held constant at the 2009 proportion for 2010–2014. DoF logbook survey data from 1998 to 2009 were used to estimate the percentage of reported catch caught outside of Thailand's EEZ.

For 1968–2014, approximately 20% of total landings of demersal taxa were estimated to be unreported and originated from outside Thailand's EEZ, based on Phasuk (1987). Total unreported landings from outside Thailand's EEZ were assumed to be equivalent to the unreported landings of demersal taxa in 1968 and were linearly interpolated to 1996 when 70% of catch was caught illegally (Butcher, 1999) and deemed unreported. The 1996 percentage of unreported catch was carried forward to 2014. In order to prevent any double counting of unreported demersal landings from foreign waters, the unreported demersal catch was subtracted from total unreported landings outside Thailand's EEZ.

Landings taken outside of Thailand's EEZ were assigned to EEZs of neighboring countries based on the number of Thai boats known to have agreements to fish in the EEZs of other coastal countries according to data presented in Lymer et al. (2008). Landings taken in Indonesian and Malaysian waters were further allocated into individual EEZ components within Indonesia and Malaysia (to match *Sea Around Us* EEZ entity definitions, see www.seaaroundus.org) based on the relative EEZ component surface area ratios within each country. Offshore landings were allocated to EEZs at constant proportions for 1968–2014. These constant proportions thus may underrepresent potential time series variations of use of foreign EEZs by Thai fleets.

Small-Scale Artisanal and Subsistence Sectors

Although national catch reports by DoF have existed since 1957, reports did not include gear type until 1974 or community fishing

[2]The detailed technical catch reconstruction report for this study is freely available at http://www.seaaroundus.org/doc/publications/wp/2015/Teh-et-al-Thailand.pdf, and can also be found at the Thailand EEZ data pages at http://www.seaaroundus.org/data/#/eez/956?chart=catch-chart&dimension=taxon&measure=tonnage&limit=10 and http://www.seaaroundus.org/data/#/eez/957?chart=catch-chart&dimension=taxon&measure=tonnage&limit=10

[3]http://www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/THA_1981_Proclamation.pdf

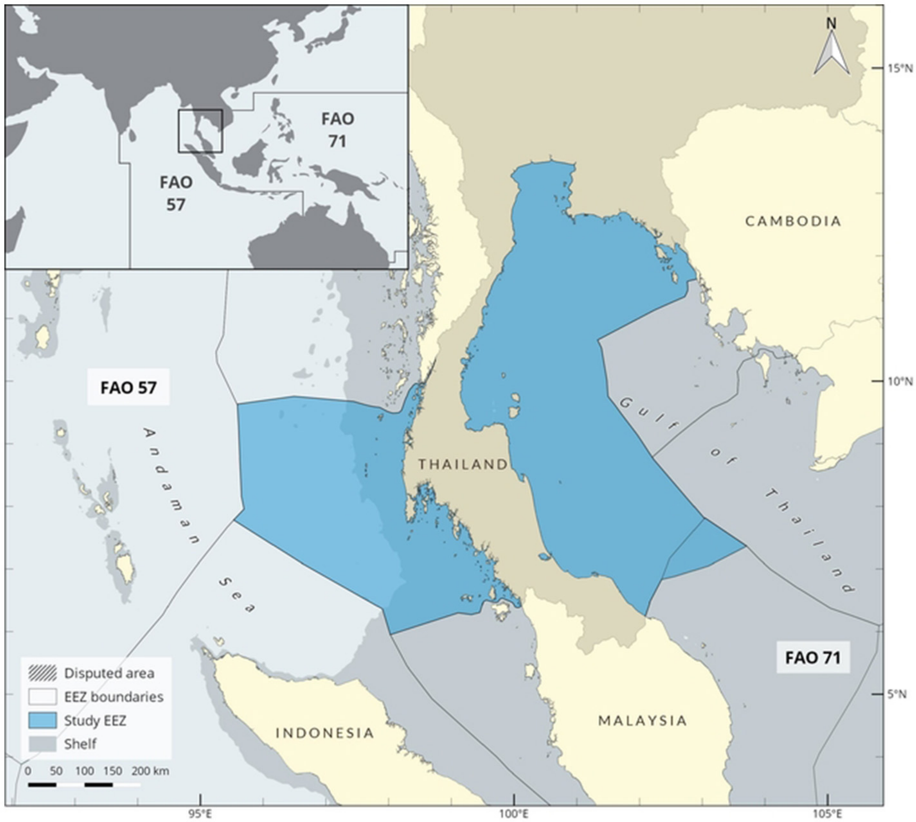

FIGURE 1 | Thailand's Exclusive Economic Zone (EEZ) and shelf waters to 200 m depth, in both the Andaman Sea (Eastern Indian Ocean, FAO area 57) and the Gulf of Thailand (Western Central Pacific, FAO area 71). Overlapping EEZ claims are indicated.

