



Untangling Tales of Tropical Sardines: Local Knowledge From Fisheries in Timor-Leste

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Tropical sardines (Family Clupeidae) are an important component of many marine fisheries in the Indo-West Pacific region. In Timor-Leste, a small, less-developed country within this region, ‘sardiña’ are some of the more commonly caught and consumed fish. Yet there is little published information from Timor-Leste about the species composition of these fisheries, nor their biology or ecology. We document the knowledge of Timorese fishers on nine locally distinguished sardine types that contribute to fisheries, and relate these to at least nine species: four species of ‘Flat-bodied Sardinellas’ (*Sardinella* subg. *Clupeonia* spp.), one species of ‘Round-bodied Sardinella’ (*Sardinella* subg. *Sardinella lemuru*), two species of ‘Tropical Pilchards’ (*Amblygaster* spp.) and a ‘Tropical Herring’ species (*Herklotsichthys quadrimaculatus*), all from the Clupeidae family; and one *Dussumieria* species from the Dussumieriidae family. We record variations in local sardine names across the country and document aspects of fishers’ knowledge relevant to understanding and managing the fisheries, including local sardine species’ seasonality, habitat, movements, interannual variation, as well as post-harvest characteristics in relation to perishability. In general, local names relate more closely with groups of species than individual species, although some names also distinguish fish size within species-groups. The local knowledge identified in this study has immediate application to inform fisheries monitoring and management, and to identify areas for future research. Notably, Timorese fishers recognize and make use of the strong association between some sardine species-groups and seasonally turbid river plumes. While further research is required to understand the underlying mechanisms of this association, this emphasizes the need to consider coastal fisheries and fisher livelihood impacts when assessing any plans or proposals that may alter river flow or water quality. Fishers also recognize migratory behavior of some sardine species, in particular the Flat bodied Sardinellas (*S. gibbosa* and others) along the north-west coast of Timor-Leste and across the border into Indonesian West Timor. Such insights complicate and need to be accounted for in initiatives for co-management or community-based management of Timor-Leste’s coastal waters and their fisheries.

Keywords: *Sardinella*, *Amblygaster*, *Herklotsichthys*, small-scale fisheries, taxonomy, biology, ecology

INTRODUCTION

Tropical sardines, herrings, shads and their allies (Family Clupeidae) form important fisheries in the Indo-West Pacific (IWP)¹, the largest dominated by single species (*Sardinella longiceps* or *S. lemuru*) but many comprising multiple species (Whitehead, 1985). These fisheries provide livelihoods for hundreds of thousands of fishers and post-harvest workers (e.g., Kripa et al., 2018; Rola et al., 2018) and an affordable source of protein and micronutrients for human consumption (e.g., Roeger et al., 2016; Rola et al., 2018). While tropical marine clupeids share some attributes – short life-spans (generally ranging from 1 to 4 years), typically reach maturity by 12 months, occupy low trophic levels and occur in continental shelf waters – species differ in maximum size, size at maturity, habitat preferences, seasonal or life-cycle migration patterns and response to climate-ocean variation (reviewed in Hunnam, 2021). Information on the composition of mixed-species fisheries and species' biology and ecology is therefore important for effective fisheries monitoring, management and sustainability.

In Timor-Leste, a small, independent country in the IWP, 'sardiña' (Tetun language, 'sardine') are some of the more commonly caught and consumed fish (AMSAT International, 2011; Mills et al., 2013; López-Angarita et al., 2019). Yet there is little documentation on the species caught or their local biology. Current national records list only one species from the Clupeidae family, the bluestripe herring *Herklotsichthys quadrimaculatus* (Erdmann et al., 2013; MAF, 2014; MAF and FAO, 2008); the FishBase list of species reported from Timor-Leste also includes the northern pilchard *Amblygaster sirm* (Froese and Pauly, 2020). Published ecological information on Timor-Leste's sardines is limited to mentions of fishery seasonality in two locations (Mills et al., 2013).² This lack of basic information could hinder efforts to sustainably develop and manage these fisheries. Fisheries management in Timor-Leste is currently limited in practice, although national catch monitoring systems are improving (López-Angarita et al., 2019) and community-based management is in effect in some coastal areas (Tilley et al., 2019). While the country's pelagic fisheries are suggested to be only lightly exploited compared to inshore reef fisheries (Mills et al., 2013), rapid population growth and government priorities to develop a diversified economy, reduce food insecurity and improve rural livelihoods, are placing increasing pressures on all coastal and marine ecosystems (Alonso et al., 2012).

Investigating the knowledge held by fishers and their communities – variously referred to as fishers' knowledge, local knowledge, traditional ecological knowledge or Indigenous knowledge in different contexts and literature (Berkes, 1993;

Johannes et al., 2000; Johannes and Neis, 2007; Davis and Ruddle, 2010) – provides an important alternative and complementary means of building understanding of fishery resources (Johannes and Neis, 2007; Silvano and Valbo-Jørgensen, 2008; Stacey et al., 2012; Thornton and Scheer, 2012). Fishers' knowledge of coastal and marine resources and their environments is often extensive and detailed, gained through practical experience and observations, exchanges with colleagues, and often learned from parents or grandparents (Lauer and Aswani, 2009; Stephenson et al., 2016). Such knowledge is increasingly recognized as part of the 'best available information' for scientists and fisheries managers (Stephenson et al., 2016), and can be the only source of information on the diverse fisheries resources of many tropical developing countries. A growing body of literature has investigated fishers' local knowledge of fishes' habitat preferences, spawning behavior, migrations and habitat connectivity, abundance trends over time and other topics, and sought to combine local knowledge with western scientific knowledge (Johannes, 1978; Ruddle and Hickey, 2008; Lavides et al., 2010; Silvano and Begossi, 2012; Berkström et al., 2019).

Local, fisher or traditional ecological knowledge on coastal and marine resources in Timor-Leste has been historically overlooked, due partly to a perception of Timorese cultural orientation away from the sea (McWilliam, 2003). Past colonization, occupation and associated displacement and resettlement of many people to coastal areas in the 1980–1990s (Thu, 2012) and its relative 'youth' as an Independent nation, perhaps have also contributed to a (misguided) notion that Timorese knowledge would lack the intergenerational time-depth to be considered 'traditional' or 'Indigenous' and therefore valid – as has occurred elsewhere (Lauer, 2017). In many coastal settlements in Timor-Leste, people have developed and maintained relationships with their coastal and marine resources over generations (McWilliam, 2003; Palmer and de Carvalho, 2008); and despite the relatively short lived-experience of fishing in some locations, all fishers are able to acquire knowledge from their regular presence in marine and coastal environments and reliance on these resources for their livelihoods. Previous research on marine-related local knowledge in Timor-Leste has concerned customary marine resource management (McWilliam, 2003; Palmer and de Carvalho, 2008) and crocodiles (Brackhane et al., 2019). Participatory processes to inform community planning and government fisheries strategy have also documented fishers' knowledge on important fish types, seasonality and potential climate change impacts (Mills et al., 2013; López-Angarita et al., 2019). However we are unaware of any detailed investigations of local knowledge or fishers' observations on fish biology or ecology.

In this study we identify the sardine species (Family Clupeidae and relatives) harvested in small-scale fisheries in Timor-Leste, with a focus on the species or groups of species that are distinguished by fishers and contribute to local fisheries, livelihoods and food production. We document knowledge held by fishers, and to a lesser extent fish traders, on sardine seasonality, habitat, movement, abundance over time and post-harvest characteristics, and discuss these observations in relation to current understanding of tropical sardines in

¹The IWP encompasses the region from southeast tropical coast of Africa, across southern continental margin of India-Eurasia landmass, east to tropical South China Sea, Hawaii, Micronesia, Polynesia, and Northeastern Australia (Lavoué et al., 2013).

²Our searches focused mainly on publicly available English-language resources. While we acknowledge there may be studies, reports or theses on sardines in Indonesian, Portuguese or Tetun languages, lack of documentation on Timor-Leste's fishery resources has been noted elsewhere (e.g., Alonso et al., 2012; López-Angarita et al., 2019).

the IWP. We use the term 'local knowledge,' rather than 'traditional' or 'Indigenous knowledge,' to avoid the perception of a fixed, unchanging body of knowledge, handed down from previous generations. Local knowledge is increasingly conceptualized as a dynamic social process, which, like all knowledge including western scientific knowledge, evolves and changes over time, and can be contested (Lauer, 2017). We do not add the term 'ecological,' since 'nature' and 'human,' and even 'spiritual/non-human' are often intertwined in Timorese (Palmer and McWilliam, 2019) and other non-Western knowledge systems (Berkes, 1993; Reid et al., 2020). However, in discussing sardine local knowledge and interpreting fishers' observations in the context of published scientific literature, we focus on components which can be considered 'ecological' and not mythical or other-worldly in the Western scientific sense.

MATERIALS AND METHODS

Study Sites and Context

Timor-Leste is located in the south-east of the Indonesian archipelago and comprises the eastern part of Timor Island, the exclave of Oecusse-Ambeno, and the islands of Atauro and Jaco (Figure 1). Timor-Leste gained independence in 2002 after several centuries of Portuguese colonization and 25 years of Indonesian occupation. It is now governed under a democratically elected national government and 13 Municipalities. The smallest administrative unit is the *suco* ('village'), each comprising multiple *aldeia* ('hamlets'). There are over 15 distinct ethnolinguistic groups across the country, some with multiple dialects; Tetun (Tetun Dili) is the *lingua franca* (Williams-van Klinken and Williams, 2015). Over 70% of Timor-Leste's 1.2 million population live in rural areas, where the majority of households engage in various small-holding agricultural activities (Williams et al., 2017). Engagement in fisheries is low compared with other small island countries (López-Angarita et al., 2019). There are an estimated 5,000 boat-based fishers, many of whom fish as part of a mixed livelihood strategy, which may include agriculture, small business and/or occasional paid employment (Alonso et al., 2012; Mills et al., 2017). Fishing is almost entirely small-scale and nearshore (within 5 km from shore), using paddle and motorized canoes (2–7 m in length) and manual-operated gears such as handlines and gill nets. Small pelagic fish, including short-bodied mackerels, sardines, halfbeaks and scads, comprise the majority of landings (López-Angarita et al., 2019). Higher levels of fishing activity, indicated by higher percentage of household boat ownership, occur along the north coast of Timor Island and around Atauro Island, with pockets along parts of the south coast (Mills et al., 2013).

