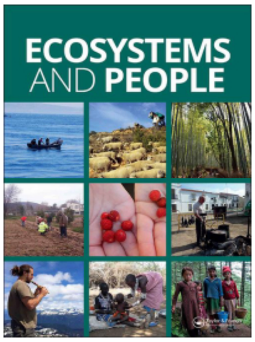

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Social and temporal dynamics mediate the distribution of ecosystem service benefits from a small-scale fishery

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ABSTRACT
Small-scale fisheries are important for the livelihoods and food security of millions of people in low-income countries. Sustainably managing these dynamic social-ecological systems requires understanding links between ecosystems and human well-being: the focus of ecosystem service approaches. However, in-depth exploration of how co-production and temporal dynamics shape ecosystem benefits in small-scale fisheries remain nascent. There is thus an opportunity to better investigate pathways through which small-scale fisheries support food security. To address this gap, we ask how households allocate seafood landings across different uses, depending on supply and season. Using a daily survey, we collected panel data on landings from 15 households on Atauro Island, Timor-Leste, over six 1-week periods across three seasons, representing 630 survey days and 179 fishing trips. We found households mediate the pathways through which seafood contributes to food security. Specifically, the proportion of landings eaten, sold or shared changed with the amount landed and across seasons. As landings increased, households ate a smaller proportion and sold a greater proportion. The greatest proportion of landings were sold in the *preparation season*, when households save money to buy staple foods. Landings were shared with family and kin, reflecting the importance of seafood for social capital and community food security. Put broadly, households shaped a dynamic and non-linear (not directly proportional) relationship between service supply and benefits. Our findings demonstrate that seasonal context and livelihood priorities shape seafood provisioning benefits in small-scale fisheries. Careful consideration of temporal scale in ecosystem service assessments is critical for sustainable management of small-scale fisheries.

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1. Introduction

For the 32 million small-scale fishers living in low-income countries (World Bank, FAO, WorldFish 2012), the provisioning ecosystem service of wild-caught seafood (inclusive of all edible aquatic animals, hereafter 'seafood') provides important food security benefits. Seafood is a vital source of protein and micronutrients (Hicks et al. 2019); income from the seafood trade is critical for buying staple foods (Fabinyi et al. 2017); and when shared, seafood strengthens social capital and mechanisms of reciprocal altruism (Vaughan and Vitousek 2013). However, stressors such as biodiversity loss, over-exploitation and climate change are all negatively impacting marine fisheries in ways that will disproportionately affect low-income countries (Allison et al. 2009; Blasiak et al. 2017).

In linked social-ecological systems such as small-scale fisheries, interdependencies between human wellbeing and ecosystems create critical feedbacks (Reyers et al. 2013; Mehring et al. 2017). Sustainable and equitable management of fisheries for human wellbeing depends on moderating and responding to relevant changes in coastal ecosystems. Ecosystem service approaches can help to integrate ecological and wellbeing objectives in fisheries management. However, the ability of ecosystem services to inform decision-making has been limited by knowledge gaps about the links between ecosystem service supply and the delivery and distribution of benefits (Bennett and Chaplin-Kramer 2016; Rieb et al. 2017; Chan and Satterfield 2020; Mandle et al. 2021). Recent research has emphasized the need for greater attention to four key knowledge gaps in ecosystem services research that limit our understanding of coastal areas as complex social-ecological systems (Solé and Ariza 2019): (1) the benefits and beneficiaries (Chan and Satterfield 2020; Mandle et al. 2021), (2) processes of co-production (Bennett et al. 2015), (3) temporal dynamics (Rau et al. 2020), and (4) fisheries in low-income countries (Lautenbach et al. 2019; Blythe et al. 2020).

First, the links between the biological resources and the social and economic benefits of fisheries, including food security, are determined by complex

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Supplemental data for this article can be accessed here.

and context-specific variables, such as local and regional markets, supply chains, and the distribution of costs and benefits amongst fishers (Smith et al. 2010; Darling 2014). Yet, small-scale fisheries management often assumes that increased fish populations will directly equate to changes in benefits for people, including food security (Foale et al. 2013; Wieland et al. 2016). These perspectives overlook the complex social systems in which fisheries operate and the multi-dimensional nature of food security. Likewise, although ecosystem services approaches can provide human centred perspectives on coastal systems (Loomis and Paterson 2014), they have tended to focus primarily on the ecosystem processes and functions (i.e. biophysical aspects) that determine the potential supply of services from a landscape (Chan and Satterfield 2020). More specifically, coastal ecosystem services research has addressed food provisioning (Blythe et al. 2020), but assessments mostly focus on the potential supply and value of food, with less attention to the benefit contributions to human wellbeing (Solé and Ariza 2019). The potential supply of an ecosystem service does not necessarily equate to benefits for people; not all services are realised and who actually benefits from a service is determined by access (Ribot and Peluso 2003; Daw et al. 2011; Queiroz et al. 2015). In addition, individual ecosystem services can support multiple benefits to individuals that contribute to human wellbeing through different mechanisms and the importance of benefits may differ between social groups (Chaigneau et al. 2019). Understanding the delivery of benefits to people is critical if ecosystem service approaches are to be relevant to household food security outcomes in small-scale fisheries.

Second, co-production and in particular, accounting for the ways that people mediate benefit flows from seafood, is critical for understanding the contributions of small-scale fisheries to household food security. Social processes mediate the multiple stages linking landscapes to human wellbeing values (Spangenberg et al. 2014a, 2014b), with many ecosystem services co-produced by people to varying extents (Palomo et al. 2016). The quantity and quality of ecosystem services delivered is therefore affected by both natural and non-natural capital inputs (Palomo et al. 2016). However, little research has focused on the co-production of marine and coastal ecosystem services (Outeiro et al. 2017), the combinations of natural and non-natural capital needed to co-produce ecosystem services in time and space are not well understood (Bennett et al. 2015; Solé and Ariza 2019), and there are knowledge gaps in the co-production of ecosystem services for food security (Cruz-Garcia et al. 2016). Ecosystem services research has shown that greater human inputs (such as labour and technology) in fishery production systems are associated with greater supply of provisioning services i.e. greater landings (Outeiro et al. 2017). However, how the supply of a service, such as seafood, translates into benefits for people depends on how people choose or allow ecosystem services to flow to different purposes and beneficiaries (the allocation mechanism of co-production) (Fedele et al. 2017). Indeed, recent food systems research in fisheries highlights the importance of linking production to food security by accounting for how seafood is used after it is landed (Hicks et al. 2019; Arthur et al. 2021; Simmance et al. 2021). Thus, empirical work on the allocation of the provisioning service of seafood service is key to understanding how people influence the delivery and distribution of food security benefits in small-scale fisheries.

