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Cover: Shama canoe beach, Ghana. Photo courtesy of Berchie Asiedu.

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ORIGINAL RESEARCH

Fishers' lives matter: social issues in small-scale fisheries migration of Ghana

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ABSTRACT. Migration is a common feature of most small-scale fisheries (SSF) across the globe. To enhance fisheries resources sustainability and management, we examined the social issues in the SSF from the perspective of fishers, Chief Fishermen, and Fisheries Technical Officers who are actively involved in SSF migration and fisheries management along the coast of Ghana. We conducted in-depth interviews in six important migrant fishers' communities and analysed documents on the socio-economic conditions of migrant fishers, conflicts among migrant fishers, rights of migrant fishers and the role of government in managing fishers' migration. Findings showed that the successful integration of migrant fishers in the host communities resulted in minimal conflictual incidents that are resolved through dialogue. Furthermore, both the Fisheries Technical Officers and Chief Fishermen are involved in conflict resolution depending on the nature of the dispute. Also, most migrant fishers (over 50%) have the same rights as the local fishers, though they are marginalized during the distribution of premix fuel. Migrant fishers with prominent status played key role during decision-making process in the host communities. Overall, the study showed that migrant fishers have aided in the progress of fishing technology, food security, and small-scale business in the host fishing communities. To avert any form of marginalization during the distribution of premix fuel, it is prudent for authorities to develop relevant policies that will ensure that migrant fishers receive enough fuel for their fishing activities in the host communities.

Key words: Migrant fishers, West Africa, conflicts, fisheries management, fisheries resources.

La vida de los pescadores importa: cuestiones sociales en la migración de la pesca en pequeña escala de Ghana

RESUMEN. La migración es una característica común de la mayoría de las pesquerías de pequeña escala (PPE) en todo el mundo. Para mejorar la sostenibilidad y la gestión de los recursos pesqueros, se examinaron los problemas sociales en las PPE desde la perspectiva de los pescadores, los Jefes de Pescadores y los Oficiales Técnicos de Pesca que participan activamente en la migración y la gestión pesquera de las PPE a lo largo de la costa de Ghana. Se realizaron entrevistas en profundidad en seis importantes comunidades de pescadores migrantes y analizamos documentos sobre las condiciones socioeconómicas de los pescadores migrantes, los conflictos entre los pescadores migrantes, los derechos de los pescadores migrantes y el papel del gobierno en la gestión de la migración de los pescadores. Los hallazgos mostraron que la integración exitosa de los pescadores migrantes en las comunidades de acogida resultó en incidentes conflictivos mínimos que se resuelven a través del diálogo. Además, tanto los Oficiales Técnicos de Pesca como los Jefes de Pescadores están involucrados en la resolución de conflictos, dependiendo de la naturaleza de la disputa. Además, la mayoría de los pescadores migrantes (más de 50%) tienen los mismos derechos que los

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pescadores locales, aunque son marginados durante la distribución de la premezcla de combustible. Los pescadores migrantes con un estatus destacado desempeñaron un papel clave durante el proceso de toma de decisiones en las comunidades de acogida. En general, el estudio mostró que los pescadores migrantes han ayudado en el progreso de la tecnología pesquera, la seguridad alimentaria y los negocios a pequeña escala en las comunidades pesqueras anfitrionas. Para evitar cualquier forma de marginación durante la distribución de combustible de premezcla, es prudente que las autoridades desarrollen políticas inteligentes que aseguren que los pescadores migrantes reciban suficiente combustible para sus actividades pesqueras en las comunidades de acogida.

Palabras clave: Pescadores migrantes, África Occidental, conflictos, manejo de pesquerías, recursos pesqueros.

INTRODUCTION

Food security, employment and sustainable utilisation of the world's natural resources are key to our survival. Globally, more than 490 million people depend at least partially on small-scale fisheries (SSF) for their livelihoods (FAO 2022). These fisheries supply 40% of global fish catch and provide protein and micronutrients like omega-3 fatty acids, calcium, selenium and zinc to billions of people. In Ghana, about 3 million people are currently involved in the fishery sector with over 90% being in the SSF sector. Fish provides about 60% of the dietary protein needs of the average Ghanaian with an average annual per capita consumption of 25 kg. Small-scale fishers use simple gears and technologies, travel for short distances and target multi-species.

The challenges encountered by SSF are recognized worldwide (Pauly et al. 1998; Muraski 2000; Hutchings and Reynolds 2004; Caddy and Seijo 2005). Common issues facing SSF include resource overexploitation, decline catches, complex and dynamic fleet interactions, competition, and conflicts between fleets (small-scale and industrial), poverty and post-harvest problems, such as lack of infrastructure (Salas et al. 2007; Asiedu et al. 2013). In order to cope with these issues most fishers migrate. In Ghana, migration is a livelihood strategy adopted by many small-scale fishers. Migration among small-scale fishers in Ghana is widespread and increasing exponentially (Overå et al. 2001; Marquette et al. 2002; GSS 2014a; Asiedu et al. 2022). This is mostly driven by biological, socio-economic, overexploitation of commercially important fish species, climate change safety and sargassum influxes (Kraan 2009; Daw et al. 2012; Peer and Miller 2014; FAO 2017). Fishers' migration provides an avenue for small-scale fishers to improve their standards of living (DFID 2004). For instance, income earned by migrant fishers is used to feed families, acquire assets, etc. Additionally, remittances by migrant fishers help in reducing poverty in their home communities. The economic aspect of migration helps fishers to earn income, take care of their families, meet other social commitments, and improve their standard of living (Asiedu et al. 2022). Migration also provides fishers with access to resources thereby contributing to the life sustenance of migrant fishers (Wanyonyi et al. 2021). In recent years, increased development, and globalization in the area of transportation and communication have facilitated fishers' migration (IOM 2005).

Migrant fishers face many social issues in their quest to migrate whether internally or internationally. As a first step, they face the challenge of moving with or without their families. During short-term migration, the majority of fishers leave their wives behind to care for their families, but during long-term travels, they move along with their families (Sall 2006). Further, migrant fishers are challenged by livelihood space. It is a concern where the migrant fisher would live, work, use available services and facilities, and earn acceptance from the local fishers (Kraan

2009). Before fishers migrate, inquiries regarding accommodation and working space are made through phone calls with friends and relatives in the host communities. However, being able to identify a niche and explore resources as well as gain acceptance from local fishers can be delicate (Odotei 2002). Although, most host communities welcome and maintain healthy relationships with migrant fishers (Sugimoto 2016), integration into the host communities is often challenging. Studies have indicated that most indigenes and migrant fishers coexist but do not collaborate (Sall 2006; Njock and Westlund 2008). They do not share the same interests since they do not belong to the same society, which results in disputes, stigmatization, marginalization, and exclusion of immigrants (Njock and Westlund 2008; Wanyonyi et al. 2017; Failler and Ferraro 2021).