This study was conducted at sites along both north and south coasts of Timor-Leste, with in-depth investigation of two fisheries on the north coast, 'Loes' and 'Comoro,' associated with nearshore fishing grounds immediately offshore from the mouths of Loes and Comoro Rivers respectively (Figure 1). Both were selected as fisheries known to target sardines (among other species) and accessible from the nation's capital and urban center, Dili.

Loes fieldwork was conducted predominantly in Tasimean and Tutubaba, two adjacent hamlets in rural Aidaba-leten village, Bobonaro Municipality, which has a combined population around 2,500 and high household boat ownership (22% at village level, GOTL, 2016). Kemak is the dominant language (Williams-van Klinken and Williams, 2015). The majority of fishers in the two hamlets carry out boat-based fishing on a seasonal basis with sardines the main target species, as well as agricultural activities such as rice farming. Comoro fieldwork was conducted mainly at fishery landing beaches to the east of Comoro River mouth in Metin I hamlet, Bebonuk village, Dili Municipality, which has a population of nearly 2,000 and household boat ownership similar to the Timor-wide average (<2% at village level, GOTL, 2016). This area is part of urban Dili and has been settled by people from around Timor-Leste. Tetun is the most common language spoken (Williams-van Klinken and Williams, 2015). The majority of fishers fish on a part-time or seasonal basis, combined with other occupations, for example as security guards, carpenters and laborers. Sardines are one of several fish families caught in the Comoro fishing grounds, often within 500 m of the river mouth and adjacent beaches. Fourteen other sites were also visited along the Timor-Leste coast (at least one in each coastal Municipality except Oecusse-Ambeno) and three inland Municipality capitals (Figure 1), based on the advice of fishery officials, fish traders and others, and/or opportunistic observations of fishery-associated activities while traveling through the area.

Timor-Leste has a tropical monsoon climate, responsible for seasonal changes in winds and waves, and marked variation in rainfall (DNMG, 2015). Rainfall patterns, sea conditions and nearshore marine environments differ on the north and south coasts. The north coast, adjacent to the Ombai-Wetar Strait (commonly referred to as the 'female sea' or *tasi fetu* in Tetun), is characterized by extreme bathymetry, with narrow reef flats (often <60 m wide) partly occupied by seagrass and coral, dropping to depths of 3,000 m within 20 km of the coast (Boggs et al., 2009). Annual rainfall is relatively low (<1,000 mm), typically occurring during a 4–6 month wet season starting in December (Barnett et al., 2007). The south coast, adjacent to the Timor Sea (the 'male sea' or *tasi mane*), has a wide and sloping continental shelf and is characterized by long beaches, larger waves and more turbid conditions (Boggs et al., 2009). Annual rainfall is higher (~1,500 mm) and occurs over a 7–9 month wet season with two peak periods around December and May (Barnett et al., 2007). Along both coasts, the roughest sea conditions occur in July–August, associated with strong southeasterly trade winds (DNMG, 2015).

Study Design and Research Approvals

The study design comprised both qualitative research methods and collection of fish specimens and photographs for taxonomic identification, and focused predominantly on the Loes and Comoro fisheries with briefer investigations elsewhere (Figure 1). Field research was carried out by the lead author over a 15-month period in 2017 and 2018, with a week-long follow-up visit in mid-2019. Frequent multi-day visits were made to the hamlets associated with Loes and Comoro fisheries (total 50+ days), while visits to other sites ranged from an hour to 3 days

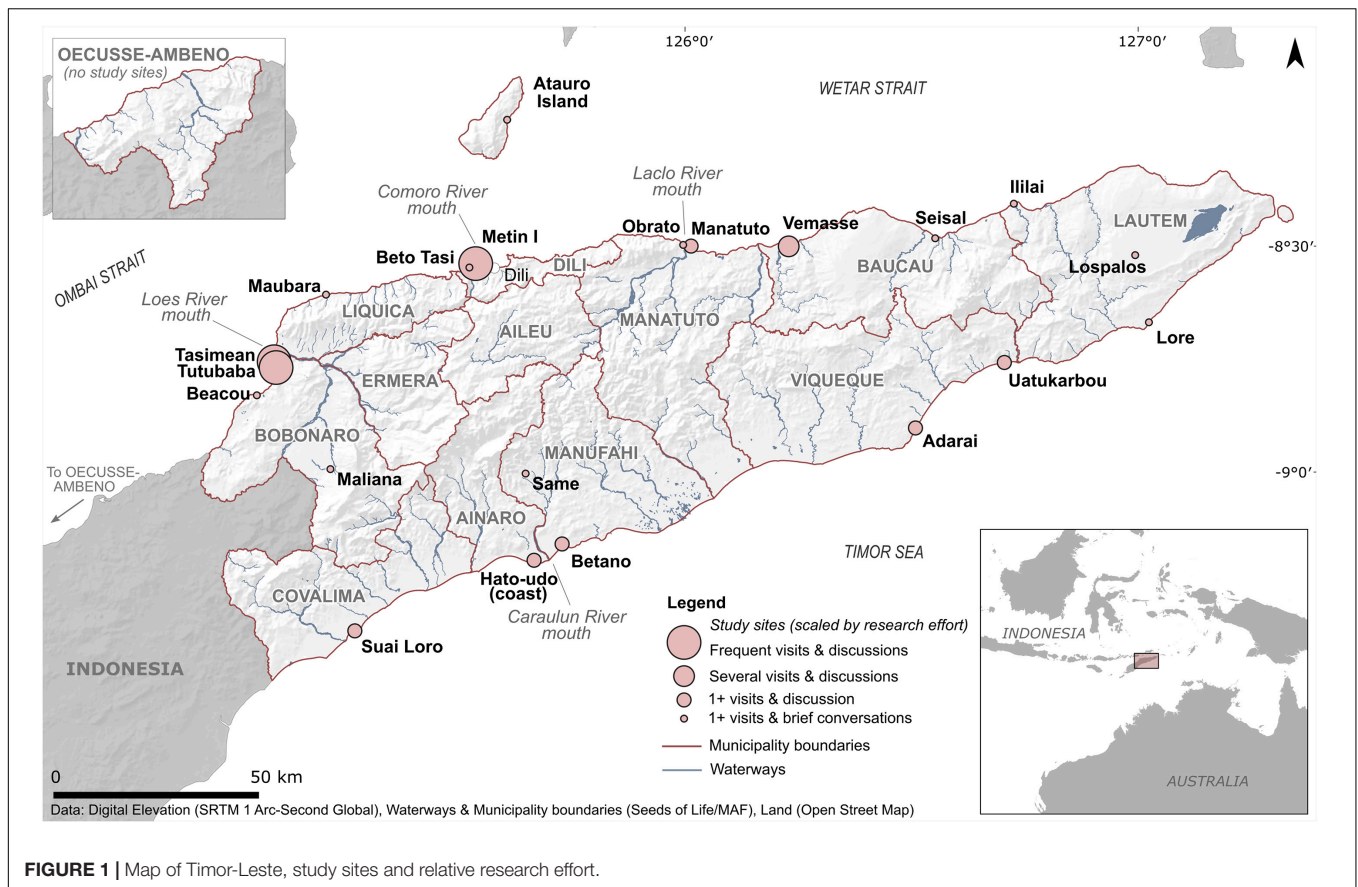


FIGURE 1 | Map of Timor-Leste, study sites and relative research effort.

(Figure 1, further details in Supplementary Table 1.1). Guidance and assistance with community engagement, cultural protocol, translation and interpretation were provided by a Timorese research assistant. Several individuals, all university students or recent graduates recruited by word-of-mouth, were engaged throughout the fieldwork period. This study was part of a broader research project on the operation and importance of small-scale sardine fisheries in Timor-Leste. Research activities were approved by the Democratic Republic of Timor-Leste Ministry of Agriculture and Fisheries (MAF; letter from Director General of Fisheries dated 15 December 2016) and endorsed by village and hamlet leaders. Research Ethics Clearances were provided by Charles Darwin University's Human Research Ethics Committee (approval H16111) and Animal Research Ethics Committee (approval A17024).

Local Knowledge Data Collection and Analysis

Local names and knowledge of the main tropical sardine species caught in Timorese fisheries were documented through focus group discussions and informal conversations, the former with groups of two to 12 fishers at Loes ($n = 5$), Comoro ($n = 1$), and four other sites ($n = 5$). At all sites, participants were identified by hamlet leaders, approached by the research team or recruited by other fishers; all were male, reflecting the male-dominated nature of boat-based fishing on mainland

Timor-Leste. Loes participants ranged from 20 to 65+ years; some older fishers were (at least) second generation fishers, others were first generation. Comoro participants were generally younger (20–30 years) second or third generation fishers. Informal conversations were held with fishers, fish traders, fisher wives, hamlet leaders and consumers approached at landing sites, fish markets and in adjacent residential areas. Several Municipality fishery officers were also interviewed. In total, over 118 men (35 in Loes, 16 in Comoro, and 67 across the 15 other sites) and 16 women (4 in Loes, 2 in Comoro, and 10 elsewhere) contributed information to this study through participation in discussions and/or conversations (further details in Supplementary Table 1.1). Participant observations were frequently carried out while assisting to remove fish from nets, as well as while accompanying fishers on several fishing trips at Comoro.