Third, seasonal food scarcity is the main cause of hunger and malnutrition among the rural poor globally (Vaitla et al. 2009) and must be addressed to achieve food security, which ' … exists when all people, *at all times*, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life' (emphasis added) (FAO 1996). Direct dependence on ecosystem services inextricably links seasons and livelihoods in low-income countries (Huq et al. 2020), creating vulnerabilities of food insecurity and poverty to seasonal variability and climatic and socio-economic change, particularly in coastal communities (Blasiak et al. 2017; ESPA 2018). Seasonal changes in the availability of fisheries resources are linked to target species' life histories (Maynou et al. 2011; Pellowe and Leslie 2017; Hunnam et al. 2021) and in access to fisheries as a result of weather, especially wind and sea conditions (Cetra and Petrere 2014; Mills et al. 2017; Gill et al. 2019; Grantham et al. 2021). Seasonality is often well understood in traditional ecological knowledge (Gunawardena et al. 2016) and reflected in fishing effort and decisions of where and when to fish (Moreno-Báez et al. 2012; Beitl 2015). Seasonal changes in catch can impact small-scale fishery values chains (Jueseah et al. 2020) and directly affect fisher livelihoods and food security (Fabinyi et al. 2017), creating cycles of hardship (Siar 2003). However, there has been limited attention in ecosystem services research to temporal changes in the delivery of benefits to people (Rau et al. 2020); for example, a majority (71%) of research on coastal ecosystem services has focused on a single point in time (Blythe et al. 2020). Temporal variability in ecosystem services can be linear or non-linear and supply of and demand for ecosystem services can change differently through time (Rau et al. 2018). As a result, the relationships between ecosystems and human wellbeing change through time and single data snapshots cannot explain variability and interactions in ecosystem services (Renard et al. 2015). Empirical work on the temporal aspects of ecosystem services, and specifically the seasonal delivery of benefits from seafood, is needed to inform the management of food security in small-scale fisheries.

Fourth, most ecosystem services research has focused on higher income countries (Lautenbach et al. 2019), including temporally sensitive research (Rau et al. 2020) and coastal research, which is mostly in Europe and North America (Liquete et al. 2013; Blythe et al. 2020). Yet, livelihoods and food security tend to be more directly dependent on local ecosystems in low-income countries (Levy et al. 2005; Yang et al. 2013), including for millions of people who depend directly on coastal ecosystems and small-scale fisheries (World Bank, FAO, WorldFish 2012). Understanding the linkages between ecosystem services and benefits for people is critical for safeguarding natural resources and particularly those important for groups most vulnerable to global change (Cinner et al. 2012; Howe et al. 2013). Given that people interact with and value nature in diverse ways (Díaz et al. 2018), extrapolating perspectives of fishery ecosystem services from higher income countries is problematic. Thus, there is a geographic mismatch between ecosystem services research and reliance on natural resources, including small-scale fisheries, and associated vulnerabilities. More empirical ecosystem services research is needed in low-income countries to understand the ways that people mediate the pathways through which seafood contributes to food security.

To address these knowledge gaps, we used an in-depth case study of a small-scale fishery on Atauro Island, Timor-Leste to explore how people co-produce seasonal benefits from small-scale fisheries. We drew on the ecosystem service cascade conceptual framework (Figure 1), which illustrates the multi-stage relationship between people and nature (Haines-Young and Potschin 2010). Later adaptations of the cascade framework explicitly highlight the influence of contextual factors and human values in shaping social-ecological feedbacks along the cascade (Spangenberg et al. 2014a, 2014b; Fedele et al. 2017). Specifically, we focused on the mediating mechanism of allocation, which links service supply to benefits, by examining the ways people use landed seafood at different times of the year (Figure 1).

The aim of the research was to strengthen ecosystem service perspectives for food security in small-

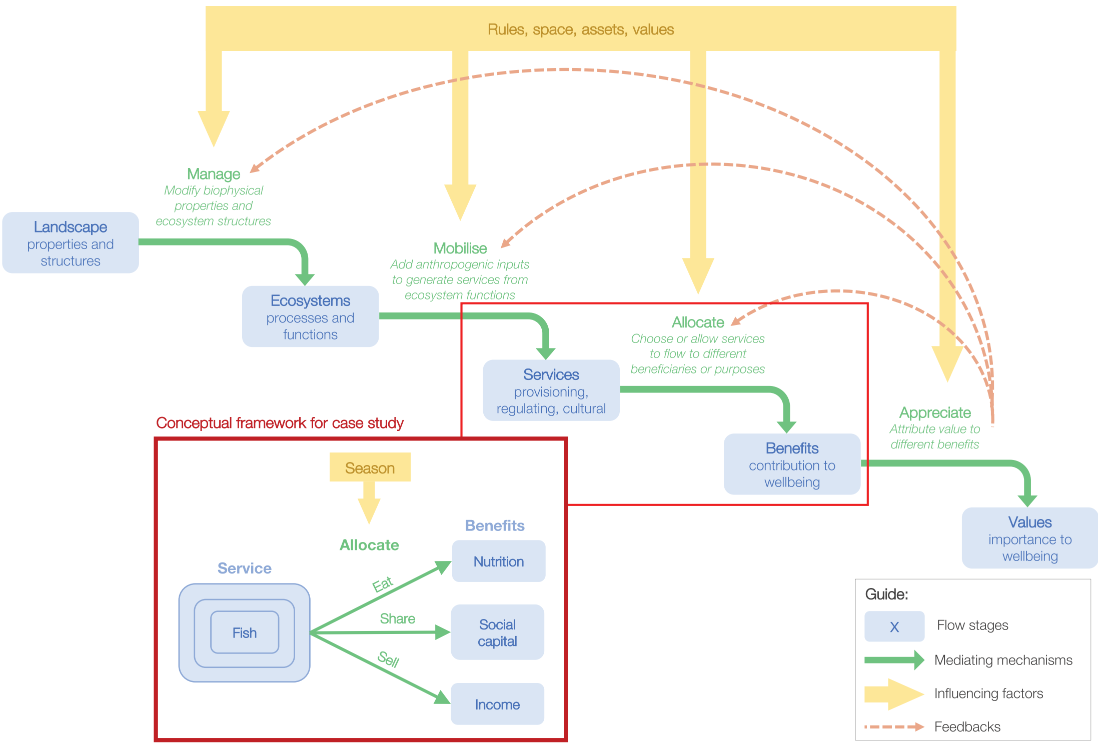

Figure 1. Ecosystem service cascade framework illustrating the multiple linkages and factors that influence how nature contributes to people (adapted from Fedele et al. 2017). Inset detail shows cascade components examined in the case study small-scale fishery, including the provisioning ecosystem service of fish at different rates of supply and season as an influencing factor.

scale fisheries through empirically examining the temporal aspects of ecosystem benefit co-production. We set out to deepen knowledge of the role of people in mediating pathways linking the provisioning service of seafood to household food security benefits, and how this changes seasonally. To address this aim, we asked how does the proportion of seafood landings used in each way (i.e. the allocation seafood services to different benefit streams) vary by (1) total quantity landed (i.e. supply of realised service); (2) season; and (3) the interaction between quantity landed and season. We triangulated quantitative analysis of the post-harvest use of landings with qualitative insights into seasonal livelihoods to examine how ecosystem service supply and season influence the ways people mediate benefit flows.