A brief overview of the small-scale fisheries sector of Ghana

The small-scale or artisanal fisheries in Ghana operate several fishing gears such as purse seine nets, beach seine nets, set nets, drifting gillnets, and hook and line. Dugout canoes comprising both motorized and non-motorized are the main crafts used by Ghanaian small-scale fishermen. Currently, over 13,000 canoes and more than 124,000 fishers are engaged in small-scale fishing activity in Ghana operating from over 300 landing sites dotted along the 550 km length of the coastline (Dovlo et al. 2016). A high proportion of the fish catch is provided by the SSF sector (around 60%), with the marine sub-sector accounting for more than 70% of the total fish production (Nunoo et al. 2014; FC 2022). Fish caught by small-scale fishers in developing countries such as Ghana is likely to contribute about a quarter of the total protein, thus playing a vital role in food and nutrition security, trade, and other economic activities in small-scale fishing communities (Marquette et al. 2002; Asiedu et al. 2018). Roles are distinguished in SSF of Ghana (Torell et al. 2016; Adjei and Sika-Bright 2019). Men are primarily engaged in fish harvesting, undertaking the main fishing activities (Nunoo and Asiedu, 2013). Contrary, women act as wholesalers, supplying catch from boats they own or negotiating with boat captains to buy landed catches to dispose of by marketing. Women also serve as financiers to fishermen and support them in purchasing fishing inputs (Appiah et al. 2021). Major species harvested by small-scale fishermen include *Sardinella aurita*, *S. maderensis*, *Cynoglosus senegalensis*, *Selene dorsalis*, *Chlroroscombrus chrysurus*, *Decapterus punctatus*, *Ilisha africana*, and others (Nunoo and Asiedu 2013). Stock assessment studies on some of these fish species landed by small-scale fishing communities have shown overexploitation and possible collapse in the absence of appropriate management measures (e.g. Amponsah et al. 2019, 2021).

The management of SSF in Ghana is challenged by the expansion of rival fleets, economic collapse, open-access regime, weak enforcement, conflicts, and environmental issues (Asiedu et al. 2013). The culminating effect of these challenges confronting small-scale fisheries is the high rate of poverty in small-scale fishing communities (Asiedu et al. 2013). Furthermore, the Ghana Living Standard Survey Round Six (GLSS 6) revealed that whereas the poverty gap is reducing in other ecological zones, the opposite is occurring in the coastal zones (GSS 2014b).

Fishers in Ghana and other parts of West Africa have adopted several strategies to cope with the decline in their catch and this includes migration to other fishing communities. The Government of Ghana has enacted several legal instruments such as the Human Trafficking Act (Act 694) and the Human Trafficking Prohibition Regulations (Legislative Instrument 2219) to enhance migration governance (IOM 2020). The enactment of these laws contributes to the attainment of migration-related Sustainable Development Goals (SDGs) and, specifically, SDG Target

10.7 to 'facilitate orderly, safe, regular, and responsible migration and mobility of people, including through the implementation of planned and well-managed migration policies' (IOM 2020). As Ghana strives to achieve SDGs Goal 8 (decent work and economic growth) and Goal 11 (sustainable cities and communities) by 2030, there is a need to highlight and address all the issues concerned with fishers' migration. Furthermore, the integration of issues concerning migrant fishers into the formulation and implementation of effective fisheries management policies is weak in Ghana and other parts of the Gulf of Guinea. In most cases, migrant fishers are marginalized and do not have a voice in the management of fisheries. Efforts to address these challenges are important to the management of the SSF sector of Ghana. Reconciling fisheries management with social issues is among the greatest challenges in the era of declining stocks, especially in developing countries such as Ghana. Generally, knowledge about SSF is particularly limited despite its dominancy, and it is also less researched than commercial fishing (Cordell 2002; Salas 2007). Even though in recent times, attention on SSF is on the rise, it is still overshadowed by the industrial sector in fisheries science and policy discourse (Smith and Basurto 2019). These create gaps and challenges in managing the fishery that must be addressed.

The FAO (Food and Agriculture Organization) has indicated that the main problems and constraints of SSF are threefold and are related mostly to social, economic and human rights aspects that lead them to poverty and vulnerability. Fishers' migration is a social and economic issue. Thus, addressing social issues in migration is crucial in sustaining fishers' livelihood and the fishery. The United Nations General Assembly has declared 2022 the International Year of Artisanal Fisheries and Aquaculture (IYAFA 2022). Thus, this study contributes to highlighting issues in SSF. Accordingly, the study aimed to assess the social issues that migrant fishers face in the host communities. Specifically, we examined: a) the socio-economic conditions of migrant fishers; b) conflicts among migrant and host fishers; c) the rights of migrant fishers; and d) the role of government in dealing with fishers' migration. Understanding social issues faced by migrant fishers is necessary for the formulation of policies for the sustainable management of SSF of Ghana.

MATERIALS AND METHODS

Study communities

Ghana has a coastline of approximately 550 km. The SSF sector consists of 13,000 canoes, employs about 124,000 (mostly male) fishers and 1.9 million fish processors and traders (mainly female) and accounts for about 80% of total annual marine fish catch by volume (Dovlo et al. 2016; Andriesse et al. 2022). For this study, we selected six fishing communities that span the four coastal regions. The communities were Shama in Western Region, Elmina and Apam in Central Region, Tema and Ahwiam in Greater Accra, and Denu in Volta Region (Figure 1). Characteristics of communities in terms of population, fishing gears and number of fishers are shown in Table 1. These communities are involved in important fishing activities and are destinations for a significant number of migrant fishers (Nunoo and Asiedu 2013; Asiedu et al. 2022).

Data collection

Interview-based questionnaire

To meet the objective of the study, we conducted in-depth interviews with the use of a semi-structured questionnaire with key migrant fishers (n = 80), Chief Fishermen (n = 6) and Fisheries Technical Officers (n = 6) in the study communities. Respondents were chosen based on their

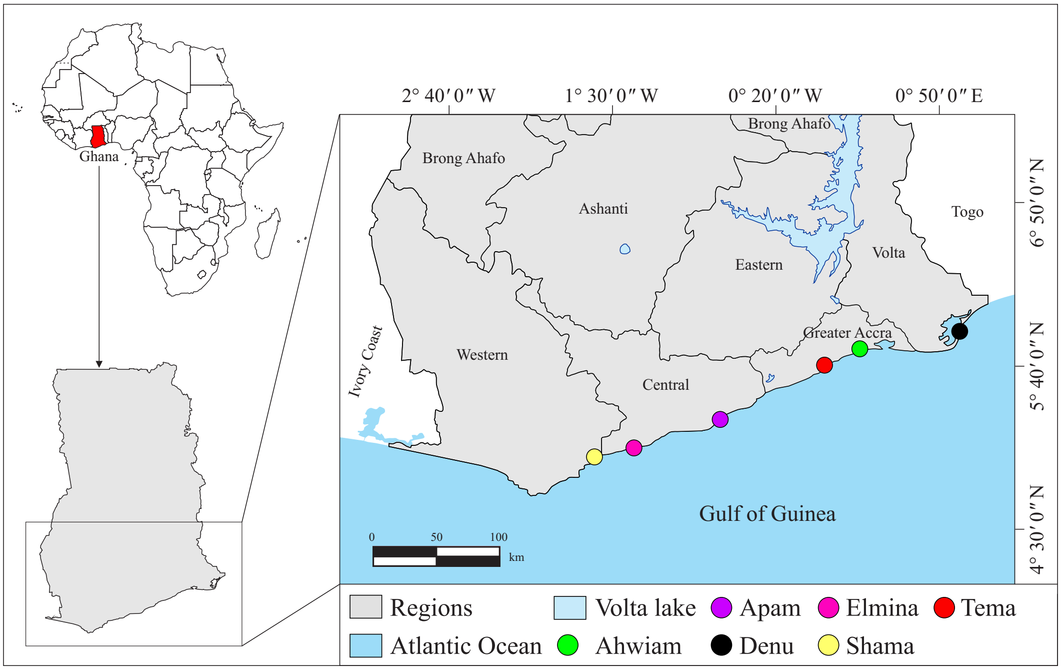

Figure 1. Map of the study communities.

Table 1. Characterization of study communities. Source: GSS (2014b) and Dovlo *et al.* (2016).