The study aimed to explore the breadth of Timorese local knowledge on sardines. Discussion and conversation topics included the types of sardines present and their importance for local fisheries; their physical appearance and relative size; their seasonality in fishing grounds and interannual fluctuation in landings; their occurrence (or availability) in different habitat types; timing of reproduction-associated observations, such as eggs; and post-harvest characteristics in relation to perishability. All discussions and conversations were conducted in Tetun; other local languages were occasionally used to

clarify questions. Initial discussions were challenging as some topics and key words did not translate easily to Tetun. Ways of asking questions and introducing the discussion topics evolved as the research team learnt and adapted to the language and terminology used and understood by the fishers. Not all topics were addressed by all groups or individuals at all sites due to the flow of discussions, participant engagement and time constraints. In initial discussions fishers were asked about local names based on photographs in fish identification guides (MAF and FAO, 2008; White et al., 2013). However this produced mixed results probably due (at least in part) to the highly similar appearance of many species particularly in small, two-dimensional photographs. Fishers also commented that not all types caught were depicted. Subsequently, after September 2017, photographs of sardines from Timorese fishers' catches (scaled to actual size) were used to document local names at each site and stimulate local knowledge discussions. Additional photos were added over the fieldwork period as additional species were observed (Supplementary Figure 1.1). Wherever possible, local names were verified based on actual specimens at landing sites and fish markets.

Participants gave written or oral consent to participate in the research and data were anonymized. Focus group discussions and interviews were conducted by a research assistant and the lead author, audio-recorded and transcribed. Informal conversations were mainly carried out by the lead author with notes written at the time or shortly after. Observations were recorded in a field diary, organized chronologically. Additional notes on sardine local knowledge at the Comoro study site were made, in Tetun, by two part-time fishers based on their personal observations and discussions with family members. Local knowledge data from all sources were translated into English with significant words and phrases retained in Tetun, coded using NVivo 11 (QSR International Pty Ltd) by local sardine name and knowledge topic, and summarized. Throughout the fieldwork period we sought to build on, validate and compare (across sites) the local knowledge shared with us in earlier discussions; this was carried out more extensively at sites visited several times (Figure 1). Where summarized local knowledge accounts were inconsistent, conflicting, unclear or inconclusive, the lead author decided whether to note the variation, seek clarification from key informants or not include data on that knowledge topic. Specimen photographs and local knowledge summaries on each locally distinguished sardine type were reviewed by key informants at Loes and Comoro sites in July 2019, and revised or clarified as necessary. Cross-validation of names was also carried out with MAF-WorldFish field staff. All data presented were cross-validated with more than one source. Maps were created using QGIS Desktop 3.10.5 and Inkscape 1.0.

Species Identification

To relate local names to Latin species names, specimens ($n = 31$) of nine locally distinguished sardine types were obtained from landing sites and fish markets in 2017 and 2018 (Supplementary Table 2.1). Specimens were fixed in 10% formalin and/or 70%

ethanol and transported to Darwin, Australia with a MAF export permit and in accordance with airline and Australian Government import requirements. Specimens were identified to genus or species level by the Museum and Art Gallery of the Northern Territory (MAGNT) using available taxonomic keys (Munroe et al., 1999; Stern et al., 2016). Additional specimens ($n = 7$) and photographs (40+) were examined by the lead author to assign genus or species level taxonomy to local names across study sites. We follow recent taxonomic revisions which consider Clupeidae (sardines, herrings, shads and allies), Dussumieriidae (round herrings) and Spratelloididae (sprats or small round herrings) as three separate families in the Clupeoidei suborder (Lavoué et al., 2014, 2017; Egan et al., 2018; Fricke et al., 2020).

RESULTS AND DISCUSSION

Tropical Sardine Species Caught in Timor-Leste's Fisheries

Across Timor-Leste, fishers distinguished over nine types of sardines, with some differences in local names between sites. We found these corresponded to at least eight species from three genera in the Clupeidae family—*Sardinella* (subgenera *Clupeonia* and *Sardinella*), *Amblygaster* and *Herklotsichthys*; and one *Dussumieria* species from the Dussumieriidae family (Table 1). Identification within these genera is challenging due to morphological similarities and overlapping distributions (Whitehead, 1985; Stern et al., 2016; Hata and Motomura, 2019b). Without genetic analyses, not all specimens collected could be conclusively identified to species-level. To accommodate these uncertainties, we present our findings in terms of four groups of species aggregated at either genus or subgenus level, as per Hunnam (2021): Flat-bodied Sardinellas, Round-bodied Sardinellas, Tropical Pilchards and Tropical Herrings. We further split the Flat-bodied Sardinellas into three groups based on distinctive external characteristics (or lack thereof), to reflect distinctions made by Timorese fishers.










 **Flat-bodied Sardinellas, *Sardinella* (subg. *Clupeonia*) spp., with no distinctive markings** corresponded to two locally-distinguished sardine types: small fish caught in 1" (25 mm) mesh nets, which grow into larger fish caught in 1.25" (32 mm) mesh nets and on jigging lines (Table 1). Based on lengths at first maturity reported elsewhere in the IWP (Hunnam, 2021), these probably refer to juveniles and adults respectively. Both small and large specimens collected were identified as *S. gibbosa*, however we suspect landings of this group in Timor-Leste comprise at least two taxonomic species. Loes fishers and community members described two varieties based on differences in scale-shedding characteristics and pigmentation around the eyes and nostrils. Slight variations in pigmentation, shading extent on caudal and dorsal fin tips and body depth were also evident from photographs taken at different sites and occasions, and sometimes between specimens from a single catch. While *S. gibbosa* has been noted to vary in body depth and fin coloration across its Indo-West Pacific distribution, several other species within the *Clupeonia* subgenus are highly similar and overlap in distribution (Stern et al., 2016).

TABLE 1 | Summary of the main tropical sardine species caught in Timor-Leste's fisheries and local names and knowledge.

Species-group and likely species	Fish length (Fishing gear)	Local names [Language]	Fishery	MAGNT specimen ID	Local knowledge summary and interpretation
CLUPEIDAE					
Flat-bodied Sardinellas with no distinctive markings <i>Sardinella</i> subg. <i>Clupeonia</i> spp. - <i>S. gibbosa</i> - Species with non-deciduous scales (<i>S. fimbriata</i> ?)		10 cm SL (1'' mesh net)	<i>matkana</i> [K], (<i>sardiña lotuk</i>) [T] <i>matkana, matakana</i> [T]	Loes Comoro	Flattened body with no distinctive markings. Widely caught along north and south coasts as a large sardine. Dominant type each year in some fisheries (e.g., Loes). Small specimens only noted from some north-coast fisheries (but may reflect research effort). Large fish (caught in 1.25'' mesh) are probably adults, while small fish (1'' mesh) are probably juveniles – based on commonly reported standard length at first maturity for <i>S. gibbosa</i> , ~11 cm (Hunnam, 2021). Seasonally abundant in coastal fishing grounds (<5 km from shore). Large fish (adults) are generally associated with turbid river plumes in the wet season (October/November to April–June). Periods of abundant small fish (juveniles) vary by fishery – wet season (Comoro), dry season (Loes). Keeps well post-harvest. Oily flesh.
		13 cm SL (1.25'' mesh net & jigging line)	<i>kobi</i> [K], <i>sardiña boot</i> [T] <i>sardiña la'o belar, sardiña la'o</i> [T] <i>sardiña la'o</i> [T] <i>sardiña boot</i> [T] <i>tembang halus</i> [T][I]	Loes Comoro Vemasse Laclo Caraulun	
Flat-bodied Sardinellas with black-tipped tail <i>Sardinella</i> subg. <i>Clupeonia</i> spp. - <i>S. melanura</i> - (<i>S. atricauda</i> ? Others?)		12 cm SL (1–1.25'' mesh net and jigging line)	<i>sardiña ikun metan</i> [T] <i>sardiña ikun metan</i> [T] <i>sardiña ikun metan</i> [T] <i>lka meta, iku meta, hio meta</i> [K]	Comoro Vemasse Laclo Loes	Flattened body with black-tipped tail. Contributes to landings along the north-coast; not mentioned by south-coast fishers (but may reflect lower research effort). Specimens commonly caught (~12 cm SL) are probably adults – based on maximum lengths reported of 12.2 cm SL (<i>S. melanura</i>) and 12.6 cm SL (<i>S. atricauda</i>) (Munroe et al., 1999) given lack of size at first maturity estimates (Froese and Pauly, 2020). No clear seasonality in fishing grounds (<5 km from shore); caught any time of year (Lacló); any time, especially dry season (Comoro); in clear water (Vemasse); and only in stray numbers (Loes). Suggests different habitat/movement to other Flat-bodied Sardinellas (above). Widely described as 'wild' and difficult to catch. Keeps very well post-harvest. Firm flesh.
		NA (1–1.25'' mesh net and jigging line)	<i>tembang kasar</i> [T][I] <i>tembang kasar</i> [T][I] (<i>sardiña goa</i>) [T] <i>tembang pasir</i>	Caraulun Suai Loro Comoro Adarai	
Flat-bodied Sardinella with deep body <i>Sardinella</i> subg. <i>Clupeonia</i> sp. - unknown sp.		NA (1–1.25'' mesh net and jigging line)	<i>tembang kasar</i> [T][I] <i>tembang kasar</i> [T][I] (<i>sardiña goa</i>) [T] <i>tembang pasir</i>	Caraulun Suai Loro Comoro Adarai	Moderately deep, flattened body with black speckled patch behind gill opening; rough or coarse skin/scales. Contributes to fisheries on the south coast. Occurs nearshore in the wet season (November–April) when rivers flow with turbid water. Not commonly caught/recognized on the north coast. Keeps well post-harvest.
Round-bodied Sardinellas <i>Sardinella</i> subg. <i>Sardinella</i> sp. - <i>S. lemuru</i>		14 cm SL (1.25–1.5'' mesh net)	<i>sardiña la'o kabuar, la'o fuik</i> [T] <i>ika mina</i> [K], (<i>kastru</i>) [K], <i>sardiña mina</i> [T]	Comoro Loes	Rounded body and elongated head. (Imported specimens have darker coloring probably due to storage on ice). Only noted at main study sites on north coast (possibly reflecting research effort). Specimens commonly caught (~14 cm SL) are probably adults – based on reported lengths at first maturity for <i>S. lemuru</i> , 11.8–14.4 cm SL (Hunnam, 2021). Small specimens were not mentioned at any sites – juvenile <i>S. lemuru</i> may not be present in Timor-Leste's nearshore waters, or may not be distinguished (or distinguishable) from other small sardines caught. Not identified as a regular dominant component of catches. Larger quantities caught only for short periods and/or in some years (e.g., reported to occur in Loes fishery in 1994, 2002 and 2003). Occurs in nearshore fishing grounds (including < 50 m from shore) in wet and dry seasons (Comoro), and in late dry season as single-species school and wet season as stray individuals (Loes). High oil content. Spoils quickly post-harvest.
		16 cm SL Imported from Indonesia	<i>sardiña 'Atabae'</i> [T]	Dili market	