2. Materials and methods

2.1. Background and study site

Research was carried out in the community of Adara, Atauro Island Timor-Leste (Figure 2). Timor-Leste is a Small Island Developing State (SIDS) located at the heart of the Coral Triangle. Improving human well-being and protecting coastal environments in concert is a key challenge for the sustainable future of the country (Rosegrant et al. 2016; López Angarita et al. 2019). In particular, addressing acute food insecurity is a high priority in Timor-Leste. Food scarcity and low dietary diversity are widespread (Bonis-Profumo et al. 2019); 36% of the population experience chronic food insecurity (IPC 2019) and 50% of children under 5 years of age are chronically malnourished (WFP 2018). One of the main causes of food insecurity in Timor-Leste is the occurrence of an annual lean season: high dependence on rainfed, low-yield subsistence agriculture leads to food shortfalls during the rainy season, when crops are growing but not yet ready to harvest (da Costa et al. 2013; Erskine et al. 2014). Thus, seasonality has important links to food and nutrition outcomes.

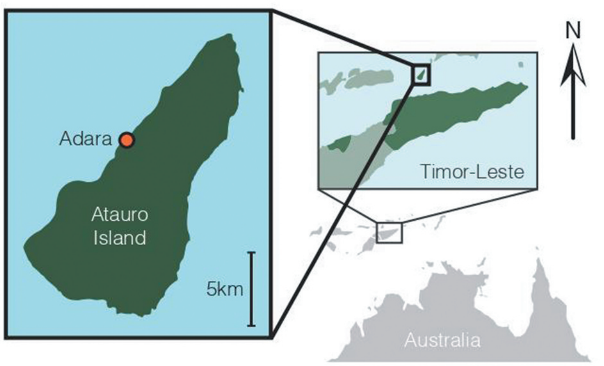

Figure 2. Map indicating location of study community (Adara) on Atauro Island, Timor-Leste.

Seafood has the potential to contribute to improved food and nutrition security in Timor-Leste. National average per-capita seafood consumption is 6.1 kg (AMSAT 2011), which is substantially lower than other Islands in the pacific (World Bank 2018). Low seafood consumption is attributed to an underdeveloped fishery sector, poor transport and storage infrastructure, weak governance and limited integration of fisheries into food security policy (Mills et al. 2013; Steenbergen et al. 2019; Farmery et al. 2020). However, the ecological status of marine resources in Timor-Leste is poorly documented (ADB 2014) and there is a pressing need to identify and establish sustainable coastal management strategies to support the integration of fisheries in food secure futures in Timor-Leste (World Bank 2018; López Angarita et al. 2019).

The need to balance diverse social and ecological needs in coastal resource management is pressing on Atauro Island, Timor-Leste's only populated islet. Located 25 km north of the capital Dili, Atauro Island is 140 km^2 in area, rising steeply up to 999 m at its highest point. The Island is home to roughly 9,200 people, living in 23 communities across five different administrative sub-districts (GDS 2015). Livelihoods and food security on Atauro Island are more fishery-based than other parts of Timor-Leste and every Saturday the Island hosts the country's largest regular fish market (Mills et al. 2013). The narrow reefs that fringe Atauro Island are also the focus of a conservation programme aimed at establishing a national network of small marine protected areas (Conservation International 2020) and its beautiful beaches and rich marine life (PIFSC 2017) make it one of the main attractions of a small but growing tourism industry. Understanding how different stakeholders, and particularly local communities, benefit from marine ecosystems, is thus critical to ensuring just and sustainable futures on Atauro Island.

The community of Adara, located on the western coast of Atauro Island, provided an apt case-study for our research (Figure 2). Similar to many rural coastal communities in low-income countries, people in Adara pursue diversified and seasonally dynamic livelihoods, which are predominantly natural resource-based. Main livelihood activities include crop farming, livestock rearing and fishing. Fisheries in Adara are low-technology and artisanal. Fishing activities are typically carried out from small wooden canoes or the shore. The main gear types used include nylon gillnets, traditional wooden spears with a sharpened metal tip, baited lines and gleaning (hand collection). Fish are used for household subsistence, traded as a source of income in the village or at the Saturday market, and also shared with friends and family. Refrigeration is limited by the lack of electricity in the village and so the main way of storing fish is salting and sun drying. Households dry fish for their own consumption and to sell. Adara is relatively isolated, accessible only by foot or boat, and has limited infrastructure, with no running water or electricity. At the time of the research, 26 households lived in Adara, with a total population of approximately 120 people.

2.2. Data collection

Data were collected between June 2018 and May 2019. We used mixed methods (specifically, a combination of seasonal calendars, key informant interviews and daily household surveys) to collect quantitative and qualitative data on livelihoods and consumption at different times of the year. We analysed the data to evaluate (1) seasonal context and (2) fishing seasonality. Below we describe each data collection method, followed by a description of the data analysis.

2.2.1. Seasonal calendars

Seasonal calendars are a participatory tool used to elicit community perceptions of annual variation in processes or conditions through time. We used seasonal calendars to collect qualitative data on weather conditions, agriculture and fisheries at different times of the year. The aim of the seasonal calendars was to understand how livelihoods in the community – particularly fishing – shift with season. Seasonal calendars were carried out with men and women separately in focus groups in July 2018. Focus groups were held in a public space and were open to all community members. In total, there were 15 participants in the men's group and 19 in the women's group. The focus group was implemented by the lead author and a facilitator, who translated between English and Tetum (one of the national languages of Timor-Leste). The aims of the seasonal calendar were explained to participants and each focus area (weather, livelihoods, fisheries) was then discussed in turn within the group. Findings were recorded as notes (in English and Tetum) on to a large format dial framework representing the annual cycle. Each seasonal calendar focus group lasted between 2 and 3 hours.