Study community	District assembly	Population	Gears used	Number of fishers
Apam	Gomoa West	23,588	Ali nets, drifting nets, purse nets, line, and set nets	1,600
Elmina	Komenda-Edina-Eguafo-Abrem (KEEA)	23,013	Ali nets, beach seine gears, purse nets, line, and set nets	2,000
Shama	Shama	11,000	Set net, purse net line, drifting net, Ali net, and beach seine	2,352
Ahwiam	Ningo Prampram	3,500	Pursing net, line, set net, and drifting net	894
Tema	Tema Metropolitan Assembly	71,711	Pursing[1] nets, line, *ali*[2] net, drifting[3] net, and set[4] net	5,167
Denu	Ketu South	6,051	Pursing nets, beach seine, and set net	418

[1] Pursing net are used by the inshore vessels with mesh sizes ranging from 10-25 mm.

[2] *Ali* net are the main net used in catching *Sardinella* normally at the beginning or towards the end of the fishing season.

[3] Drifting net are operated on the surface or at a certain distance below it, drifting freely with the current.

[4] Set net are nets that catch fish by gilling, entangling or enmeshing them in the net.

experience, availability, willingness to take part in the interview and membership of fisheries association (Table 2). In total 92 respondents were interviewed during the study period. The in-depth interviews were conducted between June and July 2022.

In the fishing industry of Ghana and many other West African countries, the Chief Fisherman is the most important traditional institution and plays a vital role in fisheries resources management. The Chief Fisherman has the authority to allow the entry of new fishers into their fishing landing communities (Nunoo et al. 2015). The position of the Chief Fisherman is hereditary and holds a lot of power and dignity. The Chief Fisherman is in charge of all the fishing operations in the fishing community. He settles disputes, imposes penalties, organizes, and monitors the allocation of any communal input as well as deals with the activities that must be undertaken in the event of risk and disasters at sea (Bennett 2002). Given their importance in the traditional management of SSF in Ghana, they were selected for the key informant interview.

The Ghana National Canoe Fishermen Council (GNCFC) is the umbrella body of most small-scale fishers. It was formed in 1982 with the objective of promoting the welfare of canoe fishers. Since then, it has grown to become an umbrella body of fishers and fishery associations in Ghana (Adjei 2021). In this study, we interviewed migrant fishers who were also members of the GNCFC.

Interviews were carried out in English. In situations where the language was a barrier, a local facilitator (i.e. the local Fisheries Technical Officer) was employed. Furthermore, responses were transcribed onto an audio recorder with the consent of respondents. The qualitative data were collected using key informants, experts interviews, and informal field discussions. The main purpose of collecting the qualitative data through these methods was to examine the major issues on migrant fishers, mostly on the mode of migrations, conflict resolution, roles of government, rights of migrant fishers, and other themes in the host fishing communities. The research team was able to obtain a better knowledge of migrant fishers through the data collected. The interview duration lasted between 30 and 50 min.

The study employed quantitative and qualitative methodologies to collect data using mixed questionnaires (closed and open-ended questions). There were three parts to the questionnaire: the first part examined the modes of migration and the settlement structure of migrant fishers; the second part assessed the rules and regulations, and conflict issues; and the third part explored the roles of government in migrant fishers and the rights of migrant fishers.

Table 2. Category of respondents, number, percentage and criteria used during the interviewed.

Category of respondents	Number	Number interviewed (n)	% n	Criteria used
Chief Fishermen	6	6	100	Traditional leader
Fisheries Technical Officers	6	6	100	Government official
Migrant fishers	622	80	13	Membership of fisheries association, experience, availability, and willingness

Desktop studies

Documents on social issues of fishers' migration were analysed on the following themes: fishers migration, SSF, social issues, patterns and impacts. Documents consulted included the 2021 Annual Performance Report (FC 2022), the Ghana Canoe Frame Survey Report (Dovlo et al. 2016), the Co-Management Policy for the Fisheries Sector of Ghana (MoFAD, 2020), Asiedu et al. (2022), Deme et al. (2021), and Failler and Ferraro (2021).

Data analysis

Responses obtained from the study were coded and fed into the Statistical Package for Social Sciences (SPSS) version 23 for statistical analysis. Descriptive statistics were performed and represented in tables and charts. Inferential statistics were carried out at a confidence interval of 95%. Non-parametric tests such as Chi-square analysis were performed to elucidate the existence of any significant differences in categorical variables as provided by the various respondents.

RESULTS AND DISCUSSION

Socio-economic conditions of migrant fishers

Many Ghanaian fishers migrate either seasonally or permanently to internal and international fishing communities in search of better fish catches, prices and alternatives to population pressures (Asiedu et al. 2022). Out of the five migrating groups, fishermen were the dominant migrant group (47.4%) (Figure 2). Fishermen are mostly recruited as crew members for fishing purposes, while men in this study refer to the older generation who are mostly engaged for their experience in providing solutions to emergencies and advice during conflictual situations at sea (21.1%). However, in situations where the crew members see old men as a liability in the fishing activities due to generational gap, reduced physical strength and advanced age, only fishermen (mostly of the younger generation) form the migrating group. Though most wives or fish

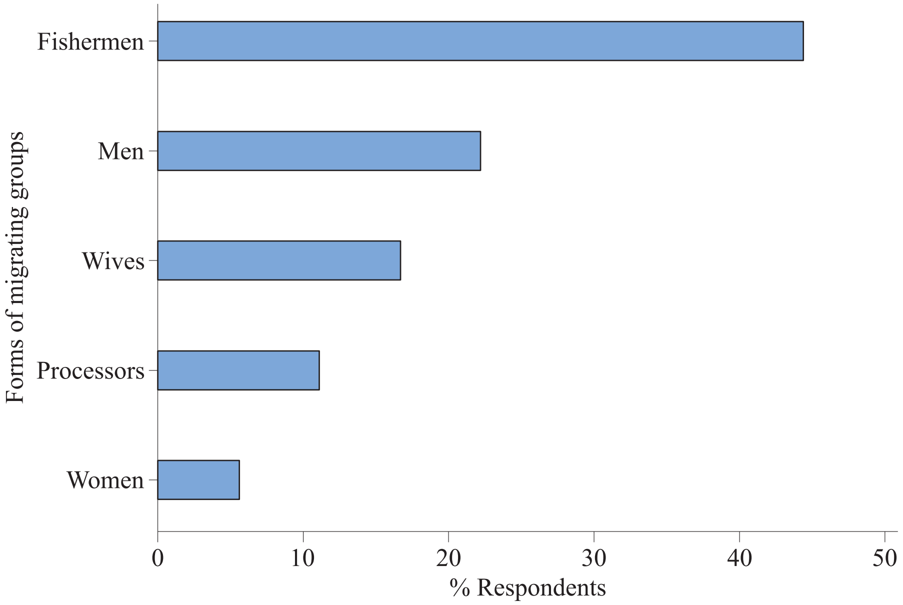

Figure 2. Migrating groups among migrant fishers.

processors join fishermen in the receiving communities by road, wives of the senior migrant fishermen are often allowed a return trip to their natal fishing community by the sea.

Most women migrate to the host communities with fishermen to provide housekeeping services for them. The women are remunerated with either a share of a catch or direct wages, thereby helping to meet food security and poverty reduction. The successful integration of women in the host communities largely depends on the generosity of the fishermen. In other cases, some migrant fishermen exclude women from migrating with them because they perceive that dwelling with women in the host communities is an expensive exercise. Nonetheless, the crew composition for the long-duration form of migration at sea tends to be influenced by kinship ties due to possible dangers the crew might face. It must be noted that women continue to play important roles within and outside the fisheries sector. Women play a big part in maintaining the social fabric of the fisheries and are central to the social context of fisheries (Szaboova et al. 2022).