survey data until 1998. Phasuk (1987), based on DoF statistics, estimated that 8.3% of total catch from the Gulf of Thailand originated from small-scale fishing. In contrast, Juntarashote and Chuenpagdee (1991), based on hired labor data taken from the Marine Fisheries Census conducted in 1967 and 1985, estimated that 25.7% of catches were from small-scale fishing. To remain within the range of estimates suggested in the literature, an assumed average 17.4% of unreported small-scale catch was added to the reported data for all years prior to 1998.

From 1998 to 2014, unreported small-scale catches were estimated as a percentage of total reported catches based on published reports and case studies. Anchor points were established in 2002 and 2005. Total fishing effort was calculated using average annual fishing effort and number of fishers. The small-scale catch rate of 3 t·fisher^{-1}·year^{-1} in 2002 was estimated based on fishing effort from a case study of small-scale fisheries in the Gulf of Thailand (Lunn and Dearden, 2006), assuming fishers fished 9½ months of the year. Annual catch per fisher was multiplied by the 94,229 small-scale fishers derived for 2004 (Lymer et al., 2008). Based on this, unreported small-scale catches were equal to 11% of total reported marine fish caught in 2002. Panjarat (2008) estimated that unreported small-scale catches were equal to 16.5% of total marine fisheries catch in the mid-2000s. Thus, 11% of total reported catch was added as small-scale unreported catches for 1998–2002, and then linearly interpolated for 2003–2004 to the 2005 rate of 16.5%, which was maintained until 2014.

Further adjustments to unreported small-scale catches were performed by estimating local *per capita* fish consumption. Estimated small-scale landings as derived above were divided by the coastal population and graphed to visualize changes in consumption rates of domestic small-scale catches over time. These appeared to be underestimated from 1950 to 1970. Coastal population was defined as the total population living within 100 km of the coast and was sourced from NASA Socioeconomic Data and Applications Center (McGranahan et al., 2007). It was assumed that the coastal fish consumption rate in the 1950s and 1960s was similar to the consumption rate when the industrial sector began (i.e., 53 kg·person^{-1}·year^{-1}), but was conservatively used as 50 kg·person^{-1}·year^{-1} from 1950-1969, and reverted to unadjusted consumption rates for 1970–2014. Unreported small-scale sector catches from 1950 to 1969 were increased by the difference that was obtained from using the 50 kg·person^{-1}·year^{-1} consumption rate and the unadjusted consumption rate, multiplied by the coastal population.

Total estimated small-scale catches were divided between artisanal and subsistence sectors based on fisheries inventory surveys in the late 1960s and 1970s (Panayotou and Jetanavanich, 1987). Panayotou and Jetanavanich (1987) estimated subsistence households to make up 70% of fishing households in 1967. Subsistence households were defined to consist of two or fewer family members fishing. This assumption reflected the fact that households with fewer members would be more likely to have a lower economic status and therefore be more likely to engage in subsistence fishing. The 1967 proportion of subsistence fishers was maintained from 1950 to 1967. Anchor points of 70%, 74%, 67%, and 63% were estimated for 1969, 1970, 1973, and 1976, respectively (Panayotou and Jetanavanich, 1987). Linear interpolation was used to fill in years with missing data. Further information on subsistence fishing was not available for later years, and thus subsistence fishing was assumed to have decreased to 20% of small-scale catches in 2008 based on related data for Malaysia (Teh and Teh, 2014). This 2008 proportion was held constant to 2014. These percentages were directly applied to the total reconstructed small-scale catches to divide small-scale catches into artisanal and subsistence sectors in line with *Sea Around Us* database definitions (Zeller et al., 2016).