2.2.2. Interviews

Individual interviews were used to explore seasonality in specific livelihood activities. Interviews were carried out in November 2018 by the lead author and a research facilitator, who translated between English and Tetum. A structured question format was used to guide interviews and interview responses were recorded as notes in a structured recording sheet. Livelihood interviews collected data on activities, harvests and challenges at different times of the year. Each interview took between 60 and 90 minutes to complete. Interview respondents were purposefully selected members of the community who were actively involved in each specific livelihood activity, and who were able and willing to participate. In total, 16 individuals were interviewed, including four for each fishing, gleaning (the manual collection of marine organisms from intertidal zones), agriculture and livestock rearing.

2.2.3. Household panel survey

We conducted a daily panel survey on household activities and consumption for two 1-week periods at three different times of the year (survey seasons). Survey seasons were selected to capture differences in weather, livelihoods and food security according to the seasonal calendar findings. The first survey season corresponded with when households were preparing for the period of seasonal food insecurity (hereafter *Preparation season*), the second was during the season of food scarcity (hereafter *Lean season*) and the third survey season was during the main harvest season (hereafter *Harvest season*). The seasonal context is described in more detail in the results section. Within each survey season, two survey weeks were chosen to correspond with the full and new moon (Table 1) to control for the impact of lunar cycles on tidal conditions. The survey was digitised using Kobotoolbox survey software (Harvard Humanitarian Initiative n.d.) and implemented by three local data collectors, who each surveyed five households daily during survey weeks. Hence in total, 15 households were surveyed for 14 days in each of the three seasons; a total of 630 household survey days. Data used in this research were collected by asking whether any household members had gone fishing the previous day, and if so, the total number of fish landed and the number of landed fish used for household consumption, traded (for income) or shared/given away.

2.3. Data analysis

The analysis was carried out in two distinct stages. First, we drew on qualitative data to evaluate the seasonal context in the study community. Second, we examined the post-harvest use of fish. Using quantitative data, we analysed how household allocation of landed fish to different uses varied with the amount landed and across seasons, and we compared differences in the total proportion of landings used in each way.

2.3.1. Seasonal context

We combined qualitative data from seasonal calendars, interviews and informal discussions to provide an overview of the seasonal context in the study community. Seasonal calendar data were used to

Table 1. Dates of household panel survey (shading and bold dates indicate data collection days).

Survey season	Year	Month	Day of the week						
			M	T	W	Th	F	Sa	Su
Preparation	2018	August	6	7	**8**	**9**	**10**	**11** ○	**12**
			13	**14**	15	16	17	18	19
			20	21	22	**23**	**24**	**25**	**26** ●
			27	**28**	**29**	30	31		
Lean	2019	January		1	2	**3**	**4**	**5**	**6** ○
			7	**8**	**9**	10	11	12	13
			14	15	16	17	**18**	**19**	**20**
			21 ●	**22**	**23**	**24**	25	26	27
Harvest	2019	April	15	**16**	**17**	**18**	**19** ●	**20**	**21**
			22	23	24	25	26	27	28
		May	29	30	1	**2**	**3**	**4**	**5** ○
			6	**7**	**8**	9	10	11	12
Lunar cycle: new moon (○)and full moon (●)									

Lunar cycle: new moon (○)and full moon (•).

provide a basic framework of typical seasonal cycles in the study community, linking weather conditions and livelihood strategies at different times of the year. Any ambiguity or uncertainty in seasonal calendar data was resolved through informal discussions with key informants. Insights from individual livelihood interviews were integrated to provide a more in-depth understanding of the seasonal livelihood context presented by the seasonal calendars.

2.3.2. Post-harvest use of landings

We quantitatively evaluated how the allocation of fish to different post-harvest uses varied with the number of fish landed and across seasons. We analysed survey data on post-harvest use of landings from household fishing trips using mixed models fitted using R statistical software (R Core Team 2018). Mixed models were fitted with a log-linked negative binomial distribution using the lme4 package (Bates et al. 2014). The effects on post-harvest use of (*i*) total fish landings and (*ii*) season were analysed in models represented as:

*i) Count ~ Use * Landings + offset(log(Qtotal)) + (1|household)*

*ii) Count ~ Use * Season + offset(log(Qtotal)) + (1|household)*

Use is a categorical variable of different post-harvest uses (Eat, Sell, Share) and *Count* is the number of individual fish used in each way. *Landings* is a categorical variable that describes the total number of fish landed (<10, 10–20, >20) and *Season* is the survey season in which the fishing trip was recorded (Preparation, Lean, Harvest). To standardise the model output across different landing quantities we included total number of fish landed (*Qtotal*) as an offset variable. *Household* was included as a random effect to account for the panel structure of the data. Post-hoc Tukey adjusted pairwise comparisons were carried out using the emmeans package (Lenth 2019). Landings data included fishing trips using all methods except gleaning. Gleaning was left out because there were distinct differences in the main target groups compared to other fishing methods and thus landing quantities were incomparable and data were insufficient to support a separate analysis. Unless specified, differences reported in the results were found to be significant at a 95% confidence interval ($p < 0.05$).

To compare how fish were used across landing groups in different seasons, we aggregated catch data from fishing trips in each landing group in each season. Using chi-square goodness of fit tests, we analysed whether the post-harvest use of fish differed significantly from what would be expected if households allocated catch equally across uses. Using Pearson's chi-square comparisons, we examined whether the allocation of fish to a particular post-harvest use within each landing quantity differed among seasons.

3. Results

3.1. Seasonal context

Livelihoods and the food security context in the study community correspond with seasonal weather and sea conditions (Figure 3). Survey seasons were chosen to capture three distinct seasons. The lean season survey was carried out in January (segment L, Figure 3). In seasonal calendars, January was identified as a main period of rainfall and rough sea conditions in the study community (Figure 3(a)). Weather conditions in