Many migrant fishers (65%) upon arrival in the host communities live in the same neighbourhood as the indigenes (Figure 3). Having the nexus of friends, relatives or former co-workers makes settlement within the vicinity of the host communities possible. According to Asiedu et al. (2022), internal host communities visited by migrant fishers from Ghana include Tema, Sekondi, Apam, Axim and others, while for international host communities, fishing communities in coastal countries like Togo, Ivory Coast, Benin and others are mostly visited by Ghanaian migrant fishers. For internal migration, it is mandatory for migrant fishers to pay a token known as landing fee, which grants them access to the resources in the host fishing communities. However, for international host fishing communities, proper documentation on the period of stay, the number of crew, and other necessary information are requested before migrant fishers will gain access to the aquatic resources without hindrance (Asiedu et al. 2022).

Land scarcity in the host fishing communities appears to be a challenge, therefore these migrant

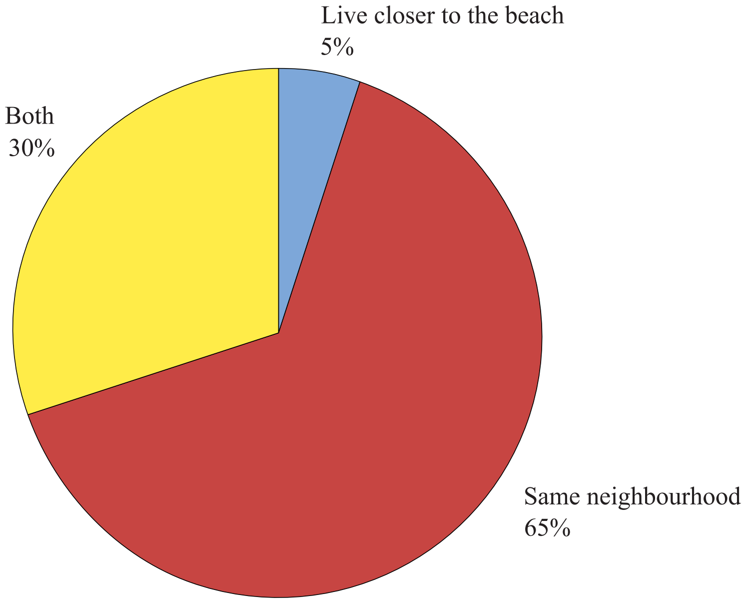

Figure 3. Settlement style of migrant fishers in the host communities.

fishers do not have the luxury of having a piece of land credited to them by the authorities of the host communities. To have access to housing units in the host communities, migrant fishers pay rent to the landlords. However, only in rare situations will migrant fishers opt to reside in separate locations within the host communities. About 5% of migrant fishers live close to beaches usually in tents and wooden structures. The UN Sustainable Development Goals (SDGs) advocate decent living as well as promote safe and secure working environments for all workers including migrant workers (Target 8.8). In most developing countries, fishers live in conditions with poor sanitation. This affects the health and well-being of migrant fishers.

Nature of fishing rules and regulations in the host communities

Migrant fishers are faced with challenges in their fishing activities even after successful integration into the host communities. They are mandated to comply with the local rules and regulations enacted by the Chief Fisherman and his council of elders (Figure 4). Prominent among these rules and regulations set aside for migrant fishers include i) obeying the non-fishing day holidays. During these days, fishers both indigenes and migrants are supposed to abstain from fishing activities. During these periods, migrant fishers indulge in mending their fishing nets, attending family gatherings such as weddings, naming ceremonies, and funerals, or spending quality time with family and friends. Fishmongers also use these fishing holidays to sell their processed fish products, particularly smoked fish, at either internal or external markets; ii) migrant fishers are mandated to partake in communal labour organized by the indigenes; iii) migrant fishers are also instructed to perform some rites which involve paying landing fees together with the presentation of local dry gin before being granted access to the aquatic resources, and iv) migrant fishers are required to halt any fishing activities during community curfews. Community curfews in this context relate to days during which funeral activities are ongoing within the

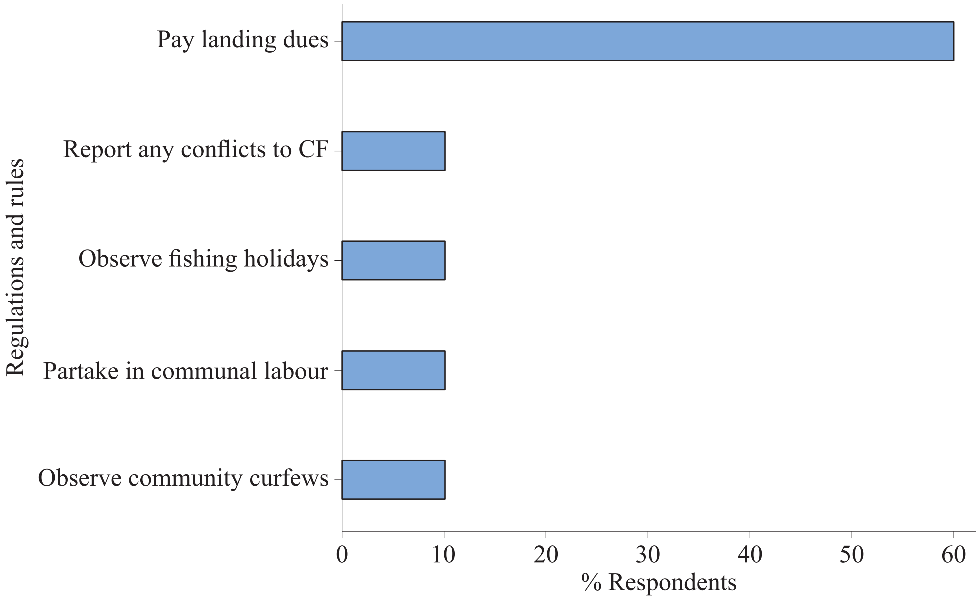

Figure 4. Prevalence of fishing rules and regulations at the host communities.

host communities. Failure to observe these rules and regulations implies that accessibility to aquatic resources is denied. In order to regain access to fisheries resources in the host community, violators are made to pay specified fines which vary from one fishing community to the other. Nonetheless, all fines include drinks that are used to pacify the sea god under the supervision of the Chief Fishermen and chief priest (Adjei and Sika-Bright 2019).

Conflictual issues among migrant fishers

Sources of conflicts between local and migrant fishers in the host communities are grouped into social and occupational (Figure 5). Occupational sources are generated because of fishing activities. For instance, rush for fishing grounds between indigenes and migrant fishers at sea, destruction of fishing equipment by locals, inadequate supply of premix fuel and stealing of landed catch by indigenes at the beach. Migrant fishers are technologically endowed with effective fishing techniques making it easier for them to explore greater fishing grounds than local fishers. These effective fishing techniques and access to wider fishing grounds lead to higher catches by migrant fishers. Such bountiful catches by migrant fishers triggers local fishers to explore similar fishing grounds after gaining access to such effective fishing techniques. The movement of local fishers to the fishing grounds exploited by migrant fishers breeds competition for fish resources, ultimately leading to conflicts between local and migrant fishers. In areas where local fishers do not have access to better fishing techniques and finances in comparison with migrant fishers (e.g. in Denu migrant fishers are offshore fishers while indigenes are mostly beach seine fishers) local fishers sometimes destroy the fishing vessels or part of the vessels belonging to migrant fishers. These actions by local fishers brew conflicts between them and migrant fishers.