Continued

TABLE 1 | Continued

Species-group and likely species	Fish length (Fishing gear)	Local names [Language]	Fishery	MAGNT specimen ID	Local knowledge summary and interpretation	
Tropical Pilchards <i>Amblygaster</i> spp. - <i>A. leiogaster</i> - <i>A. sirm</i> - (<i>A. clupeioides</i> ?)	 	10 cm SL (1'' mesh net)	<i>kostazul</i> , <i>sardiña kostazul</i> [T] ?	Comoro Laclo	– S.18318-002	Rounded body, dark green blotch behind gill opening. Caught along north-coast; not mentioned by south coast fishers (possibly due to lower research effort). Small specimens are probably juveniles, while large specimens are probably adults of a size able to spawn –based on reported sizes at first maturity for <i>A. sirm</i> elsewhere, 12.4–18.0 cm SL (Hunnam, 2021) and spawning size, ~18 cm SL (Milton et al., 1994b). Similar morphology to <i>S. lemuru</i> , as reflected in occasional use of shared names (Loes). Habitat and seasonality varies by life-stage. Small fish (juveniles) generally occur nearshore in wet season, in turbid river plume, and can be abundant and dominant in catches (Comoro). Large fish (adults) move around; caught sporadically for short periods any time of year (including at night with lights in Comoro). Soft flesh. Spoils quickly post-harvest. Does not store well on ice.
		18 cm SL (1.25-1.5'' mesh net; jigging line & mini-lampara net in Comoro)	<i>kobi</i> , <i>sardiña kobi</i> [T] <i>kastru</i> , (<i>ika mina</i>) [K]	Comoro Loes	S.18317-001 –	
Tropical Herrings <i>Herklotsichthys</i> spp. - <i>Herklotsichthys quadrimaculatus</i>		10 cm SL (1'' mesh net)	<i>tilmodok</i> , <i>tilun modok</i> , <i>sardiña tilmodok</i> , (<i>sardiña lotuk</i>) [T] <i>timorok</i> [K], (<i>sardiña lotuk</i>) [T] <i>tilun modok</i> <i>tilun modok</i>	Comoro Loes Lacló Vemasse	S.18320-001 – S.18318-001 –	Flattened body, yellowish blotch behind gill opening. Occurs along north coast and occasionally Atauro Island; not mentioned at south coast sites (but may reflect lower research effort). Specimens caught in 1'' mesh net are probably adults – based on length at first maturity reported elsewhere, 7.0–9.1 cm SL (equator to 21°S, Milton et al., 1994b). Caught every year at some sites (Comoro, Lacló, Vemasse), as both a dominant and minor component of landings. Can be caught any time of year – thought to live permanently in local area. Higher landings often associated with wet season. Elsewhere occurs in stray numbers, or is sporadically abundant nearshore (<50 m from shore) for a few days (e.g., Loes and probably Atauro Island). Widely reported as 'tame' and easy to catch. Keeps well post-harvest. Second variety mentioned in Comoro not sampled or photographed.
DUSSUMIERIIDAE						
Other <i>Dussumieria elopsoides</i>		NA (jigging line, net)	<i>kostazul fuik</i> [T] <i>sardiña</i> [T] <i>sardiña</i> [T] <i>sardiña kuruin</i> , <i>sardiña mina</i> [T]	Comoro Suai Loro Caraulun Adarai	S.18317-002 – – –	Smooth body with few scales. Occurs along both north and south coasts, possibly more abundant on the latter. Caught in clear water (October–December, Suai Loro) but also in the wet season in turbid water (Caraulun). Spoils quickly post-harvest.

Sardine icons correspond to locally distinguished sardine types (symbol and color) and species-group (color). Length: Standard Length (SL) commonly caught in Timor-Leste; Gear: commonly used; Local name(s): additional names are also likely to be used, e.g., at sites not visited during study and in other Indigenous Timorese languages. Bracketed names seemed less widely used; Language: T, Tetun; K, Kemak (used in Loes-Atabae area); I, Indonesian. Further details on species identification, including specimens examined, are provided in **Supplementary Tables 1, 2, 2.1**.

Evidence of cryptic species within *S. gibbosa* has also been reported (Thomas et al., 2014). Non-deciduous scales have only been noted in *S. fimbriata* (Stern et al., 2016; Hata and Motomura, 2019b), which is now thought to be an Indian Ocean endemic (Hata and Motomura, 2019b; Fricke et al., 2020). Further sampling and genetic analyses are therefore required to confirm species composition in Timor-Leste. Discussions and observations indicated that this species-group is widely caught in nearshore fisheries around the country (Figure 2). It was reported as the dominant species-group landed each year in Loes and relatively abundant in Comoro, Laclo (Manatuto–Obrato) and Caraulun (Betano–Hato-udo) fisheries.

Flat-bodied Sardinellas, *S.* (subg. *Clupeonia*) spp., with a distinctive black-tipped tail corresponded to a single locally distinguished sardine type (Table 1). Specimens collected were identified as *S. melanura*. However, one had a black mark at the base of its dorsal fin, a feature not present in either *S. melanura* or the highly similar *S. atricauda*, which is also present in the region (Munroe et al., 1999). While two species, *S. hualiensis* and *S. electra*, do have a dorsal fin spot and shaded black-tipped caudal fins, neither are known to occur outside Taiwan and the Philippines (Willette et al., 2011) and Japan (Hata and Motomura, 2019a) respectively. This group may therefore contain more than one taxonomic species in Timor-Leste, but confirmation through further sampling is required. Discussions and observations indicated that this species-group is caught

regularly in some north coast fisheries including Comoro and Laclo, but it was not mentioned by south coast fishers (Figure 2). **Flat-bodied Sardinella, *S.* (subg. *Clupeonia*) sp., with a deep body and a black mark posterior to the upper gill cover** was preliminarily identified from photographs taken on the south coast. This species corresponded to a single locally distinguished sardine type, reportedly caught commonly in Suai Loro and Caraulun fisheries. Fishers described its scales as rough. North coast fishers rarely recognized photographs of this species, suggesting it is uncommon in north coast fisheries.

Round-bodied Sardinella, *S.* (subg. *Sardinella*) *lemuru* was identified from specimens collected on the north coast. This species corresponded to a single locally distinguished sardine type. Fishers only distinguished large specimens, caught in 1.25" (32 mm) or 1.5" (38 mm) mesh. Based on lengths at first maturity reported elsewhere in the IWP (Hunnam, 2021), these are probably adults. Juvenile *S. lemuru* may not be present in Timor-Leste's nearshore waters, or may not be distinguishable from other small sardines caught. *S. lemuru* was not identified as a regular dominant component of current fisheries in Timor-Leste, although both Comoro and Loes fishers reported abundant catches have occurred some years. Large quantities observed in Dili markets over the fieldwork period were reportedly imported from Indonesia via the West Timor border – these had darker coloring, presumably from prolonged storage on ice.