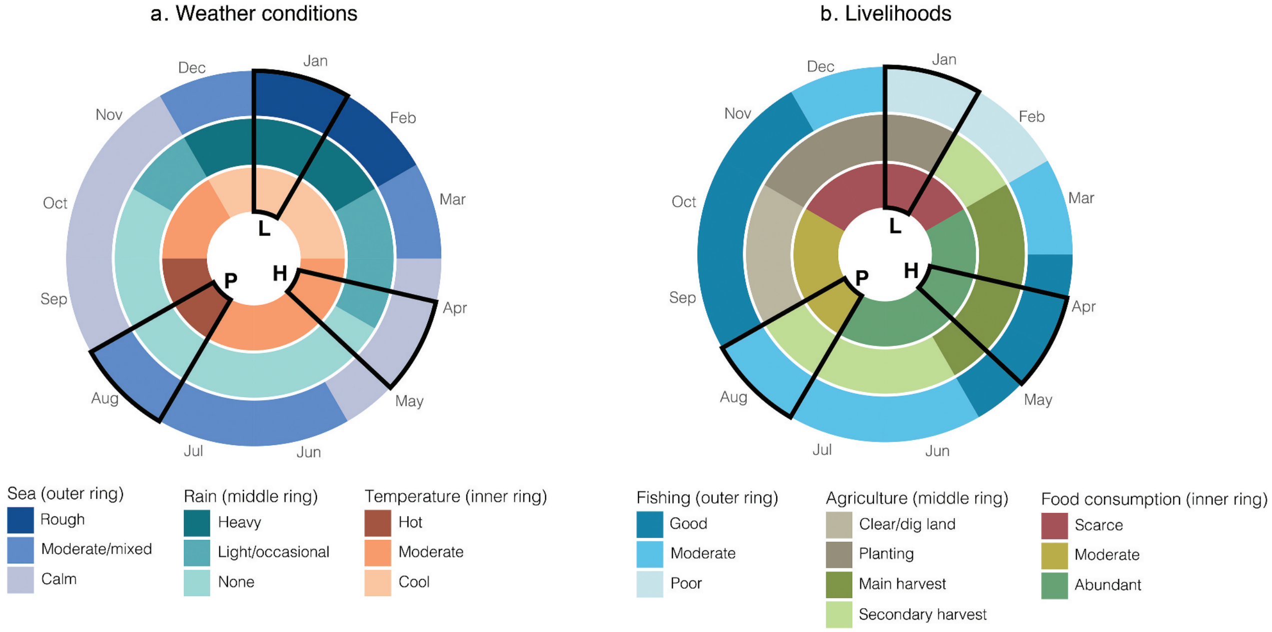

Figure 3. Summary of seasonal weather conditions and livelihood context in the study community based on seasonal calendars. Outlined segments indicate seasons in which daily household survey was implemented: L = lean season, H = harvest season, P = Preparation season.

January are characterised by the western monsoon, which typically occurs between December–February. The lean season in the study community coincides with the rainy season because of the high dependence on rainfed agriculture. Crops are planted during the rainy season (Figure 3(b)) and in interviews, respondents described how the first rains signify the time to start planting and the timing, reliability and quantity of rain are all key determinants of crop success. During the planting season there are no crops available to harvest and so households must rely on stored crops and bought foods, such as rice. During interviews, focus groups and informal discussions, members of the community described how during the lean season, stored staple crops run low and households must reserve some staple crops as insurance in case of a low harvest the following year or for re-sowing. Therefore, a household may have stores of staple crops available that they do not consume during the lean season because being able to replant is the main priority. Some interview respondents stated that in previous years, poor rains and pest damage have meant that within a single season they have had to replant crops up to three times.

The lean season also corresponds with the poor fishing season. In seasonal calendars, interviews and informal discussions, January and February were identified as the worst months for fishing (Figure 3(b)) with rough sea conditions during the western monsoon (Figure 3(a)) make fishing risky or even impossible in the study community. During rough weather fishers reported using mostly baited handlines from the shore or gleaning in the intertidal zone. Gleaning in particular is an important source of subsistence seafood during the lean season when food in general is scarce (Grantham et al. 2021). For instance, during an interview, one woman explained how she gleans when they have nothing else to accompany rice. Gleaners described being less selective during the rough season than in the calm season, for example collecting smaller shells and less preferred types of seafood. Weather conditions also affect fish processing and trade. During focus groups, women described how the processing and trade of fish cease during the rainy season because fish are sun dried outside and cannot be dried in the rain. Selling dried fish is a main source of income in the study community, particularly for women. Women buy fish from local fishermen, which they then salt and dry to sell at the weekly market held on Atauro Island's eastern coast. Rough weather also affects boat transport to the market for fish sellers and buyers, reducing the trade of fresh and dry seafood in the lean season.

The harvest season survey period was carried out in March–April (segment H, Figure 3). These months are characterised by light rainfall, moderate temperatures and calm seas (Figure 3(a)) and encompass the main agricultural harvest and good fishing (Figure 3(b)). In seasonal calendars and interviews, the main harvest of staple crops including corn and beans was reported to occur between March and May (Figure 3(b)). A small harvest of early corn in February is the first harvest of the year and some secondary crops are harvested through until August. Staple crops are predominantly used for household subsistence; they are harvested intensively and stored, whereas secondary crops, including fruits and vegetables, are harvested as needed and occasionally sold. Interview respondents highlighted how the success of a year's harvest can stipulate annual fishing activities. Households know how many ears of corn and sacks of beans they must harvest to be able to eat through the following year. If annual harvests of staple crops are insufficient to last through to the end of the following lean season, households will increase their livelihood focus on fishing as a source of income to buy food and staple crops for planting. Calm seas during the harvest season characterise the good fishing season in the study community (Figure 3(b)). In interviews, some fishers reported that during months when the sea is calm, they may go on multiple fishing trips in a single day. Gillnets are a common fishing method in calm weather. The nets are laid from wooden canoes, usually at dawn, to target schools of fish on the reef edge. Spearfishing is also a common method in calm weather. Unusually for Timor-Leste, a number of women in the study community are spear-fishers, who specifically target octopus as a high-value catch.

The preparation season survey was carried out in August (segment T, Figure 3). In seasonal calendars, August was described as being hot, dry and windy, with variable sea conditions (Figure 3(a)). The hot weather and lack of rain between August and September (Figure 3(a)) brings the harvest season to a close (Figure 3(b)). In focus groups, community members described how as the harvest finishes, they begin to prepare for the lean season by saving money, stocking up on rice and managing their consumption of subsistence crops. In seasonal calendars, mixed sea conditions were reported in August (Figure 3(a)) and it was considered to be a moderate fishing season (Figure 3(b)). Poor water clarity prevents spearfishing but gillnets can be used on calm days.

3.2. Post-harvest use of landings

In total, 179 fishing trips were recorded across the three survey seasons (Preparation = 70, Lean = 48, Harvest = 61). Total landings ranged from 1 to 100 fish and the mean number of fish landed per trip varied by season (P = 22, L = 10, H = 12).

3.2.1. Allocation across landing groups

The post-harvest use of fish was related to the number of fish landed (R^2 = 0.43, Figure 4(a), Appendix 1 Landings). Paired comparisons (Appendix 2.1) show that the proportion of fish allocated in a particular way varied *among* landing groups (<10fish, 10–20 fish, >20 fish). Specifically, the proportion of fish eaten was greater for small landings (<10 fish) than large landings (>20 fish). The proportion of fish sold was greater for large landings, followed by medium landings (10–20 fish), and lowest for small landings. There were no differences in the proportion of fish shared across landing groups. Paired comparisons (Appendix 2.2) of the proportion of fish used for eating, sharing and selling *within* landing groups show that the relative importance of different post-harvest uses also varied with the number of fish landed. Within the small and medium landing groups the proportion of fish sold and shared was similar and less than the proportion eaten, while for large landings the proportion of fish sold or eaten was similar and greater than the proportion that was shared.