The social source of conflicts occurs due to derailing from the accepted way of life practiced by the indigenes. This includes going after the wives or fiancée of the indigenes, not partaking in communal labour and defecating at the beach, etc. Most of the conflictual incidents are resolved through dialogue between the indigenes and migrant fishers amicably at the beach. For instance, when indigenes at the beach, tagged as

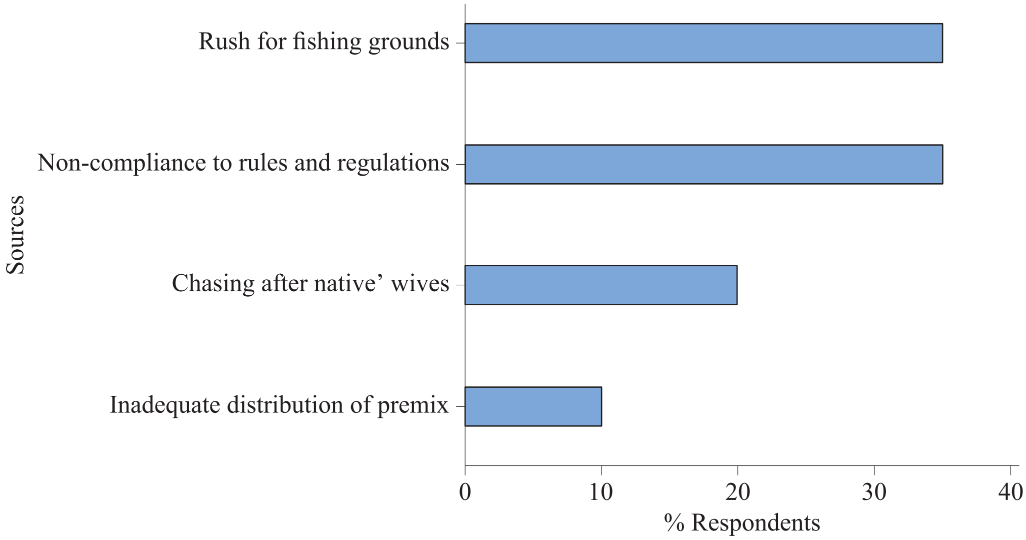

Figure 5. Source of conflicts between local and migrant fishers in the host communities.

'hustlers', steal a portion of the landed catch and are caught, such incidents are resolved in a friendly manner. Conflicts of higher magnitude such as going after another man's wife or destroying the fishing equipment of migrant fishers are mostly resolved through dialogue in the presence of the Chief Fisherman in the host community and at times the Fisheries Technical Officer is involved. However, in the absence of the Fisheries Technical Officer, justice for the migrant fishers in wake of any conflict with indigenes is stalled. Nonetheless, the long stay of migrant fishers in the host communities largely results in little or no conflictual incidents between them and the indigenes because they have accepted and are practicing the norms set aside by the host communities (Bennet 2002).

Rights of migrant fishers in the host communities

Rights enjoyed by migrant fishers in the host communities are outlined in Table 3. Migrant fishers in the various host communities raised concerns about not having constant access to premix fuel. In some host communities, members of the local committee act as middle agents who sell the fuel at exorbitant prices to these migrant fishers. These migrant fishers have no other option than to buy the premix fuel, which eventually affects the prices of landed catch as well as the expenses made for their fishing activities. The premix fuel is distributed to various fishing committees based on the number of local fishers. However, the influx of migrant fishers increases the total number of fishers, thus resulting in the unequal distribution of premix fuel. Such occurrences have the propensity of fuelling conflicts between migrant and local fishers. Therefore, it will be appropriate to quantify the number of migrant fishers moving into various fishing communities, and this could serve as an input for the recalculation of premix fuel for distribution in these communities.

Partaking in decision-making by migrant fishers in the host communities is a right that most migrant fishers enjoy. The zeal to contribute to

Table 3. Rights of migrant fishers in the host fishing community.

Role of Government	Response	Frequency (%)
Rights to social amenities	Yes	92 (100%)
	No	0
Right to vote	Yes	92 (100%)
	No	0
Right to own properties	Yes	92 (100%)
	No	0
Access to premix fuel	Yes	0
	No	92 (100%)
Decision management	Yes	92 (100%)
	No	0
Any discrimination	Yes	18 (20%)
	No	74 (80%)
Rights to marriage	Yes	92 (100%)
	No	0

such a decision-making process is mostly reliant on the fact it is geared towards sustainable management of the fisheries that form their main livelihood. However, in certain communities, migrant fishers with good standings sometimes have a degree of involvement when it comes to decision-making. For instance, a migrant fisher who possesses many fishing vessels, the Chief Fisherman of the migrant fishing community in the host communities, and highly experienced migrant fishers can be tagged as migrant fishers in good standings in the host communities. Nonetheless, the successful involvement of migrant fishers in decision-making depends on the benevolence of the council of elders in the host communities. Given this, there is a need to gazette policies with legal backing which would allow migrant fishers to partake in decision-making for the welfare of both locals and migrant fishers. Such policies are crucial mainly in areas where migrant fishers are not involved in decision-making and may tend to engage in illegal fishing methods without recourse to its implication to the ecosystem and the dependent livelihoods. For example, Muttenzer and Andriamahefazafy (2021) noted that the way migrant fishers fish greatly affects the populations of aquatic resources. The long stays and successful integration of migrant fishers in the host communities lower the likelihood of any form of discrimination. Also, the fact of establishing and maintaining social capital with locals through marriage, goodwill gestures, and other relationships enables migrant fishers to cohabitate successfully with locals in the host communities. However, discrimination between local and migrant fishers in the host community surfaces at certain happenings. For instance, during conflict resolution between local and migrant fishers, there is a high probability of migrant fishers being marginalized, resulting in stalemate or postponement of judgment. To avoid such results, especially during conflict resolutions, migrant fishers prefer the involvement of government officials who play a neutral role, thus ensuring fair treatment. The right to marry women or men in the host communities has been enjoyed for decades by migrant fishers. Migrant fishers become the preferred spouse of women in the host communities because they are seen as hardworking and financially stable. Furthermore, some migrant fishers employ women to assist them in their fishing business, which eventually ends in marriage.

Roles of government in managing fishers' migration

Table 3 indicates the role of government regarding the activities of migrant fishers during their stay at the host communities. The majority of the respondents (80%) agreed that the government, through the Fisheries Technical Officers plays a major role in resolving conflictual issues (Table 4). Officially, issues of conflict are in two forms, either it involves only small-scale fishers, or it occurs between small-scale fishers and semi-industrial fishers. When involving two or more small-scale fishers, they are mostly resolved by the Chief Fisherman and his elders within the host communities. However, conflicts existing between small-scale fishers and semi-industrial or industrial fishers are mostly brought to the notice of the Fisheries Technical Officers in-charge of the fishing community. Nonetheless, the lengthy or stressful procedure of tabling the case or allegations for mediation by the government deters some migrant fishers from reporting such incidents to the Fisheries Technical Officers. In some instances, the expenses involved before receiving attention from Fisheries Technical Officers is also a demotivating factor on the part of migrant fishers to report such incidents. Thus, some migrant fishers resort to resolving conflict with other small-scale fishers without involving government officials.

The majority of the respondents (60%) supported the claim that government do monitor the

Table 4. Role of government in the lives of migrant fishers in the host community. IUU: illegal, unreported, and unregulated.