Discards

Thailand utilizes low value fish, often discarded in many other countries, to produce fish sauce and fish meal, and therefore, the rate of discarding is expected to be low (Pauly, 1996). The proportion of low value fish out of total catch was about 31% in 1999, 95% of that was derived by trawling (Kaewnern and Wangvoralak, 2004). As a result of the demand for low value fish, discards from small-scale and commercial fisheries are low (Funge-Smith et al., 2005), and estimated at 1% of total marine catches (Kelleher, 2005). However, conflicting information regarding the level of discarding exists. FAO (2004) estimated discarding from shrimp and demersal trawl fisheries at 22% of total landings while Kungsawan (1996) reported little discarding from Thai shrimp fisheries. In order to estimate discards, it was assumed that discarding initially occurred at 22% of reported catch when trawling began in the 1960s, but declined as a market for low value catch developed, which lead to an estimated discard level of 1% of total catches by 2000, which was held constant to 2014.

Recreational

Recreational fishing is performed by both tourists and Thai anglers. The approximate catch from recreational fishing was estimated by multiplying the number of recreational fishers by an average catch rate. Coastal recreational fishing by tourists and Thai citizens were estimated separately from "big game" fishing for tuna and billfishes.

Recreational fishing by locals was assumed to begin in 1980. In a global study of marine recreational fishing, the average participation rate of recreational fishers in Asia was 18.2% (Cisneros-Montemayor and Sumaila, 2010). Because most of Thailand's recreational fishing is performed by tourists[4], and to remain conservative, the national participation rate was assumed to be half the rate estimated by Cisneros-Montemayor and Sumaila (2010), i.e., 9.1% for 2010. Because recreational fishing is unlikely to be undertaken by people living under the poverty level (who would engage in subsistence fishing, see above) or far from the coast, local recreational catch per year *n* from 2010-2014 was estimated as:

$$C_{local,\,n} = \left(P_{coastal} - P_{poverty}\right)_n \times T \times C_t$$

Where $C_{local,n}$ is local recreation catch in year n, $P_{coastal}$ is the number of people living within 100 km from the coast, $P_{poverty}$ is the number of people living under the poverty level (UNCTAD, 2012), T is the participation rate (here 9.1%), and C_t is the average annual recreational catch rate (kg·fisher^{-1}·year^{-1}). The number of recreational fishers for each year *n* prior to 2010 was estimated by adjusting the number of recreational fishers for year *n* by the relative changes to Thailand's *per capita* annual average GDP growth from year *n-1* to year *n*. GDP values were obtained from the United Nations Conference on Trade and Development (UNCTAD, 2012). No estimates of Thailand's per fisher recreational catch rates were found and so the recreational catch rate estimated for Malaysia (7 kg·fisher^{-1}·year^{-1}) was used as it was expected to be similar in Thailand (Teh and Teh, 2014). This catch rate was assumed constant from 1980 to 2014.

Recreational fishing by tourists was assumed to have only begun in earnest in 1990 (Kontogeorgopoulos, 1998). The number of coastal tourists that fish was multiplied by a tourist recreational catch rate for 1990–2014. The total number of tourists that participated in recreational fishing was determined for 2007 by multiplying the number of fishing operators by the number of clients per trip and number of fishing trips taken per year. In 2007, the number of big game operators and coastal fishing operators were assumed to be the same. An average of 22 big game operators was estimated for the Andaman Coast and half as many in the Gulf of Thailand based on available anecdotal accounts[5] Based on written reports and photos of tourist coastal fishing trips, an average of 4 clients per trip was assumed. Coastal fishing operators were assumed to run five fishing trips per week during peak months of November to March and half as many during non-peak months.

Estimates of tourist arrivals to Phuket for 1989–2005[6], 2008–2010[7] and 2014[8] were obtained and linear interpolation was used to estimate years without data. The change in tourist arrivals per year was used to estimate the number of coastal tourist fishers before and after 2007. Catches varied widely from 0 fish to 40 tunas caught by 7 participants in a single day[9] As a result, a likely conservative catch rate of 3 kg·fisher^{-1}·trip^{-1} was assumed for 1990–2014, assuming each tourist who fished participated in one fishing trip per year.