3.2.2. Allocation across seasons

Season also had a significant effect on the post-harvest use of fish (R^2 = 0.44, Figure 4(b), Appendix 1 Season). The proportion of landed fish allocated to non-consumption uses differed *by* season (Appendix 3.1). A greater proportion of fish were sold in the preparation season, followed by the harvest season, with the smallest proportion of fish sold in the lean season. The proportion of fish that was shared was lower in the preparation season than other seasons. Paired comparisons of the proportion of landed fish used in different ways *within* each season (Appendix 3.2) highlights differences in the relative importance of post-harvest uses. In the preparation season, the proportion of fish eaten or sold was similar and greater than the proportion shared. In the lean season, the greatest proportion of fish was used for eating, followed by sharing and the smallest proportion was sold. In the harvest season, eating was also the main use of fish, but the proportions sold and shared were similar.

3.2.3. Seasonal allocation within landing groups

Landed fish were not equally allocated across uses (Figure 5). For all landing quantities in all seasons, we compared the proportions of landed fish used in each way compared to proportion expected if fish had been allocated equally (i.e. one-third). Catches were only allocated equally across post-harvest uses for large landings (>20 fish) in the lean season (Table 2). For all other seasonal landing groups, except large landings in the preparation season, significantly more than one-third of fish were eaten (paired comparisons Appendix 4.1). Large landings during preparation season were the only group in which significantly more than one-third of fish were sold. Significantly less than one-third of fish were sold from large landings in the harvest season, medium landings (10–20 fish) in the lean season and small landings (<10 fish) in all seasons. The proportion of fish shared was significantly less than one-third across all landing groups in the preparation season, and small landings in the lean season and large landings in the harvest season.

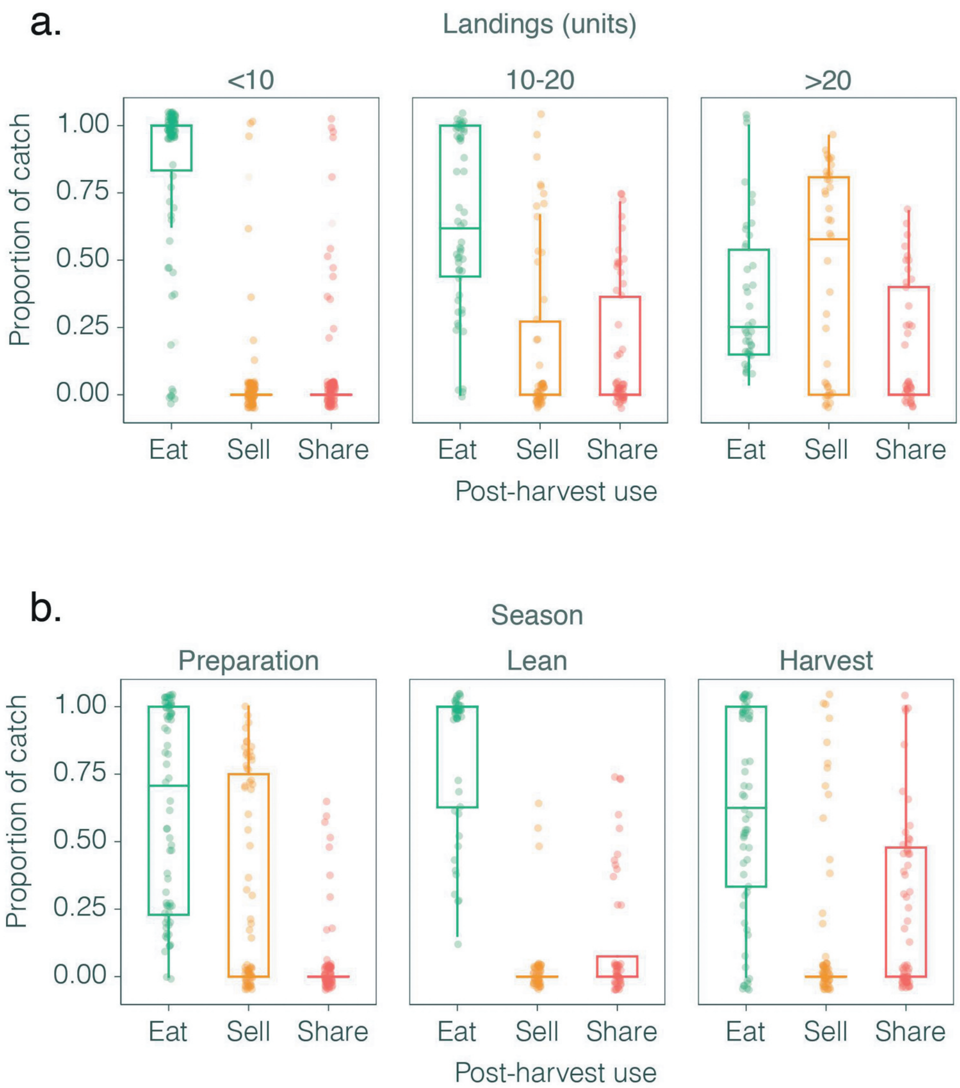

Figure 4. Boxplots showing proportion of total fish landed that were eaten, sold or shared for (a) fishing trips in each landing group category and (b) fishing trips in each survey season.

There were significant differences between seasons in the proportion of fish within landing groups used in each way (Figure 5, Table 3, paired comparisons Appendix 4.2). For small landings (<10 fish), the proportion eaten was greatest in the lean season, followed by the preparation season and the smallest proportion was eaten in the harvest season. The proportion sold was similar in the preparation and harvest seasons, while in the lean season none were sold. The proportion shared was greater in the harvest season than in other seasons.

For medium landings (10–20 fish), similar proportions were eaten in the preparation and lean seasons, and this was less than the proportion eaten in the harvest season. The proportion sold was similar in the preparation and harvest seasons and was greater than in the lean season. The proportion shared was greatest in the lean season, followed by the harvest season and with the least shared in the preparation season.

For large landings (>20 fish), a greater proportion was eaten in the harvest season than the preparation season. The proportion sold was greatest in the preparation season, followed by the lean season, and smallest in the harvest season. The reverse was true for the proportion shared, which was greatest in the harvest season, followed by the lean season and lowest in the preparation season.