Role of Government	Response	Frequency (%)
Conflict resolution	Yes	74 (80%)
	No	18 (20%)
Social amenities	No	83 (90%)
	Yes	9 (10%)
Data records	Yes	55 (60%)
	No	37 (40%)
Efforts on IUU	Yes	28 (30%)
	No	64 (70%)

fish catch landed on daily basis (Table 4). However, the monitoring of landed catch by Fisheries Technical Officers is not disaggregated into catch landed by migrant and local fishers. Some respondents (40%) were concerned that government does not record catches landed by migrant fishers in the host communities. However, this appears to be not the case, instead, the procedure used by the Fisheries Technical Officers in monitoring the catch statistically excludes some fishers. Nevertheless, to statistically have an idea of the percentage of the catch landed by migrant fishers as well as the contribution of migrant fishers to food and nutritional security in the host communities, there is a need to segregate such fish catch data. This, when instituted can aid in drafting proper management policies for migrant fishers.

The majority of respondents (70%) indicated that government officials play no key role in curbing the involvement of migrant fishers in illegal, unreported, and unregulated (IUU) fishing methods (Table 4). Allegations stem from the fact that most migrant fishers believe that the government cannot control the engagement of fishers in IUU fishing due to the large number of fishers along the coast and the isolation of these areas. Furthermore, the inability or reluctance in punishing violators of sustainable fishing on the part of the Fisheries Technical Officers was cited as another factor for the government's inability to ensure that migrant fishers desist from practicing IUU fishing methods. In view of this, there is a need to strengthen the coordination between the Fisheries Enforcement Unit and the judiciary system for prompt issuing of varying levels of punishment to violators. When such coordination is firmly rooted within the framework of fisheries management, migrant fishers will have no option but to comply with the existing fisheries management measures at the various host communities.

CONCLUSIONS

Activities of migrant small-scale fishers continue to play critical roles in food security, livelihood support and the development of the local economies. Migration among fishers is mostly male-dominated due to the tedious nature of the job. Socio-economic conditions of migrant fishers must be critically examined and incorporated into fisheries management programmes and policies. Following adherence to fishing regulations in the host communities, migrant fishers tend to enjoy many benefits in the host communities including the right to partake in decision-making for sustainable management of the fisheries resources. Nonetheless, there is a need to empower the Chief Fishermen and government authorities in the management of migrant fishers in the host communities as these institutions play a significant role in resolving conflicts between migrant and local fishers as well as ensuring that migrant fishers adhere to existing fishing rules and regulations. Additionally, Fisheries Technical Officers must record catches of migrant fishers. To ensure that migrant fishers do not engage in IUU fishing methods without considering the integrity of the marine ecosystem, equity in the distribution of premix fuel should be addressed in the host communities using relevant strategies. There is an urgent need for better integration of the social issues of migrant fishers into national fisheries policy to address challenges emanating therefrom.

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Declaration of interest

The authors have nothing to declare.

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ORIGINAL RESEARCH

Behavior and diet composition of fiddler crabs in Guang-guang, Dahican, Mati City, Davao Oriental, Philippines

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ABSTRACT. This paper aims to provide information about the behavior and diet composition of fiddler crabs. The large percentage of sediments present in the stomach of fiddler crabs proves that fiddler crabs play an important role in aerating the soil, which would help in the growth of mangrove and wetland plants. Observations were done in sandy, muddy, and coralline substrates for four months. Thirty fiddler crabs were collected for laboratory test of their diet composition. Sediments had the highest percentage in the stomach content of the fiddler crabs (60%), followed by chum (25%), and leaf particles (15%). The analysis of the fullness of their stomach showed that it was highly significant (df = 2, MS = 2.09, F = 34.34, p = 0.001). While the fiddler crabs ate all three colors of mangrove leaves, it preferred to forage on yellow leaves (n = 104) followed by the brown leaves (n = 78) and the green leaves (n = 77), proving that nutrient recycling occurs in the mangrove area. The existence of the fiddler crabs contributes to a more stable mangrove ecosystem. In addition, this study is the first assessment of fiddler crabs documented in Mindanao, Philippines. Results of the study can be used as a baseline for the protection of mangrove ecosystem species.

Key words: Antagonistic behavior, bioturbation, mangrove, sediments, soft-bottom ecosystem.

Comportamiento y composición de la dieta del cangrejo violinista en Guang-guang, Dahican, Mati City, Davao Oriental, Filipinas

RESUMEN. Este trabajo tiene como objetivo proporcionar información sobre el comportamiento y la composición de la dieta de los cangrejos violinistas. El gran porcentaje de sedimentos presentes en el estómago de los cangrejos violinistas demuestra que los cangrejos violinistas juegan un papel importante en la aireación del suelo, lo que ayudaría al crecimiento de las plantas de manglares y humedales. Las observaciones se realizaron en sustratos arenosos, fangosos y coralinos durante cuatro meses. Treinta cangrejos violinistas fueron recolectados para estudiar en de laboratorio la composición de su dieta. Los sedimentos tuvieron el porcentaje más alto en el contenido estomacal de los cangrejos violinistas (60%), seguidos de la carnada (25%) y las partículas de hojas (15%). El nivel de llenado del estómago mostró que era altamente significativo (df = 2, MS = 2,09, F = 34,34, p = 0,001). Si bien los cangrejos violinistas comieron los tres colores de las hojas de mangle, prefirieron alimentarse de las hojas amarillas (n = 104), seguidas de las hojas marrones (n = 78) y las hojas verdes (n = 77), lo que demuestra que el reciclaje de nutrientes ocurre en la zona de manglares. Los cangrejos violinistas contribuyen a mantener un ecosistema de manglar más estable. Además, este estudio representa la primera evaluación de cangrejos violinistas documentada en Mindanao, Filipinas. Los resultados se pueden utilizar como referencia para la protección de las especies del ecosistema de manglares.

Palabras clave: Comportamiento antagonista, bioturbación, manglar, sedimentos, ecosistema de fondos blandos.

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INTRODUCTION

The Genus *Uca* contains about 100 species of semi-terrestrial marine crabs which includes fiddler crabs, sometimes called 'calling crabs' (Rosenberg 2019). Fiddler crabs are members of the Family Ocypodidae of brachyuran crabs, marine animals that recently invaded the land. They are active on the surface at low tide, feeding on soil debris, bacteria, and algae (Zeil et al. 2006). Sandy beaches, mudflats, mangrove areas, and salt marshes are all locations where fiddler crabs can be found. Fiddler crabs rely on the sediment which they use for food, burrowing, and for collecting bacteria, debris, and benthic macroalgae (Ribeiro and Iribarne 2011). The intertidal zone and the nearby marine and terrestrial habitats are connected by fiddler crabs, which are recognized as ecosystem engineers and significant connectors of energy flow. According to a recent study, fiddler crabs are the primary food source for some fish and may be more important than was previously thought as food for predators (Grande et al. 2018).