[4]https://www.angloinfo.com/how-to/thailand/lifestyle/sports-leisure/fishing

[5]http://megafishingthailand.com/guided-fishing-in-thailand/deep-sea-fishing-gulf-of-thailand-koh-chang-koh-kut/

[6]http://phuketland.com/phuket_links/touristinfo.htm

[7]http://www.c9hotelworks.com/press-best-year-ever-for-phuket-tourism-arrivals.htm

[8]http://www.thephuketnews.com/phuket-sees-over-seven-per-cent-increase-in-tourist-arrivals-on-2014-51903.php; http://www.c9hotelworks.com/downloads/phuket-hotel-market-update-2014-09.pdf

[9]http://www.tripadvisor.com/ShowUserReviews-g1389361-d1873466-r126026076-Puket_Fishing_Charters_Chalong_Phuket.html#REVIEWS

Big game fishing was assumed to be performed mainly by foreign tourists and so catches by locals were not estimated. Based on reports in 2007 and 2008 from a sport fishing operator[10], it was estimated that an average of three multi-day trips were performed per operator from the high season of March to November with an average of 2.6 clients per trip. During the non-peak season, clients were assumed to drop by 50%. Thus, for 2007, 2 115 big game fishers were estimated. The number of big game fishers was assumed to fluctuate with tourist arrivals in Phuket for 1990–2014 as described above. Average big game catch per client was estimated from trip reports and photographs posted on the internet[11]. From three trip reports, average catch per big game fisher was estimated at 60 kg·fisher^{-1}·trip^{-1} for 1990–2014, assuming fishers participated in one trip per year, with no catch and release.

Taxonomic Composition

The taxonomic composition of unreported landings was assumed to be similar to reported landings for each sector. Landings reported as "marine fishes nei" (nei = "not elsewhere included"; assumed to largely represent catches of low value taxa) were disaggregated with greater taxonomic composition based on the top 10 species that accounted for 60% of total composition from sampling surveys of so-called "trash" fish and low-value fish caught in the Gulf of Thailand in 1966 and 1999 (APFIC, 2007). The percentage breakdown of low-value species was interpolated between 1966 and 1999 anchors and held constant prior to 1966 and at the 1999 breakdown for 1999–2014. This composition was also applied to discards (**Table 1**).

Recreational catch composition was different for big game fishing and coastal fishing trips. Big game catches included marlins and sailfishes (Istiophoridae), tunas (Scombridae), dolphinfish (*Coryphaena hippurus*), barracudas (Sphyraenidae), and giant trevally (*Caranx ignoblis*) based on reports from fishing trips. Coastal recreational catch was composed of Scombridae, Carangidae, Sphyraenidae and demersal fish including Serranidae, Lutjanidae, Nemipteridae, Holocentridae, Lethrinidae and Dasyatidae. All taxa were assigned equal proportions except for Scombridae and demersal fish taxa, which were weighted double because catches were likely more common.

Data Uncertainty

Reconstructed catch data by fishing sector were evaluated in terms of underlying data uncertainty or reliability using the methods applied globally in Pauly and Zeller (2016a), which updated an earlier use in Zeller et al. (2015). This approach is modified from the method used by the Intergovernmental Panel on Climate Change for evaluating uncertainty of information sources (Mastrandrea et al., 2010). For each time period (1950–1969, 1970–1989, 1990–2014) the data and information sources were scored for data reliability between 1 (very low) and 4 (very high), with no option for "medium" (**Table 2**). We deliberately exclude an uninformative "medium" score, to avoid the "non-choice" that this option would effectively represent. Each of these scores is assigned a percentage uncertainty range (**Table 2**), which allows the overall mean weighted percentage uncertainty (over all sectors) to be computed for Thai fishing.

TABLE 1 | Percentage composition of major species of so-called "trash" and low value fish caught in the Gulf of Thailand in 1966 and 1999.

Taxon	Percentage of total catch	
	1966	1999
Nemipteridae	30.6	26.8
Synodontidae	15.7	14.2
Leiognathidae	13.6	20.2
Cynoglossidae	10.9	10.0
Platycephalidae	10.8	10.0
Sciaenidae	9.5	8.9
Carangidae	8.9	10.0

TABLE 2 | Scoring system for evaluating the quality and reliability of time series of reconstructed catches, for deriving uncertainty (reliability) bands for reconstructed catches.

Score	Reliability	+/− %[a]	Corresponding IPCC criteria[b]
1	Very low	50	Less than high agreement and less than robust evidence
2	Low	30	High agreement and limited evidence ***or*** medium agreement and medium evidence ***or*** low agreement and robust evidence
3	High	20	High agreement and medium evidence ***or*** medium agreement and robust evidence
4	Very high	10	High agreement and robust evidence

Adapted and modified from Mastrandrea et al. (2010). [a] *Percentage uncertainty derived from Monte-Carlo simulations (Ainsworth and Pitcher, 2005; Tesfamichael and Pitcher, 2007).*