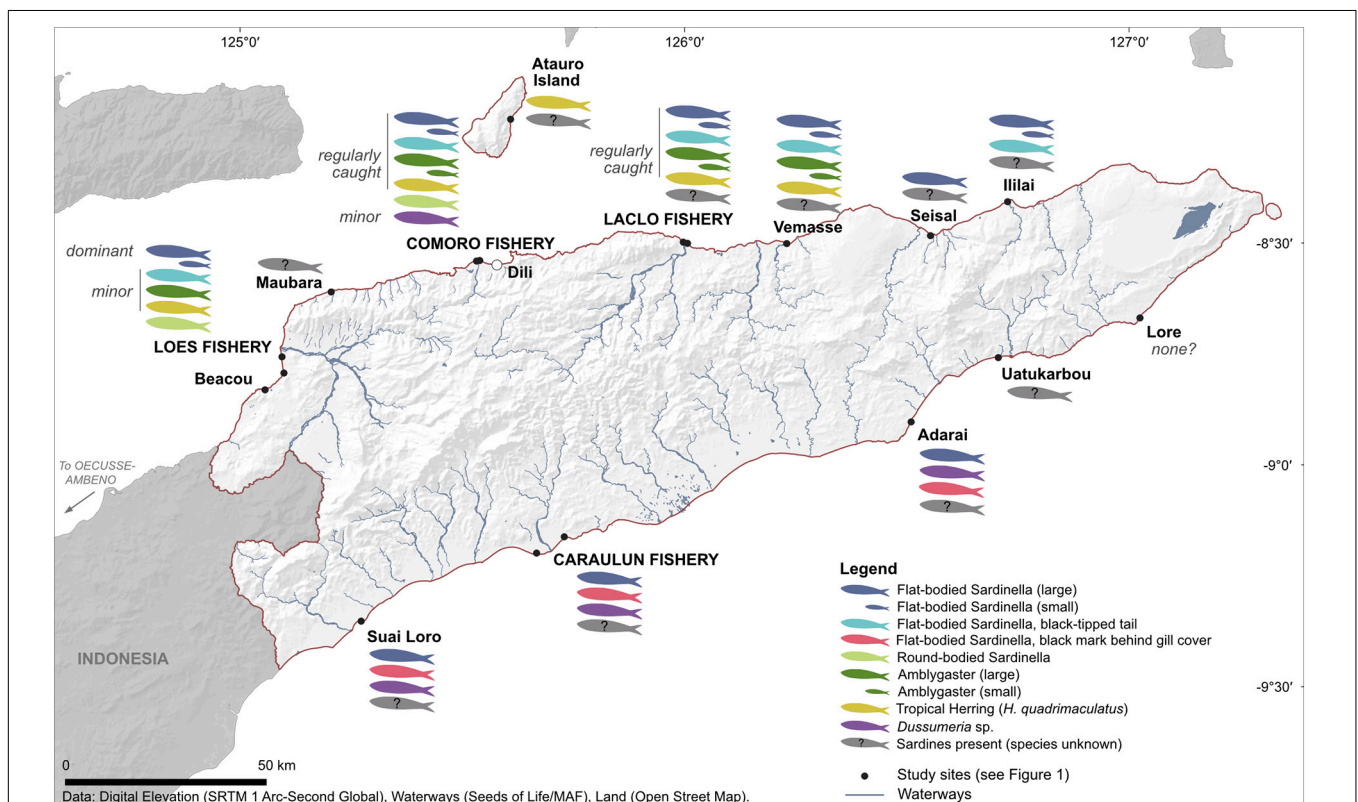






FIGURE 2 | Tropical sardine species reported at fishery locations around Timor-Leste. Data have been grouped for sites where fishers fish at the same location – these fisheries are described by the name of the associated river mouth.

 **Tropical Pilchards, *Amblygaster* spp.**, were distinguished as two sardine types by fishers at some sites, including Comoro: small fish caught in 1" (25 mm) mesh nets, which grow into larger fish caught mainly in 1.25" (32 mm) or 1.5" (38 mm) mesh nets (Table 1). Based on lengths at first maturity reported elsewhere in the IWP (Hunnam, 2021), these probably refer to juveniles and adults respectively. Both small and large specimens collected were identified as probable *A. leiogaster*. Photographs of fishers' catches also indicated the presence of *A. sirm.* Highly similar *A. clupeioides*, which also occurs in the region and is only distinguishable from *A. leiogaster* by number of lower gillrakers (Munroe et al., 1999), may also be present. Discussions and observations indicated that both small and large Tropical Pilchards are landed regularly at some north coast fisheries including Comoro and Laçlo. In Loes, fishers only distinguished large specimens and suggested this sardine type is typically only caught in low numbers in their fishery. Neither small or large specimens were mentioned in discussions with south coast fishers (Figure 2).

 **Tropical Herring *Herklotsichthys quadrimaculatus*** was identified from specimens collected in north coast fisheries. This species corresponded to a single locally distinguished small sardine type caught in 1" (25 mm) mesh net. Based on lengths at first maturity reported elsewhere (Hunnam, 2021), these are probably adults. Discussions and observations indicated that *H. quadrimaculatus* occurs regularly in some north coast fisheries including Comoro and Laçlo, and occasionally Loes and Atauro Island. However it was not mentioned by south coast fishers (Figure 2). Some Comoro fishers described a second, less common variety of the same local name, but it was unable to be sampled or photographed for identification.

 **Other: *Dussumieria* species** (formerly Clupeidae family, now Dussumeriidae, Fricke et al., 2020) was commonly mentioned by south coast fishers. It also appeared occasionally in the Comoro fishery (Figure 2). A specimen collected was identified as *Dussumieria elopsoides*. Photographs of other specimens were also probably *D. elopsoides*, since the similar *D. acuta* is not thought to occur as far south as Timor (Munroe et al., 1999; Fricke et al., 2020).

 **Others:** Specimens of other genera from the Clupeidae family were occasionally observed in fishers' mixed-species catches, such as gizzard shad, *Anodontostoma* sp. near Suai Loro. Photographs of fishers' catches taken after the main fieldwork period also indicated the presence of sardine and herring species additional to those documented here. This is unsurprising given over 40 species from the Clupeidae family are known to occur in marine and brackish habitats in the Indo-West Pacific region (Hunnam, 2021).

Based on comparison across sites, we found that the occurrence of sardine species-groups in local fisheries and their reported relative importance varies across Timor-Leste (Figure 2). For instance, Comoro and Laçlo fishers noted several sardine species-groups (as well as other small pelagic fishes) as important components of landings each year. In contrast, Loes fishers indicated their fishery is usually dominated by large Flat-bodied Sardinellas with no distinctive markings, while other sardine species-groups are typically only caught

occasionally, for short periods and/or in low numbers. This likely reflects different ecosystem characteristics and species-specific habitat requirements. For instance, the Loes River mouth area is characterized by long, sandy, surf beaches, while Comoro is adjacent to a bay with areas of intertidal seagrass, coral reef and mangroves (DesRochers et al., 2017); river catchment size and flow also differ.

Comment on Local Naming

Through this study, we identified two main common names for sardines in Tetun language, 'sardiña' and 'tembang', in use on the north and south coasts respectively. Some north coast fishers attributed the two names to Tetun (Tetun Dili) and Indonesian languages respectively. However on the south coast, we found that fishers from Suai Loro and coastal Ainaro and Manufahi (where the majority are Tetun Terik speakers) use 'sardiña' for *Dussumieria* sp. and 'tembang' for *Sardinella* spp. The former is of Portuguese origin (Williams-van Klinken, 2019) and the latter is from Indonesian/Malay (White et al., 2013). Tetun Dili has had a long period of contact with the Portuguese language from the late 1700s to 1975, and as such many Portuguese words have been incorporated into Tetun Dili. In contrast, Tetun Terik generally shows greater Indonesian/Malay influence (Williams-van Klinken et al., 2002). Limited fish trade between coasts (Steenbergen et al., 2019) may have reinforced this difference in naming. We also found that some fish traders use 'sardiña' or 'sardine' for small mackerel (*Rastrelliger* spp.), or anchovies (*Encrasicholina* spp. and *Thryssa* spp.). There are also other common names for sardines in Indigenous Timorese languages, but these were not investigated in this study.

The nine locally distinguished sardine types were generally consistent with the seven groups of species identified above. Each local type corresponded to a single species-group, with the exception of the Flat-bodied Sardinellas with no distinctive markings and Tropical Pilchards, which each comprised two local types distinguished by size (Table 1). Most species within these local types or species-groups are highly similar in appearance (see Supplementary Figure 1.1), which explains the aggregation of these species under single local names. In many instances, but not all, local naming corresponded to the physical appearance or characteristics of the sardine. For instance, fishers explained that 'sardiña ikun metan,' which translates as 'black tail sardine,' refers to its distinctive black-tipped tail; 'tilun modok' refers to a 'yellow-green "ear" or blotch behind the gill opening; 'tembang kasar' and 'tembang halus,' which translate as 'rough sardine' and 'smooth sardine' respectively, refer to scale texture; and 'sardiña mina,' or 'oil sardine,' is used for several species (at different sites) said to have high oil content. However the etymology of other names, while translatable to individual words, is less certain. For example, 'sardiña la'o belar' and 'sardiña la'o kabuar' translate as 'flattened' and 'rounded' (referring to body shape) 'walk/go sardine,' which could possibly relate to the seasonal and migratory nature of these species-groups. Fishers implied other names, such as 'matkana,' were just names. Further in-depth discussions with knowledgeable fishers, particularly using Indigenous Timorese

languages, may reveal further distinctions within these delineated species-groups.

Comparison of local naming across sites indicated that some local names are shared (or are similar), while other names differ. Furthermore, we found one instance where the same name is used for different species-groups (i.e., different genera) in two locations: large Tropical Pilchards in Comoro have the same name (*'kobi'*, Tetun language) as large Flat-bodied Sardinellas with no distinctive markings in Loes (*'kobi'*, Kemak language but also commonly used when Kemak speakers converse in Tetun). Also in Loes, the local names for large Tropical Pilchards (*Amblygaster* spp.) and Round-bodied Sardinella *S. lemuru* were occasionally suggested to be interchangeable, reflecting their similar body shape. A shared local name for *A. sirm* and *S. lemuru* has also been reported in parts of Indonesia (Potier and Nurhakim, 1995).

Local Knowledge on Tropical Sardines in Timor-Leste

Many Timorese fishers have considerable knowledge on the different types of fish they commonly catch, particularly on aspects relevant to their seasonal abundance, fish behavior, and post-harvest qualities, as discussed below and summarized in **Table 1**. Details of fishers' observations and knowledge by site and locally distinguished sardine type are provided in **Supplementary Tables 1.3, 1.4, 1.5**.