Fiddler crabs are recognized for having extraordinary claws. Male claws are much larger compared to those of females, who have claws of the same size. They stay close to their burrows to quickly escape from predators, as well as find shelter from the heat and water loss (Macintosh et al. 2002). Male fiddler crabs use their minor claw for feeding and the major claw for displaying and fighting. Major claws are typically brightly colored and four to five times longer than minor claws, making up around one-third of the total body mass of the crab. Female fiddler crabs have two tiny claws almost always cryptic (Rosenberg 2001). Fiddler crabs can tolerate a wide range of salinities, high temperatures, and low levels of oxygen (Nagelkerken et al. 2008). Fiddler crabs attract a female for mating by waving their enlarged claw. Courtship activity of male fiddler crabs peaks semi-monthly and coincides with the peak in the temporal distribution of receptive female fiddler crabs. A female fiddler crab mate once a month, 4-5 days prior to one of the semi-monthly spring tides. The relationship between the timing of reproduction and tide cycles may represent an adaptation to maximize the likelihood that the last stage of planktonic larvae will be carried by tidal currents to substrates suitable for adults (Swanson et al. 2013). They protected themselves against other fiddler crabs or predators using their enlarged claws (Bergey and Weis 2006). Burrows are the most crucial resource for the reproduction and survival of fiddler crabs, and males must defend them for females to be attracted to them. Each fiddler crab concentrates its territorial defenses on a single burrow (Mautz et al. 2011). Research on the behavior of fiddler crabs is critical to understanding when and how much sediments impact and how they affect the overall functioning of ecosystems. As with other intertidal invertebrates, their activity is significantly influenced by tides. According to several studies, fiddler crabs only engage in surface behaviors including feeding, burrowing, and mating during low tide and stay in their burrows during high tide (Reinsel 2004; Sanford et al. 2006; Zeil and Hemmi 2006; Dugaw et al. 2009). Fiddler crabs can significantly influence the ecology of mangrove communities, acting as ecological engineers by adjusting resources accessible to marsh plants and by changing the physical, chemical, and biological characteristics of these communities of soft sediments (Smith et al. 2009). Fiddler crab bioturbation would improve the oxygenation of the sediments and promote the growth of mangrove saplings (Macusi and Tipudan 2021). Various species of fiddler crabs, each have different behaviors like feeding, mating, walking, etc., can be found in the same habitat in many tropical environments (Nordhaus et al. 2009; Shih 2012).

Because there are few studies of fiddler crabs in the Philippines, this paper provides a new understanding of the species. The objective of this study was to provide information about the behavior and diet composition of fiddler crabs in Guang-guang, Dahican, Mati City, Davao Oriental. Findings of this study will be used as a reference for anyone interested in studying fiddler crabs in the Philippines, particularly in Mindanao, and will provide additional information to assist in the development of a conservation strategy for various marine species.

MATERIALS AND METHODS

Study area

The study area was located in the mangroves of Guang-guang, Barangay Dahican under the municipality of Mati City, Province of Davao Oriental. The study area is situated at 60° 55′ N and 126° 15′ E. The area is characterized by sandy, sandy-muddy, sandy coralline and muddy substrate with different species of seagrasses thriving in it. The Guang-guang mangrove area is part of the National Integrated Protected Areas System (NIPAS) as Protected Landscape/ Seascape under Proclamation No. 451 dated July 31st, 1994 of the Philippine government with an approximate area of 168 km^2 (Abreo et al. 2020) (Figure 1).

Data collection

The study focused on observing the behavior and the diet composition of fiddler crabs in relation to low tide in Guang-guang, Dahican, Davao Oriental. Three sampling stations of 10 × 10 m quadrats each were established on the shoreline

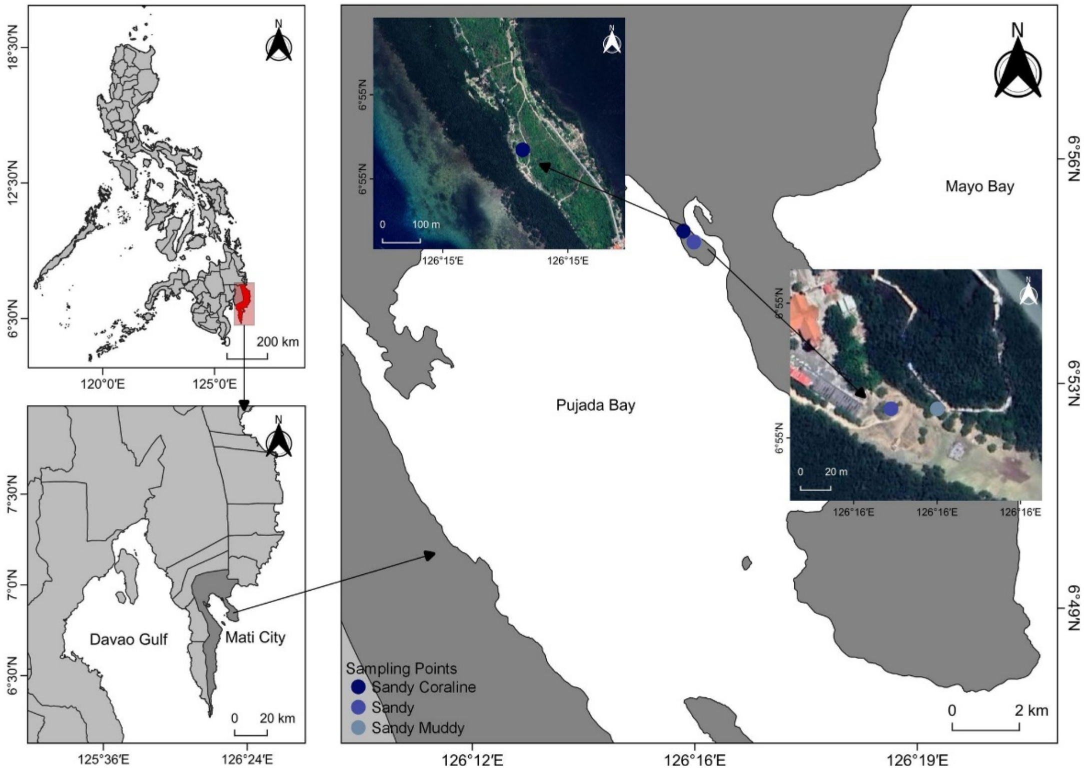

Figure 1. Study area in Guang-guang Dahican, Mati City, indicating different substrates (blue colors).

of Guang-guang: sandy, muddy, and sandy coralline. Each station had four quadrats for easier observation on their behaviors with a minimum distance of 100 m from each other to maintain independence and prevent one station from being influenced by the others. The behavior of fiddler crabs was assessed according to their sex, whether they perform courting, defending burrows, fencing or predation, waving, enhancing their burrows, walking/grasping or foraging. Foraging activities of fiddler crabs were also categorized as either collecting leaves (grasping the item and retreating to the burrow) or foraging (slow walking, associated with tapping or tasting sediment or litter). In each station, fiddler crabs and their burrows were counted and burrows were examined for leaf taking. The duration of the observation and counting of fiddler crabs took one hour during low tide and these activities were photographed for documentation. The regularity of the observation in the three stations were thrice a week for four months. Three different hues of leaves (green, yellow, and brown) were tied with a thread, anchored by a bamboo stick, and placed close to the burrows for determining the preferred color. Scoring and observation were carried out by evaluating the leaves that were eaten or missing and scored positive when fiddler crabs had bite marks on that particular leaf color or if leaves were missing. Ten randomly selected burrows from each of the three stations were used in the experiment. Each station was observed for one hour during low tide. The experiment was repeated four times and then after the fourth test, crab burrows were sampled for leaf coloration in each of the three stations.

Laboratory work

Species identification and diet composition of fiddler crabs

Fiddler crab species were identified by morphological characteristics from Rosenberg (2019) and by using the following taxonomic references: the *Austruca annulipes* (Milne Edwards, 1837), *Gelasimus vocans* (Linnaeus, 1758), *Tubuca capricornis* (Crane, 1975), *Tubuca urvillei* (Milne Edwards, 1852), *Paraleptuca crassipes* (White, 1847) and *Tubuca alcocki* (Shih, Chan and Ng 2018). Thirty male and female fiddler crabs from each of the three stations were sampled for diet composition. These samples were collected in the field and placed immediately in 70% ethanol and brought to the laboratory. Fiddler crabs were injected with 10% formalin solution to stop the digestion process and then they were photographed. Next, fiddler crabs were dissected and stomach contents were washed with distilled water, transferred to a solution of 10% formalin, and stained with safranin red (this stain was used because it was the only one that could be found in the laboratory during the study). Contents were classified into distinguishable food categories, e.g. leaf, algae, and sediments. Stomach fullness, percentage of the total volume visible contributed by each of the food categories, and frequency of occurrence of different food categories were determined. To get the percentage of the stomach fullness the following values were $D_0 = 0\%$, $D_1 = 25\%$, $D_2 = 50\%$, $D_3 = 75\%$ and $D_4 = 100\%$.