[b] *"Confidence increases" (and hence percentage ranges are reduced) "when there are multiple, consistent independent lines of high-quality evidence" (Mastrandrea et al., 2010).*

RESULTS

Thailand's total reconstructed catch for 1950–2014 was on average 2.9 times the data Thailand reported to FAO for the Eastern Indian Ocean and Western Central Pacific Ocean (**Figure 2**). Surprisingly, while Thailand is known to fish also in the Western Indian Ocean, no data were reported by FAO for this area (FAO area 51) other than landings of sharks and large pelagic taxa. Reconstructed total catches increased from just over 400,000 t·year^{-1} in 1950 to a peak of nearly 10 million tons in 1996, before declining to just over 5.5 million t·year^{-1} by 2014 (**Figure 2**). Of the total reconstructed catch, 84% was attributed to the industrial sector, approximately 5% of which was discarded, 16% was assigned as small-scale fisheries (artisanal and subsistence) and less than 1% was deemed from recreational fishing (**Figure 2**). The industrial, artisanal, subsistence and recreational sectors contributed 154, 14, 12, and 0.3 million tons of unreported

[10]http://www.fishing-khaolak.com/reports/index.html
[11]http://www.fishing-khaolak.com/reports/index.html

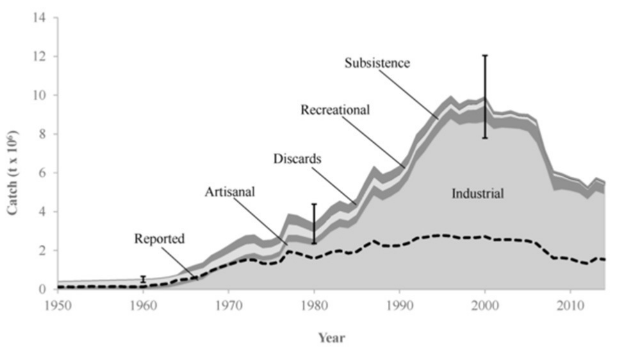

FIGURE 2 | Reconstructed total catches for Thailand for 1950–2014 (catches within and outside of Thailand's EEZ), showing contributions of different fisheries sectors. Reported landings data are overlaid as a dashed line.

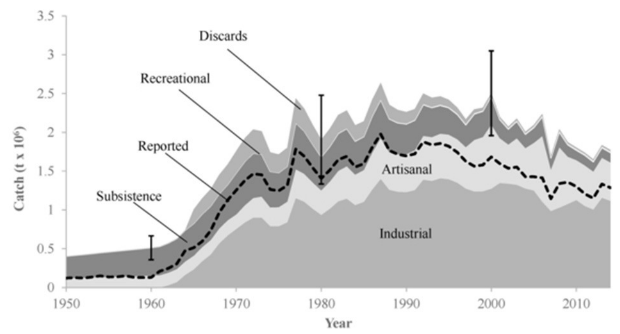

FIGURE 3 | Reconstructed domestic catches for Thailand within Thailand's EEZ only for 1950–2014, showing contribution of different sectors. Reported landings data are overlaid as a dashed line.

landings respectively, while 13 million tons were discarded over the entire time period.

Thai catches taken within the two separate EEZ entities of Thailand (Gulf of Thailand and Andaman Sea EEZs, **Figure 1**) increased from 400,000 tons in 1950 to a peak of 2.6 million tons in 1987, before beginning a gradual but continuous decline to 1.7 million tons by 2014 (**Figure 3**). The majority of unreported catches, as estimated here, were derived by Thai fisheries operating outside of Thailand's EEZ (**Figure 4**). Under the current assumptions for assigning "offshore" catches to neighboring EEZs, Indonesian, Cambodian and Malaysian waters accounted for the majority of catches taken by Thai fishers outside of their own domestic waters (**Figure 4**). However, Thai fishers have operated as far as Somalia in the Western Indian Ocean (Bahadur, 2011), and in eastern Indonesian waters in the east (**Figure 4**). The strong decline in total catches starting in the mid-2000s seems to be driven mainly by major declines in Thai catches from Indonesian and Malaysian waters (**Figure 4**), due mainly to increased efforts by these countries to reduce illegal foreign fishing (DoF, 2015).