4. Discussion

Overall, we found the relationship between the supply of the food provisioning service of seafood and benefits to people was neither direct nor constant through time. Fishing households used landed fish differently depending on the quantity landed and season, which were defined by weather conditions and the food security context linked to agricultural cycles. Uses of landings characterise different pathways through which the provisioning service of seafood contributes directly and indirectly to the wellbeing domain of food security (Chaigneau et al. 2019). Changes in the proportion of

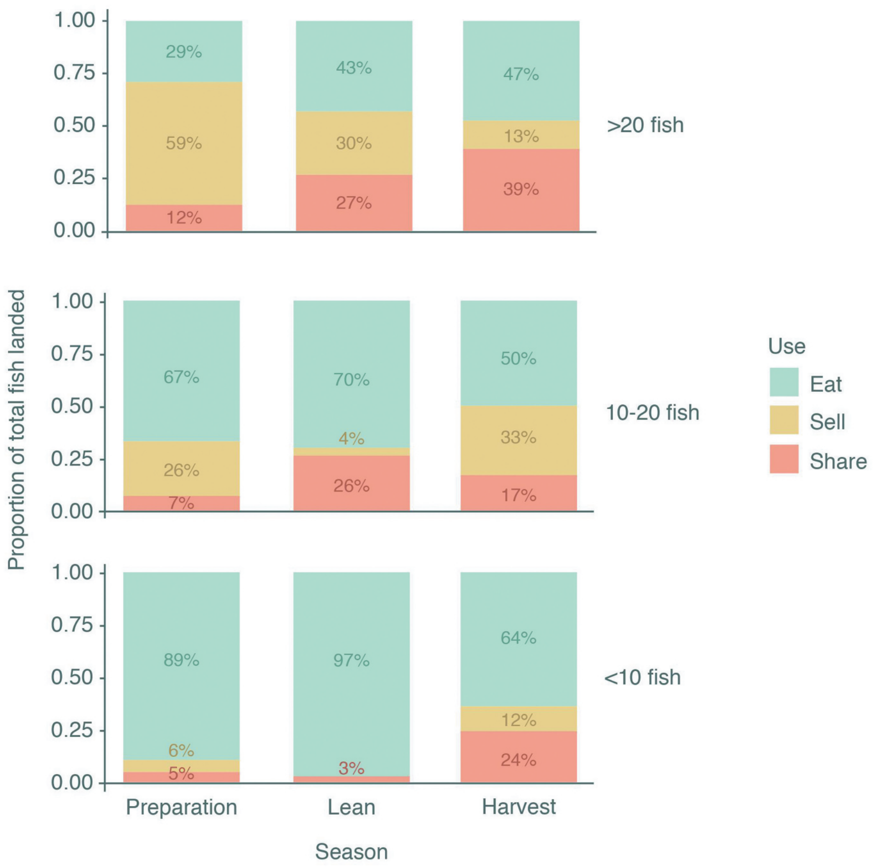

Figure 5. Post-harvest use of fish for different landing groups in each season, proportion of total landings shown on bars.

Table 2. Summary of chi-square tests comparing the proportion of fish used in each way in each landing group in each season.

Landing group	Season	X^2	*df*	*p*
Small (<10 fish)	Preparation	147.25	2	**< 0.001**
	Lean	260.68	2	**< 0.001**
	Harvest	78.237	2	**< 0.001**
Medium (10–20 fish)	Preparation	171.17	2	**< 0.001**
	Lean	164.95	2	**< 0.001**
	Harvest	32.337	2	**< 0.001**
Large (>20 fish)	Preparation	361.02	2	**< 0.001**
	Lean	5.19	2	0.07466
	Harvest	66.916	2	**< 0.001**

Table 3. Summary table of chi-square tests comparing the proportion of fish used in each way in each landing groups among different seasons.

Landing group	Use	X^2	*df*	*p*
Small (<10 fish)	Eat	63.624	2	**< 0.001**
	Sell	18.647	2	**< 0.001**
	Share	40.874	2	**< 0.001**
Medium (10–20 fish)	Eat	21.577	2	**< 0.001**
	Sell	66.19	2	**< 0.001**
	Share	37.426	2	**< 0.001**
Large (>20 fish)	Eat	44.789	2	**< 0.001**
	Sell	232.61	2	**< 0.001**
	Share	125.95	2	**< 0.001**

landings that were eaten, sold or shared illustrate how households mediate flows of nutrition, income and social capital from seafood. Ecosystem services (and specifically the cascade framework) offer a way for analysing small-scale fisheries dynamics from production to consumption with a focus on how fisheries benefits are co-produced. Specifically, examining the allocation of ecosystem services across benefits can more accurately connect fishing dynamics to a range of wellbeing outcomes that ecosystem services approaches explicitly examine (MA 2003a) but that may be less emphasized in fisheries literature (Coulthard 2012). Our findings highlight the ways that attending to the temporal aspects of co-production, and specifically the allocation of seafood across food security benefits, can strengthen ecosystem service perspectives of small-scale fisheries as dynamic social-ecological systems. In particular, our findings shed light on (i) the importance of temporal scale in ecosystem service assessments; (ii) changing benefit trade-offs; (iii) the role of co-production in adaptation; and, (iv) contributions of fisheries to social capital and community food security.

4.1. Temporal scale

First, seasonal differences in how households used landed fish shows that our understanding of how small-scale fisheries support household food security is influenced by choices of temporal scale in ecosystem service assessments. In the lean season, almost all fish were consumed directly by fishing households, whereas in the preparation season fish were also often sold. Therefore, as in other small-scale fisheries (Clark et al. 2002), fishing in the study community shifted seasonally from subsistence focused and providing predominantly direct nutrition benefits for fishing households to being small-scale commercial and so also providing indirect food security benefits as a source of income. Hence, a seasonal lens reveals the pathways through which fishing supports food security benefits at different times of the year, which would not be visible at annual resolutions.

Choices of temporal scale in ecosystem services evaluation matter instrumentally and morally. Our ability to detect, understand and predict ecosystem service dynamics is affected by the temporal scale of ecosystem service assessments, including the temporal grain (time frame of minimum unit), resolution (time between minimum units) and extent (total duration) of observation and analysis (MA 2003b; Kandziora et al. 2013). Dominant processes vary with scale and thus, particularly when the wellbeing of vulnerable groups is at stake, consideration from whose perspective ecosystem service dynamics are defined, valued and managed is important because choices of scale can favour the interests of certain groups (MA 2003b; Wilbanks 2006). Fine resolution perspectives are important for understanding local drivers of change in multi- and cross-scale ecosystem service assessments (Scholes et al. 2013). Crucially, accounting for local-scale dynamics increases the relevance of ecosystem services research to the interests of key stakeholders (Folke et al. 2005) and by extension the priorities of decision-makers. The use of single snapshots to assess food provisioning services in coastal systems (Blythe et al. 2020) risks overlooking the dynamic pathways through which small-scale fisheries contribute to household food security. This research illustrates how seasonal ecosystem service assessments can strengthen understanding of the links between ecosystem services and their benefits for people.