Seasonal Abundance and Habitat

Sardines were generally reported to occur seasonally in nearshore fisheries in Timor-Leste. However seasonality and habitat preferences were said to differ among species-groups and fish life-stage. At most sites, fishers reported that larger catches of small pelagic fish, like sardines, coincide with the wet season and formation of turbid plumes extending out from river mouths. Fishers noted that they often target the plume edges, and suggested that the sardines move into the turbid water during daylight to feed and hide from predators. Flat-bodied Sardinellas with no distinctive markings (*S. gibbosa* etc.), in particular, were noted to be wet season and river plume-associated in Loes, Laclo, Comoro and Caraulun fisheries. Existing literature on tropical sardines and their fisheries in the IWP does not report a specific association with river plumes (Hunnam, 2021). However there are a number of references to tropical sardine occurrence in and around river mouths: *S. albella* and *H. quadrimaculatus* in landings near Zambezi River mouth in Mozambique (Johnsen et al., 2008); juvenile *S. gibbosa* aggregations near river mouths in northeast Australia (Cappo, 1995); fishers' reports of *A. sirm* schools near river mouths after rain in Solomon Islands (Roeger et al., 2016); and '*S. fimbriata*' now *S. pacifica* (Hata and Motomura, 2019b) in productive fisheries associated with riverine nutrient input in Butuan Bay in the Philippines (Villanoy et al., 2011; Naguit, 2016). More generally, higher abundance of fish, larvae and fish eggs have been found in river plumes compared to surrounding areas (Grimes and Kingsford, 1996; Krakstad et al., 2017b). Rivers are important sources of nutrients to coastal waters, which can stimulate phytoplankton and benthic microalgal production,

increasing food availability for higher trophic organisms (Caddy and Bakun, 1994; Loneragan and Bunn, 1999). The physical dynamics created by river plumes and plume fronts, at the freshwater-saltwater interface, can concentrate and retain food particles, eggs, larvae and fish, and create areas favorable for larval survival. As such, reproduction of some fish and other organisms may be synchronized to seasonal freshwater pulses (Grimes and Kingsford, 1996; Bakun, 2010). River plumes may also provide small fish protection from predators in some locations (Litz et al., 2013), although turbid water can also advantage fishers. Monofilament drifting gillnets, the dominant gear used in Timor-Leste, are more effective in turbid water or at low light levels (Bjorndal, 2009).

In the Comoro fishery, small Tropical Pilchards (*Amblygaster* spp.) were also reported to seasonally occur in the turbid plume, while large specimens could occur at any time of year but only for short periods. While *A. sirm* has also been associated with river plumes in the Solomon Islands (Roeger et al., 2016), in Indonesia it is considered an oceanic species (Potier and Nurhakim, 1995). Similarly, surveys in Kiribati and north-eastern Australia found juveniles rarely occurred near shore and only when sea conditions were calm and clear (Rawlinson et al., 1992; Cappo, 1995). The presence of small and large *Amblygaster* spp. in nearshore fishing grounds in Timor-Leste may be due to its steep bathymetry (**Figure 3**), which can result in species typically considered oceanic occurring closer to shore (Dalzell, 1993). Differing turbidity or salinity tolerances between *Amblygaster* spp. could also account for apparent differences in juvenile habitat associations.

Other species, such as Tropical Herring *H. quadrimaculatus*, were thought to live permanently nearshore at some sites in Timor-Leste (e.g., Comoro, Manatuto and Vemasse) and were said to be caught year-round in both turbid and clear water. Elsewhere in the IWP, *H. quadrimaculatus* similarly occurs in a wide variety of nearshore habitats including mangroves, sandy atoll lagoons and sheltered bays, but may move to deeper water at night (Williams and Clarke, 1983; Milton et al., 1994a).

Life Cycle and Migrations

Timorese fishers have some knowledge of sardine reproductive patterns. For example, Flat-bodied Sardinellas with no distinctive markings were reported to contain eggs at wet season onset (Vemasse), mid-season (Loes) and end (Comoro). Very small sardines were said to occur in the dry season (Vemasse), late wet (Loes) and early wet (Comoro). However further investigations are required in order to draw conclusions from these observations. As some fishers highlighted, very small fish cannot be visually determined as a certain type or species. A Comoro fisher also remarked that television documentaries and an Indonesian study had informed his understanding of the fish life cycle and the type of habitat where female fishes release their eggs. Furthermore we did not query fishers to determine, for example, the internal appearance or maturity stage at which they describe eggs to be present. Elsewhere in the IWP, the timing and duration of spawning for Flat-bodied Sardinellas, such as *S. gibbosa*, varies between locations, probably reflecting the strong

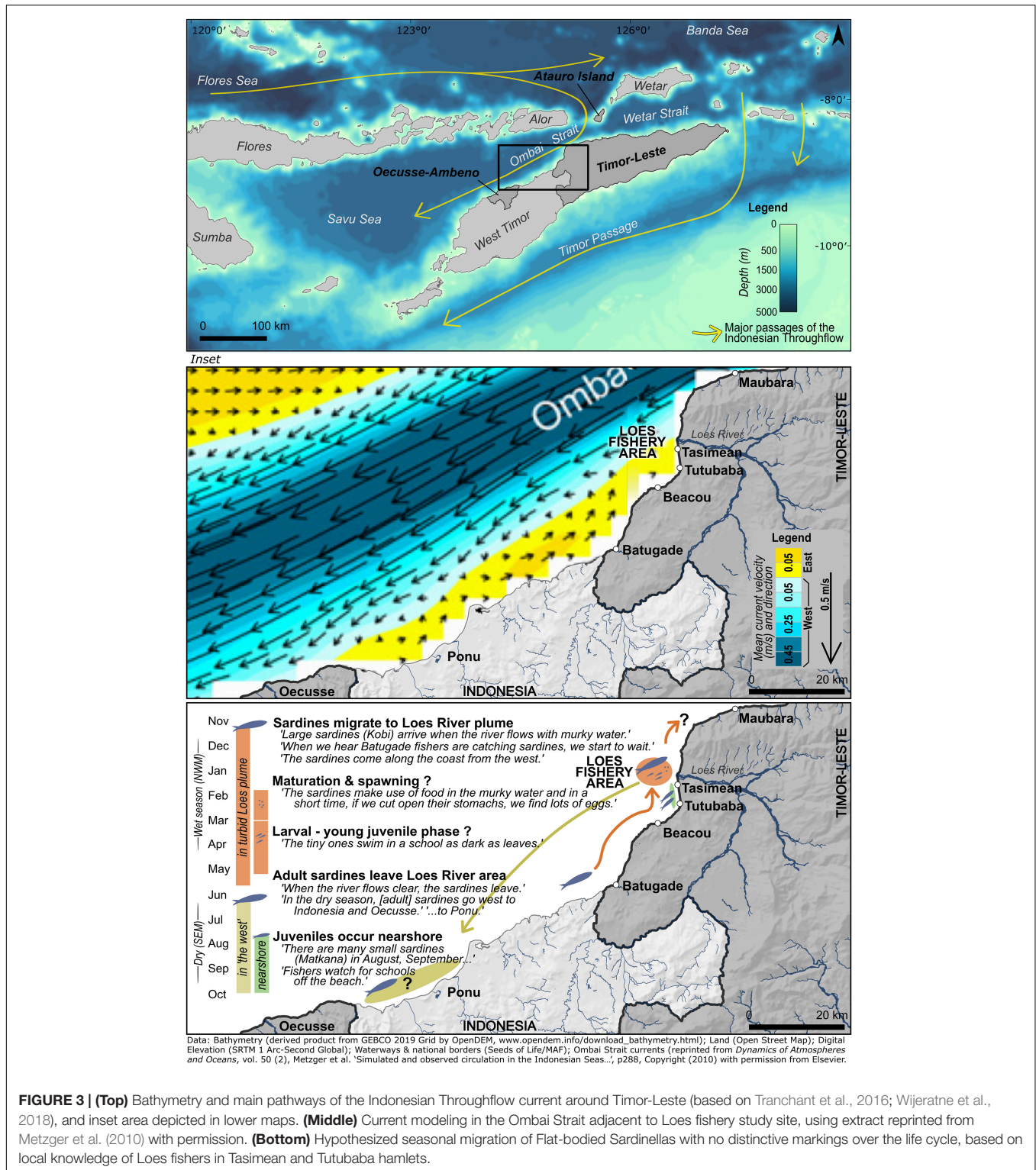


FIGURE 3 | (Top) Bathymetry and main pathways of the Indonesian Throughflow current around Timor-Leste (based on Tranchant et al., 2016; Wijeratne et al., 2018), and inset area depicted in lower maps. **(Middle)** Current modeling in the Ombai Strait adjacent to Loes fishery study site, using extract reprinted from Metzger et al. (2010) with permission. **(Bottom)** Hypothesized seasonal migration of Flat-bodied Sardinellas with no distinctive markings over the life cycle, based on local knowledge of Loes fishers in Tasimean and Tutubaba hamlets.

influence of local environmental conditions. Spawning durations ranging from 2 months to year-round have been reported (Hunnam, 2021).

Seasonal migrations are common among small pelagic fish including sardines, reflecting responses to spatial and temporal

changes in food availability and abiotic conditions, and different habitat requirements at different fish life-stages (Fréon et al., 2005). Timorese fishers' observations on reproductive processes, together with insights on the seasonal occurrence, movement and habitat of locally distinguished small (juvenile) and large

(adult) sardine types, provide hypotheses on potential migration patterns, as summarized for Flat-bodied *Sardinellas* with no distinctive markings in the Loes fishery (Figure 3). Large (adult) Flat-bodied *Sardinellas* ('*kobi*') are thought to migrate from Oecusse and Indonesian waters in the west, to fishing grounds in and around the seasonally turbid Loes River plume. Fishers' observations of adults with eggs followed by schools of tiny fish a few months later, suggest one or more of the Flat-bodied *Sardinella* species with no distinctive markings may be spawning in or near the Loes River plume mid-wet season. Based on existing understanding of the region's oceanography and weather patterns, this timing and location coincides with favorable reproductive habitat (or an 'ocean triad' of conditions, as per Bakun, 2010). Nutrient-enrichment of coastal waters from wet season river discharge is likely to stimulate plankton blooms, increasing food availability for maturing adults and newly hatched larvae. Furthermore, the strong, prevailing, south-westward flowing currents of the Ombai Strait (Sprintall et al., 2010), adjacent to Loes fishing grounds, are weakest during the wet season north-east monsoon (December–February, Tranchant et al., 2016), which also brings strong westerly (onshore) winds and waves (DNMG, 2015). These conditions, together with the physical dynamics of the river plume and front, would create conditions favorable for retention and concentration of eggs, newly hatched larvae and food particles within the local area, thus increasing chances of larval survival. *Sardinella* spp. in the tropical West Atlantic Ocean were shown to spawn in a river plume, at a time of year when seasonal currents promote maximum retention of eggs and larvae in highly productive coastal waters (Krakstad et al., 2017a). Passive transport via currents is common during early life-stages when larvae are small and fin development is incomplete (Llopiz et al., 2014). Based on the few IWP studies available, tropical sardine eggs hatch in less than 24 h. Larvae then take 40–60 days to develop into juvenile fish (Kuthalingam, 1960; Williams and Clarke, 1983). Current modeling of the Ombai Strait suggests anti-clockwise circulation along the concave coastline between Oecusse and Loes (Metzger et al., 2010; Figure 3), which would transport larvae and create juvenile nursery sites along this coast. Fishers in Oecusse, Batugade and Loes have all reported catching small Flat-bodied *Sardinellas* ('*matkana*'); this study and WorldFish-MAF unpublished). Off Tasimean and Tutubaba beaches, small Flat-bodied *Sardinellas* were said to typically occur in the dry season, although reportedly less reliably in the past 10+ years (Figure 3). If hatched mid-wet season, these small sardines (~10 cm SL) would be 6–8 months old by the dry season (August–October), and would then become large sardines (~13 cm SL) in the subsequent wet season, aged 10–12 months. This rate of growth and development is generally consistent with published studies from elsewhere. *S. gibbosa* is generally reported to reach first maturity around 11 cm SL, aged 6–12 months (reviewed in Hunnam, 2021).