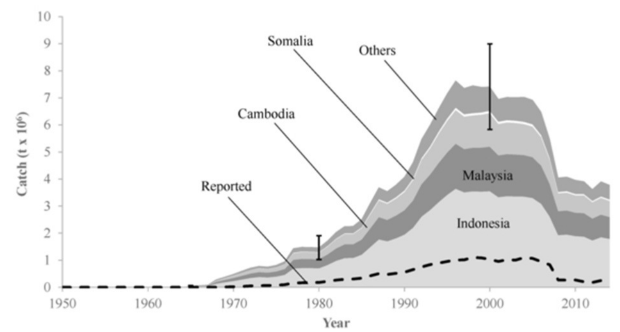

FIGURE 4 | Reconstructed catches for Thai fleets fishing outside of Thailand's EEZ for 1950–2014. Reported landings data are overlaid as a dashed line, illustrating the poor catch data monitoring and reporting by 'offshore' fleets fishing internationally. "Others" includes Myanmar, Bangladesh and India.

The major taxonomic groups in the total catch of Thailand are Nemipteridae (threadfin breams), *Rastrelliger brachysoma* (short mackerel), Leiognathidae (ponyfishes), Carangidae (jacks and scads), Engraulidae (anchovies), *Sardinella* spp. (sardinellas), Synodontidae (lizardfishes), *Decapterus russelli* (Indian scad), Scyphozoa (jellyfish) and Sciaenidae (croackers), with around 75 additional taxa accounting for the remainder of total reconstructed catches (**Figure 5**).

All data presented here are free available for downloading via www.seaaroundus.org.

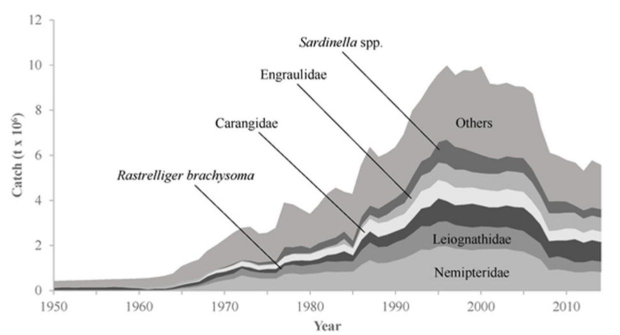

FIGURE 5 | Taxonomic composition of total reconstructed catches for Thailand, 1950–2014. Major taxonomic groups are shown only. "Others" includes 79 additional taxonomic groups.

DISCUSSION

Total reconstructed catch from Thailand's marine fisheries in the Indian and Western Pacific Oceans is almost three times higher than the data reported by Thailand to FAO for 1950–2014. Considering that Thailand is currently working to reform its fisheries and reduce fishing effort to levels that have been estimated as leading to Maximum Sustainable Yields (MSY) (DoF, 2015), the level of catch that is currently not accounted for by official statistics is disconcerting. However, most unreported catch seems to be derived from offshore fisheries in neighboring EEZs (and likely not considered in the stock MSY estimations above) rather than Thai EEZ waters. Of concern, and likely also indicative of the status of stocks and associated ecosystems, is the observation that catches within Thai's EEZ have been on a continuous declining trend for many years (Pauly, 1979; Christensen, 1998; Pimoljinda, 2002), despite increasing domestic fishing effort. Future research should examine comprehensive catch-per-unit-effort trends over time to determine more closely potential status and trend of stocks. This will require an equally detailed reconstruction of total fishing effort by all Thai vessels and fleets, to complement existing fleet effort data sets.

Reconstructed Thai catches from waters outside of Thailand's EEZ were nearly seven times higher than the catch that was reported to the Department of Fisheries as being obtained outside Thai waters. Reports of the number of vessels fishing outside of Thailand's waters and the EEZs where fishing was occurring varied substantially. Furthermore, fishing by Thai vessels took place under both official and private agreements, as well as illegally.

The number of industrial vessels fishing outside of Thailand's EEZ that were known to the Department of Fisheries were likely around 760 in 2007 (Lymer et al., 2008). However, as many as 3,889 Thai vessels were reported to operate in other countries' waters in 1996, only 28% of which were estimated to be fishing legally according to a report by the Foreign Ministry of Thailand cited by Butcher (1999). Our reconstructed catch by Thailand's fishing vessels from other countries' EEZs may even represent an underestimate as it may not encompass all countries where Thailand's fleets have been fishing. Catches from outside of Thailand's EEZ seem to have declined since their peak in the late 1990s-early 2000s (around 77% of total Thai catches), and by 2014, such catches had declined to less than 70% of total Thai catches. Declining catches from outside Thailand's EEZ are driven by declining stocks, countries imposing restrictions, ending foreign fishing permits and increasing their crackdown on illegal fishing (Amindoni, 2015; DoF, 2015; Makur, 2016).