4.2. Trade-offs

Second, changes in how landings were allocated between uses suggest that perceived opportunity costs of different food security contributions from fishing vary at different rates of supply and with season. Each fish landed can only be used in one way, thus the opportunity cost of one type of benefit (e.g. nutrition) is the other benefits forgone (e.g. income or social capital). The allocation of landings to different uses therefore represents a trade-off between different benefits. We found that as landings got larger, the proportion eaten decreased and the proportion sold increased. This is unsurprising as households can only consume a limited amount of seafood, so once households have satisfied their own consumption needs, they make choices to sell or share fish, particularly in the context of poor storage infrastructure. Thus, beyond a certain quantity, the benefits forgone of gaining more nutrition benefits from a fish diminishes relative to potential to gain from other benefits. Allocation choices also differed between seasons. For example, the proportion of small landings that were eaten by the fishing household was greater in the lean season than in other seasons. This result may reflect the greater importance of fish as a source of nutrition to fishing households (as opposed to income), when food in general, including seafood, is scarce and market access limited. Hence, the allocation of landed fish across different uses reflects the perceived relative importance of benefits, and the constraints and opportunities to realise them by surveyed households. Factors influencing benefit trade-offs are likely to be context specific and vary, for instance with socio-economic context and cultural values, as well as with season. Thus, the findings from the study community cannot be assumed to be generalisable elsewhere. Within a particular fishery, understanding how benefit trade-offs and factors influencing them shape the seasonal use of seafood, will strengthen the capacity of ecosystem service assessments to support food security objectives in small-scale fisheries.

4.3. Adaptation

Third, our findings highlight the importance of understanding how fishing households use benefit co-production to adapt to the seasonal context and recognising limits to adaptation. Through the seasonal allocation of landed fish across different uses households adjust the pathways through which fishing contributes to household food security. For example, by selling a greater proportion of landings in the preparation season, surveyed households use fishing as a source of income that enables them to buy staple foods during the lean season. That fishers adjust the use of landings to prioritise certain benefits at particular times has been demonstrated elsewhere, for example prioritising fishing as a source of income to support recovery rather than for subsistence in response to crises (Thomas et al. 2019). Human responses to stressors are at the core of resilient livelihoods (Tanner et al. 2015) and understanding the capabilities, opportunities and constraints that determine the ability of people to negotiate the social-ecological context is essential to understanding adaptation to environmental change (Brown and Westaway 2011). For people living in poverty, ‘ordinary’ micro-practices of evaluation and adaptation (everyday agency), such as how landings are used, are often particularly important, but unrecognised, strategies for navigating change and vulnerabilities in their day-to-day lives (Payne 2012; Lister 2015; Mcmichael et al. 2019; Selimovic 2019). In small-scale fisheries, accounting for factors that affect everyday agency, such as how seasonal market access influences the ability of households to earn income from fishing, is crucial for identifying the opportunities and constraints to adaptation in small-scale fisheries as part of resilient livelihoods. Our findings thus reiterate the importance of human agency in ecosystem service co-production and mediating links between ecosystems and human wellbeing (Spangenberg et al. 2014a; Rademacher et al. 2019). Placing people central to ecosystem service perspectives in small-scale fisheries, and recognising factors that influence the ability of fishers to exercise everyday agency, would advance understanding of seasonal vulnerability in coastal communities.

4.4. Social capital

Finally, understanding how fishing households allocate seafood to different benefits, and specifically the decision to share landings, highlights the importance of small-scale fisheries for social capital and community-level food security. Gifting and exchange, including of food, is an important customary practice in Timor-Leste (Mcwilliam 2011) and food sharing provides a means through which households redistribute surplus and alleviate food shortages within social networks (da Costa et al. 2013; Inder et al. 2014). We found that fishing households shared a substantial proportion of landings, particularly in the lean season and the harvest season. Landings are typically shared amongst family and kin networks within the study community, and particularly with people who cannot fish themselves (e.g. elderly individuals) or who did not go fishing on that particular day. Landings are also shared with community members who help with fishing activities (e.g. sorting nets) and, if a fishing trip was particularly successful, some fishers will offer fish to any passing community members to 'share the blessing'. Sharing landings therefore represents a way that fishing households engage in social relations and influence the distribution of nutrition benefits from seafood. Thus, when seafood is shared it contributes to bonding social capital, which has been positively linked to food security through improved food availability, access and stability (Mertens et al. 2015; Lee et al. 2018; Nosratabadi et al. 2020). However, intangible benefits, including social capital, are difficult to measure and value and have therefore been historically underrepresented in ecosystem service assessments (Chan et al. 2012). This research illustrates that greater attention to social capital in ecosystem services would strengthen understanding of how fishing households benefit from the provisioning service of seafood and factors influencing the distribution of nutrition benefits from seafood as part of resilient food security in coastal communities. Identifying ecosystem service beneficiaries is essential for addressing the priorities of decision-makers concerned with the links between nature and human wellbeing (Rieb et al. 2017), including food security. Ensuring fish reaches those who need it would substantially improve nutrition in, and beyond, coastal areas (Hicks et al. 2019).

5. Conclusions

The contribution of small-scale fisheries to local food security is not only determined by available fish populations and the ability of people to catch them, but also on how landings are used. People mediate flows of benefits from the provisioning service of seafood through their use of landed fish. Using the case study of a small-scale fishery in Timor-Leste, we found that the proportion of landings eaten, sold or shared by fishing households changed seasonally and with the quantity landed; people mediate a dynamic and non-linear relationship between seafood and nutrition, income and social capital benefits. These findings highlight the importance of understanding how benefits are co-produced at temporal scales appropriate to the livelihood dynamics of coastal communities. Specifically, attending to seasonal allocation would strengthen understanding of the types and distribution of benefits from the provisioning service of seafood, which is critical for informing resource management and decision-making for food security in small-scale fisheries. This research reiterates calls for people centred and temporally sensitive assessments of ecosystem benefits, particularly in small-scale fisheries, to enhance the relevance of ecosystem service perspectives for coastal food security. To understand who benefits from what and how in small-scale fisheries we must also ask *when*.

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Ethics and consent

Household survey data presented in this study were collected as part of research activities conducted in accordance the James Cook University human ethics guidelines. Research activities were approved (reference number H7626) prior to being carried out. Participants were informed of the nature and purpose of research activities through a verbal statement in local language and, if they were willing to participate, they were asked to give signed consent.

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