However, further research is required to investigate these hypotheses. Migrations and spawning grounds may differ for species within the Flat-bodied *Sardinella* species-group, and/or may change with population size and age class as shown for some temperate species (see review, Giannoulaki et al., 2014).

Spawning may occur year-round, with periods of peak activity, as reported for some Flat-bodied *Sardinella* populations elsewhere (Hunnam, 2021). There is also evidence of upwelling and elevated phytoplankton concentrations (and therefore food availability) in parts of the Ombai Strait, particularly during the dry south-east monsoon (Moore and Marra, 2002), which may also influence sardine movement and reproduction.

Fluctuations in Sardine Landings and Perceived Drivers

Fluctuations in sardine landings in Timor-Leste were commonly attributed to rainfall, river flow and turbid river plume extent. Comoro and Loes fishers reported the occurrence of good landings when moderate rainfall created a medium-sized river plume, sufficient to attract sardines from afar but with a plume edge still accessible with their small canoes. Wet season duration and river plume persistence were also regarded to be closely linked to the duration of sardine occurrence in fisheries. This was particularly the case in Loes, where it was said that rain late in the wet season could extend the main large Flat-bodied *Sardinella* fishing season. Conversely, fishers associated very small or large river plumes, caused by too little or too much rain respectively, with poor landings. In Loes, poor catches were also often considered ancestral or spiritual retribution for fishers and/or fish traders not adhering to customary rules governing the fishery. However at one site, Vemassee, fishers did not consistently associate turbid river flow with good (or poor) sardine landings, possibly reflecting the influence of other larger rivers nearby and/or more variable fishing conditions.

Seasonal and interannual variations in river discharge, determined by rainfall patterns, evaporation rates and catchment management, are known to have profound effects on estuarine and coastal ecosystems, including fish (Loneragan and Bunn, 1999; Gillson, 2011). Fisheries production is typically positively associated with rainfall and river flow, but responses are influenced by a complex of interacting ecological factors as well as fisher behavior, and therefore underlying processes driving responses can differ by species and region (Loneragan and Bunn, 1999; Gillson, 2011; Meynecke and Lee, 2011). In Timor-Leste, sardines may be attracted to seasonal river plumes by higher food concentrations, protection from predators and/or reproductive cues. This aggregation would rapidly increase localized abundance and availability to fishers; although higher catch rates may also be achieved in plumes due to the type of fishing gear used. There may also be a lagged increase as small sardines feed, grow and enter the fishery—as alluded to by some Timorese fishers and reported to occur elsewhere (Sartimbul et al., 2010). In addition, catches may be influenced by fishers' access to preferred fishing grounds, generally the plume edges, which is potentially dependent on both ocean–climate processes that determine plume size (rainfall, river flow, tide and currents), as well as fishers' behavior, attitude and associated factors such as canoe sturdiness, motor reliability, personality, motivation and experience. Variability in reproductive conditions and larval survival 4–12 months earlier is also likely to be a fundamental driver of fisheries landings (Hunnam, 2021), although this aspect was not mentioned by Timorese fishers.

Fishers in both Loes and Comoro reported that sardine catches typically vary between years. However in the absence of written records, discussions about specific years of high or low catches were only partly successful. While fishers recalled some years in which sardines were particularly abundant, actual years mentioned rarely coincided with those noted in other discussions. This could suggest that Timorese sardine fisheries are not characterized by the extreme highs and lows of major sardine fisheries elsewhere. It is possible that their mixed-species nature, combined with species-specific responses to environmental variables, moderate fluctuations in overall landings. As one Comoro fisher noted, “Fishers aren’t more dependent on any particular type of sardine, but just catch whatever sardines [and other types of fish] are around.” Notably, the Round-bodied Sardinella *S. lemuru* was not reported as a regular dominant component of sardine landings at any site visited in Timor-Leste. This species, or closely related *S. longiceps*, dominates each of the major sardine fisheries in the IWP—in the Philippines, Indonesia and India (Merta et al., 2000; Rohit et al., 2018; Rola et al., 2018). This species-group appears to form large (but variable) populations in locations with strong seasonal upwelling of nutrient-rich water and high concentrations of plankton (Hendiarti et al., 2005; Villanoy et al., 2011; Hunnam, 2021). In Timor-Leste, local environmental conditions may not be regularly favorable for the formation of large *S. lemuru* populations. Alternatively, this species may not regularly frequent the nearshore habitat accessible by Timorese fishers. The occasional years when large numbers of *S. lemuru* are caught in nearshore Timorese fisheries, are likely the result of climate-ocean conditions being unusually favorable for reproductive success and larval survival, and expansion of the resulting large population into nearshore fishing grounds (as known to occur in several temperate sardine populations, Giannoulaki et al., 2014). Loes fishers recalled large catches dominated by *S. lemuru* in 1994 and 2002–2003, both periods coincident with prolonged *El Niño* conditions (BOM, 2005), which generate strong upwelling and high primary productivity in the Ombai Strait (Moore and Marra, 2002). *El Niño* conditions are known to result in above-average *S. lemuru* landings in Bali, Indonesia (Buchary et al., 2011) and parts of the Philippines (Rola et al., 2018). However further research is required in Timor-Leste to determine whether these are more than isolated co-occurrences.

Fishers across sites (Loes, Comoro and Vemassee) also shared a general perception that sardine landings were higher in the past, and attributed declines over the past 20 years to a number of human factors. Comoro fishers noted there are now more boats and nets (i.e., higher fishing effort), and speculated on the negative impact of plastic pollution in stormwater runoff and river discharge after heavy rainfall. In Loes, fishers reported that motorization of canoes (i.e., increased fishing power or efficiency) since the 2000s has led to more boats and nets in sardine fishing grounds near the Loes River mouth, including from neighboring communities. According to fishers, these changes mean sardines are now caught more quickly and/or have become ‘wilder’ and harder to catch. Loes fishers also expressed concern about the impacts of larger-scale, less selective fishing gear now being

used in neighboring communities. Detrimental impacts on fish populations have been shown to result from noise disturbance and pollution from small motor boats (Whitfield and Becker, 2014). However, while plastic ingestion by marine fish, including those of commercial importance, is increasing globally, there is no evidence as yet of negative effects on fish populations (Lusher et al., 2017; Savoca et al., 2021). Small pelagic fisheries in Timor-Leste are orders of magnitude smaller than the major sardine fisheries elsewhere in the region—the entire national fisheries production (all species) was estimated to be under 2,500t in 2017 (López-Angarita et al., 2019). However, increases in fishing effort and power have led to the unsustainable exploitation of fish stocks in many instances worldwide, including in tropical small-scale and small pelagic fisheries (Dalzell and Ganaden, 1987; Pauly and Chuenpagdee, 2003; Stevens et al., 2014; Kripa et al., 2018). Therefore the perception of declining sardine landings by Timorese fishers is an important area for further investigation, particularly in the context of current efforts and policies aimed at enhancing fisheries production in Timor-Leste.

Post-harvest Characteristics

Local knowledge from fishers, fish traders and other fishing community members highlighted differences between species-groups in terms of their post-harvest characteristics, with strong agreement across locations. This is important given the hot conditions in Timor-Leste and often limited availability of ice. Fishers noted that some sardine types are sold more readily to traders, while others tend to be kept by fishers for immediate home consumption. The Flat-bodied Sardinella with black-tipped tail (*S. melanura* etc.) was widely noted to keep exceptionally well post-harvest. Other Flat-bodied Sardinellas with no distinctive markings (*S. gibbosa* etc.) were also said to keep well. In contrast, Tropical Pilchards (*Amblygaster* spp.) were noted to spoil quickly and not store well on ice. Round-bodied Sardinella *S. lemuru* was also said to spoil quickly, a characteristic attributed to its oily flesh. In India, the closely related Round-bodied Sardinella, *S. longiceps*, is widely used for oil extraction (Kripa et al., 2018). Based on sensory evaluations, a study in Sri Lanka found *A. sirm* had a shelf-life of 6 days on ice (Perera et al., 2020), while a temperate herring, *Clupea harengus*, had a shelf life of 8 days on ice and 4 days when only chilled (Özogul et al., 2000).

Reflections on Collecting, Interpreting and Valuing Local Knowledge

Fishers in Timor-Leste have considerable knowledge relevant to the successful operation, development and management of their local fisheries. This knowledge, largely gained through practical experience, trial and error, observations and exchanges within their community and families rather than through formal education or training, forms a significant resource that should be valued, supported, and developed.