Uncertainty over the level of fishing that is occurring outside of Thailand's EEZ results in fisheries policy and management challenges. This is of particular concern to Thailand as it attempts to address illegal, unsustainable fishing practices and human rights violations by its offshore fishing fleets in order to prevent trade sanctions from being imposed by the EU (Neslen, 2015). In the last few years, Thailand has been strengthening Monitoring, Control, and Surveillance to deter illegal fishing activities and updating its legal framework to improve labor conditions on board its fishing vessels (DoF, 2015; Hodal, 2016). Despite these improvements, the EU continues to maintain Thailand's fisheries at "yellow card" status. Some reports suggest that illegal fishing, slavery, and human trafficking are still widespread, and illegal fishing vessels are simply moving further afield to avoid Thailand's new policies and enforcement (Greenpeace, 2016; Hodal, 2016; Walk Free Foundation, 2016). This will continue to provide a substantial challenge for Thai authorities, who will have to consider addressing these issues as what they are: international and transnational criminal and law enforcement activities, rather than fisheries management issues (UNODC, 2011; Ewell et al., 2017). For example, to support member countries in identifying, deterring and disrupting transnational fisheries crime, INTERPOL has established Project Scale (https://www.interpol.int/Crime-areas/Environmental-crime/Projects/Project-Scale) that is willing to assist member countries upon request.

Receiving a "yellow card" status from the European Union in 2015 marked a major turning point for Thai fisheries. Within a few months of being issued the "yellow card" status, a country-wide survey of existing Thai-flagged fishing vessels was conducted with urgency[12] Several tools have since been developed to tackle illegal fishing both in domestic waters and distant waters, including an electronic fishing licensing system, logbook reporting system and a Vessel Monitoring System (VMS) (DoF, 2015). Furthermore, a fisheries observer program has been launched and implemented first on Thailand's overseas fishing fleet[13] with observers onboard domestic vessels intended to be stationed later (DoF, 2015). Fisheries landings are now validated by Port-In and Port-Out Control Centers. Moreover, the national fisheries data collection system is planned to be established in 2017 (DoF, 2015), and is billed as one of the most significant reforms of catch data collection. It is hoped that these newly developed instruments will benefit catch data collection and that observers will play an important role as demonstrated by observer programs in several developed countries (Karp and McElderry, 1999; Porter, 2010).

To our knowledge, recreational catches have not been previously estimated for Thailand. While reconstructed recreational catch estimates contributed less than 1% of total catch, they are part of the general tourist attraction for Thailand, and as such contribute far more to the general economy than the catch tonnages would suggest. As the government continues to build the tourism industry, removal of marine species by growing numbers of visitors should not be overlooked by fisheries management officials. For example, the number of tourists to Phuket, Thailand, has grown from 1.25 million in 1990 to 3.76 million tourists in 2014 (Thepbamrung, 2015). Estimates of recreational fishing are highly uncertain due to the lack of information, but present a first estimate of an important and often overlooked contributor to the economy of Thailand.

Overexploitation of nearshore marine resources is common in Southeast Asian countries (Funge-Smith et al., 2012). While average catches for the Western Central Pacific began to decline in the late 2000s, average catches in the Eastern Indian Ocean appear to be stable but are highly questionable, in part due to fundamental mis-reporting and due to the "presentist bias" (Pauly and Zeller, 2016a, 2017a). However, based on Thailand's recent stock assessments, the current fishing effort of demersal fisheries is greater than the effort required to reach Maximum Sustainable Yield by 32.8% in the Gulf of Thailand and 5.2% in the Andaman Sea, while the fishing effort of pelagic fisheries exceeds the optimum level by 27.0% in the Gulf of Thailand and 16.5% in the Andaman Sea (DoF, 2015). Consequently, substantial and ongoing reductions in fishing effort are urgently

[12]http://www.thaiembassy.org/bucharest/contents/files/news-20170125-163408-373852.pdf

[13]http://www.thaiembassy.org/bucharest/contents/files/news-20170125-163408-373852.pdf

needed. Trawl catch per unit effort (CPUE) estimates have declined in the Gulf of Thailand by an order of magnitude from 300 kg·hour^{-1} in the early 1960s (Boonyubol and Pramokchutima, 1984; DoF, 2015) to around 20–30 kg·hour^{-1} by the 1990s (Pauly, 1979; DoF, 2015). In the Andaman Sea, the trawler catch rate in 2014 had declined by 75% compared to the mid-1960s (DoF, 2015). CPUE has also been declining for the majority of fisheries in the Gulf of Thailand, South China Sea, and Bay of Bengal (Funge-Smith et al., 2012).

Between 1950 and 2014, the proportion of catch of low-value (unfortunately mislabeled as "trash-fish") species has increased while landings of marketable demersal fish have declined, and in recent years, small pelagic species contribute the most significant proportion of catch. The latest estimates by DoF (2015) report that 82% of demersal species and 78% of pelagic species within Thailand's waters are overexploited. It has been estimated in 2007 that 42% of trawler catch in the Gulf of Thailand is comprised of small, low-value fish with 35% of these fish belonging to juvenile members of commercial fish species (Supongpan and Boonchuwong, 2010). The shift in catch composition toward low-value and juvenile fish is not unique to Thailand, but is common to fisheries in many parts of Asia due to many years with unsustainable exploitation rates and excessive fishing effort (Funge-Smith et al., 2012; Cao et al., 2015).

By evaluating available information, our reconstructed catch data by fisheries sectors were estimated with uncertainty ranges of ± 20–30%, depending on sector and time period. In the case of recreational catches, uncertainty was higher at ± 50% due to the paucity of information available. While it is theoretically possible that the reconstructed catches presented here have been overestimated, it is more likely that, given our conservative approach to using and interpreting data (Pauly and Zeller, 2016a, 2017a), our estimates may be underestimates (or minimal estimates) of the likely true, but unknown actual total past catch. Nevertheless, the levels of uncertainty in Thailand's reconstructed catch data further highlight the need to improve data reporting and data collection systems. It also suggests that further, focus research should target the past, to potentially refine and improve historical data for Thai fishing.

Furthermore, the reader should note that proper uncertainty estimates (such as confidence intervals etc.) actually address issues of statistical *precision* of sampled data, while catch reconstructions address issue of statistical *accuracy* in data, on which statistical theory is essentially silent in terms of "confidence" or "uncertainty." Thus, the ranges of "uncertainty" around our estimates need to be treated with caution, as they cannot be interpreted as one would interpret normal confidence intervals or error bars. Finally, it needs to be clearly stated that official reported data (both national data as well as data presented by FAO on behalf of countries) are also largely based on estimates in most countries, with their own sources of uncertainty (see also Pauly and Zeller, 2017a). Yet no official reported time series data are ever presented with confidence intervals or other indicators of data uncertainty.

We attempted to remain conservative during reconstruction of unreported components and compared estimates from different methods, where possible. For example, reconstructed landings from small-scale fisheries were compared to an analysis of coastal fish consumption to confirm small-scale catches were high enough to meet local demand for fish. This reconstruction of Thailand's marine fisheries was also compared with other reconstructions in the same general region that eventually contributed to a global study (Pauly and Zeller, 2016a,b). High levels of unreported catches occur in many countries in the Southeast Asia region. For example, separate reconstructions for Malaysia and Cambodia determined unreported components of marine fisheries in these countries to be on average 1 and 2 times the reported catches (Teh and Teh, 2014; Teh et al., 2014).

Here we present comprehensive estimates of unreported marine fisheries catches by Thai fishing fleets, both inside and outside domestic waters, for the period 1950–2014. This study highlights areas for improvement to fisheries data collection in Thailand to better encompass all fishing sectors and components. Furthermore, we highlight the need for retroactive corrections to earlier decades of nationally and internationally reported data, to ensure a proper historical foundation of actual total reported catches exists on which to base policy considerations and discussions of Thai fisheries. This would also address the "presentist bias" of current reported data sets (Pauly and Zeller, 2017a). Recent efforts to improve fisheries legislation, catch statistics, limit fishing effort, and curb illegal fishing and human trafficking show promise, but much remains to be done to place Thai fisheries on the path to sustainability (Pauly et al., 2002).

AUTHOR CONTRIBUTIONS

BD: Completed data reconstruction update to 2014, and revised and drafted the manuscript. PN: Contributed country-specific information to the manuscript and co-wrote the manuscript. DZ: Advised on methods, guided analysis, contributed to the manuscript and reviewed and edited the manuscript. LT: Completed earlier data reconstruction and analysis and edited the manuscript. DP: Guided the conceptualization of the study.

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