Timor-Leste’s complex history of colonization, conflict and associated movement of people, as well as post-independence nation building, is reflected in the different types of knowledge, experience and engagement with fishing as a livelihood among fishers (and others), and differing degrees of shared knowledge

within fishing communities. This context differs to those typically investigated in early local knowledge studies (e.g., Inglis, 1993; Johannes et al., 2000; McWilliam, 2003), which tended to focus on the ancient wisdom of elders; more recent framing of local knowledge as a dynamic process opens up broader avenues of research (Lauer, 2017). In the Loes area, where some families have fished for multiple generations, there appeared to be greater cultural connections with sardines, including the existence of rules and rituals to govern fishing activities. These shared cultural or spiritual beliefs also influenced local thinking about fisheries resources, including aspects such as seasonal movement. In contrast, fishers in Vemasse often mentioned their inland origin—they had moved to the coastal area during Indonesian occupation and only started fishing in the last 40 years, largely out of necessity to adapt to living in the arid, marginal coastal lands. Fishers' observations here were more varied and at times contradictory, for instance regarding associations between fish and turbidity, suggesting weaker shared fishing-related narratives. Local knowledge and explanations for observations were also shaped by fishers' backgrounds. In Comoro, our key participants were predominately young and literate (some with university education) with access to television and internet, which they drew on and referenced in our discussions. While our study took a broad, exploratory, inclusive approach, factors such as age, experience and background have been shown in previous studies to have important implications for investigations into local knowledge and fisher knowledge (Johannes et al., 2000; Berkström et al., 2019).

The depth and consistency of fishers' (and others') knowledge also varied by topic. Seasonal occurrence and habitat associations were generally topics on which fishers had strong knowledge and observations. On other aspects, local knowledge appeared to be relatively weak and perhaps not used to guide or govern their fishing activities. For instance, understanding of life cycle characteristics was often vague or based on conjecture. While some fishers expressed concern that non-selective fishing gears catching very small fish may damage future generations of fish, we did not have any discussions in which fishers linked fishing pressure on small sardines with catches of large sardines of the same species (e.g., Tropical Pilchards '*kostazul*' and '*kobi*' in the Comoro fishery). However we also recognize that some in-depth knowledge was lost in translation—for instance on tides, currents and lunar cycles. This was due to working across the Tetun–English language interface (and at times a Tetun–Indigenous language interface); the multiple meanings of some Tetun words and the typically high-context communication style employed; as well as the broader challenge of articulating and discussing knowledge which is embedded in practical activity (Lauer and Aswani, 2009).

Establishing a clear understanding of local naming was key to holding successful discussions with fishers about their observations and experiences. Local names are closely linked to local knowledge. Local knowledge can emerge through the process of identifying local names (Davis and Ruddle, 2010) and names themselves can contain information on characteristics such as habitat, behavior and appearance (Foale, 1998). However, differences in naming across Timor-Leste due to the use and

influence of multiple languages and historical separateness of some coastal communities, combined with the highly similar appearance of some sardine species, posed a considerable challenge for the research team. While fishers enjoyed looking through fish identification guides, we found this was not a reliable method on which to base our data collection due to the small photos, exclusion of some species and the subtle morphological differences between sardine species. Freshly caught specimens were most reliable, as found in other similar studies (e.g., Foale, 1998; Hamilton and Walter, 1999). Life-size photos of specimens taken in Timor-Leste also generally worked well, once we had collated sufficient photographs to represent most of the important species. Participation in fishery activities, such as assisting to remove fish from nets, was also beneficial as it not only allowed us to verify local names with a group of people simultaneously, but also often prompted conversations on distinguishing features less apparent in photographs, such as body shape and texture.

Relating local names with an accurate taxonomic identification (to species or genus level) is also important because it enables local knowledge to be compared and contrasted with other research, and can facilitate the use of information from elsewhere to fill knowledge gaps or provide the basis of hypotheses for future studies. It also enables the contribution of local knowledge to the broader set of information about a particular species. However, as we found, local names may not correspond neatly to an individual species—particularly for a group such as sardines where species within some genera are highly similar. Our species-group approach allowed us to account for both uncertainty in taxonomic identification and the fact that local names often are used for multiple species.

Finally, the process of accurately documenting local naming and knowledge required time and effort across social and natural science disciplines from fish taxonomy and biology to linguistic and cultural understanding. More time spent in the hamlets associated with the two case study fisheries meant we were able to build greater rapport with community members and this resulted in a greater depth of understanding compared to our briefer visits elsewhere.

Considerations for Fisheries Monitoring and Management, and Future Research Needs

Fishers' local knowledge recorded in this study has immediate application in efforts to formalize fisheries monitoring, and in the broader consideration of potential impacts on Timor-Leste's coastal fisheries from catchment developments, climate change and fishing pressure in neighboring Indonesia.

Fisheries monitoring programs need to account for differences in local naming across sites, and also acknowledge where local names may relate to more than one taxonomic species. A key example is provided by the local name '*kobi*' or '*sardiña kobi*,' which we found can refer to two different sardine genera or species-groups in Timor-Leste: large Flat-bodied Sardinellas with no distinctive marking in Loes and large Tropical Pilchards in Comoro. In addition, an existing national fish

identification booklet records '*sardiña kobi*' as the oxeye herring *Megalops cyprinoides*, an unrelated species from the Megalopidae family which shares some superficial similarities in appearance. Furthermore, Timorese common names listed on FishBase also include similar name '*kopi*' for fusiliers of the Caesionidae family, as well as for Tropical Pilchard *A. sirm* (Froese and Pauly, 2020). National fisheries monitoring in Timor-Leste currently records landings at the family level due to the difficulties associated with accurately identifying mixed-species catches to species level across the country (Tilley et al., 2020). However, this example illustrates that the same or similar local name could relate to three different families. Findings from this study suggest landings of '*sardiña kobi*' are most likely to be members of the Clupeidae family, either *Sardinella* spp. in Bobonaro municipality or *Amblygaster* spp. in Dili—but not 'herring' from the 'Elopidae family,' as currently recorded (Tilley et al., 2020; WorldFish and MAF, 2021). We cannot provide any insight on where this name may relate to fusiliers or oxeye herring. This current misidentification has potential fisheries management implications. While the two clupeids have similarly short life-spans (generally 1–4 years) and small maximum size (usually under 20 cm SL), *M. cyprinoides* can live up to 44 years and reach a maximum size around 110 cm SL (Froese and Pauly, 2020).

The strong association between sardine fishery productivity and seasonally turbid river plumes (or freshwater flow), recognized by fishers at several sites, emphasizes the need to consider coastal fisheries and fisher livelihood impacts in any catchment development proposals or assessments that may alter river flow or water quality. Rivers in Timor-Leste are currently largely unregulated, although some water is extracted for irrigation via free-intake and weir-based diversion systems. Post-independence policy targets to achieve food self-sufficiency and reduce malnutrition have led to a focus on water infrastructure development for agricultural use, including plans for new irrigation schemes and small and large dam construction (WB, 2018). Elsewhere, anthropogenic modification of catchments and river flows have caused major declines in coastal fisheries production, including tropical sardine fisheries (Loneragan and Bunn, 1999; Gillson, 2011). Findings from this study strongly suggest that changes to Timorese river flow regimes could have similar negative consequences for coastal fisheries. Catchment erosion due to land-use changes has already increased river sediment loads in Timor-Leste, and is suggested as one possible cause for perceived fisheries declines in some areas due to lower nutrient availability from sandier sediment (Alongi et al., 2009). River flow in Timor-Leste is highly dependent on rainfall, which is highly variable and may become more so with climate change (DNMG, 2015). Further research is required to understand the mechanisms underlying the observed relationship between rainfall, freshwater flows and sardine fishery productivity in Timor-Leste in order to elucidate likely responses to such changes. Due to the different life-cycles of different sardine species-groups, responses may be species-specific.

The seasonal movement patterns of fishes need to be considered (and better understood) in future fisheries management planning in Timor-Leste, given evidence that at least some sardine fisheries cross community, municipality

and probably even national boundaries. Fishers in the Loes area have already expressed concern over increasing numbers of boats and nets, the non-appearance of juvenile sardines nearshore in their 'usual season' in some recent years, and the potential impact of the larger capacity mini-purse seine gear used in neighboring fishing communities. In the absence of resources to support fisheries governance and management in Timor-Leste, there are multiple examples where co-management partnerships between conservation organizations and local communities have tended to favor delineation of marine protected areas or no-take zones. For mobile fishes, like most sardine species-groups, such site-based protection may not be the most appropriate management mechanism (Tilley et al., 2019).

In conclusion, this study provides further evidence of the value of knowledge held by fishers, and demonstrates how local naming and knowledge can provide useful foundational knowledge to inform fisheries monitoring and management, and identify future research needs.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Materials**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The research component involving human participants was reviewed and approved by Charles Darwin University's Human Research Ethics Committee (approval H16111), and informed written or oral consent was provided by all participants. The animal research component was reviewed and approved by Charles Darwin University's Animal Research Ethics Committee (approval A17024).

AUTHOR CONTRIBUTIONS

KH, NS, and DM designed the research. KH, IC, and JRL collected the data. MH identified the fish specimens. IC transcribed and translated the audio-recorded discussions. KH analyzed the data and wrote the manuscript. NS, DM, MH, JRL, and IC provided edits and feedback. All the authors contributed to the article 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.2021.673173/full#supplementary-material>

Supplementary Figure 1.1 | Photographs of sardines used in local knowledge and naming discussions.

Supplementary Table 1.1 | Details of research activities carried out at each location.

Supplementary Table 1.2 | Local naming corresponding to reference photos of sardine species-groups.

Supplementary Table 1.3 | Discussions, conversations, and observations at Loes fishery study site.

Supplementary Table 1.4 | Discussions, conversations, and observations at Comoro fishery study site.

Supplementary Table 1.5 | Discussions, conversations, and observations at other locations around Timor-Leste.

Supplementary Table 2.1 | Details of fish specimens examined for study on sardine species of Timor-Leste.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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