Categorizing food Items from crab stomachs

By using a dissecting microscope, food items in the stomach of each crab were classified as sediment, leaves, or algae. There were also stomach samples in which no leaf fragments were found. Foraging behaviors of fiddler crabs were also classified according to whether they forage (slow walking, associated with tapping or tasting sediment and litter) or collect leaves (grasping the item and retreating into the burrow).

Data analysis

All count data were first checked for normal distribution before comparisons were made. If data were not normally distributed, they were $\log_{10}$ transformed and checked again for normal data distribution and homogeneity of variance using Kolmogorov-Smirnov test. Once the requirement of ANOVA was satisfied, then all tests were considered statistically significant at $p \leq 0.05$. *Post hoc* analyses using Tukey's HSD test and the modified Tukey's HSD test for unequal sample N were performed. The Kruskal-Wallis test was used to analyze the frequency of various behaviors and the diet composition of fiddler crabs in order to compare them when data transformation did not work out for normal distribution and homogeneity of variance.

RESULTS

Species composition

Family Ocypodidae is the family of fiddler crabs found in different stations: the muddy, sandy coralline, and sandy muddy substrate in the study area. Six species were identified from samples: *Austruca annulipes* (Edwards, 1837), *Gelasimus vocans* (Linnaeus, 1758), *Tubuca capricornis* (Crane, 1975), *Tubuca urvillei* (Edwards, 1852), *Paraleptuca crassipes* (Adams and White, 1848), and *Tubuca alcocki* (Shih, Chan and Ng 2018). In species identification, the genus level was used due to a lack of exact information about their species composition. Pictures taken during the sampling period were compared to descriptions from Rosenberg (2014) (Figure 2).

Behavior of fiddler crabs

There were different behaviors of fiddler crabs observed in the study area. They consisted of antagonistic, walking, foraging, waving, and burrow enhancement. The frequency of these activities during the observation days were analyzed using Kruskal-Wallis test and no significant differences in terms of the walking (df = 2, $H = 2.65$, p = 0.266), foraging (df = 2, $H = 0.36$, p = 0.834),

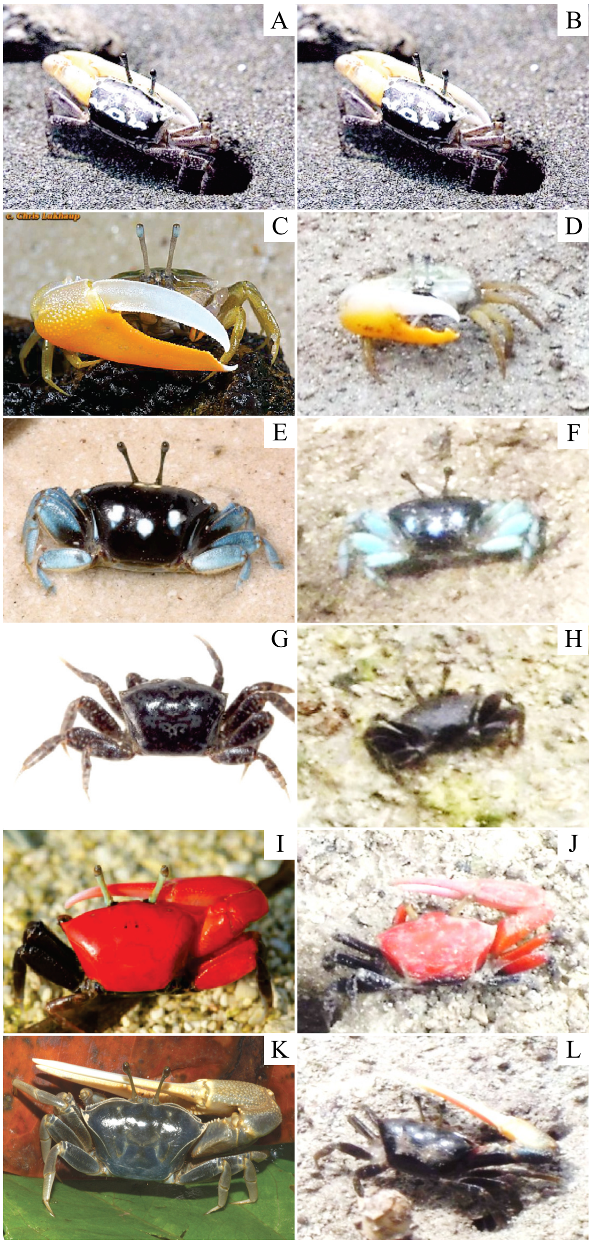

Figure 2. Side by side, comparison of species found in the study area together with published photos from Rosenberg (2014) and their corresponding names. *Austruca annulipes* (Edwards, 1837) (A and B), *Gelasimus vocans* (Linnaeus, 1758) (C and D), *Tubuca capricornis* (Crane, 1975) (E and F), *T. urvillei* (Edwards, 1852) (G and H), *Paraleptuca crassipes* (Adams and White, 1848) (I and J), and *T. alcocki* (Shih, Chan and Ng 2018) (K and L).

antagonistic (df = 2, H = 0.36, p = 0.834) and burrow enhancement activities of the various fiddler crabs (df = 2, H = 5.71, p = 0.058) were detected. Observations were done in three different substrates (muddy, coralline, and sandy substrates) for three days to assess their behaviors. Waving and antagonistic activity were two patterns of activity that only male fiddler crabs were able to perform more actively than female fiddler crabs (Figure 3).

The various behaviors of fiddler crabs observed included courting (waving), defending burrows (antagonistic), and burrow enhancement mostly performed by *Paraleptuca crassipes* (Figure 4 A, D, and E). A waving behavior was usually performed by *Paraleptuca boninensis* (Figure 4 B), while fencing/predation behavior was performed by *Tubuca dussumieri* (Figure 4 C), and foraging behavior was performed by *Tubuca capricornis* (Figure 4 F). In addition, walking was performed by *Gelasimus tangeri* (Figure 4 G), and foraging was also performed by *Paraleptuca chlorophthalmus* (Figure 4 H).

Diet composition

Fiddler crabs were collected to identify their stomach content. Most of stomach samples contained sediment, leaf fragments, and algae. The *post hoc* comparison showed that sediments comprised 34% of stomach contents followed by 12% of chum and 10% of leaf particles. Comparison of sediment contents of stomachs from the various substrates showed no significant differences (df = 2, H = 1.19, p = 0.551), and the same was observed for chum (df = 2, H = 2.17, p = 0.339) and leaf contents (df = 2, H = 1.38, p = 0.501) when compared to those in the sandy, muddy, and coralline area.

Mangrove leaf preference

During the three-day experiment regarding leaf preference of fiddler crabs, the most eaten leaves were the yellow ones with a total count of n = 104. In the muddy substrate, yellow leaves were the most eaten among the three colors (n = 27), while green leaves were the least consumed (n = 23). The highest count of total leaves eaten in the coralline substrate was yellow leaves (n = 37), while brown leaves were the least eaten (n = 21). For the sandy muddy, the highest count of eaten leaves were also yellow leaves (n = 40), while green leaves were also less consumed (n = 29) (Figure 5 A). On the third day of the experiment, some leaves were missing in each station, both green and yellow leaves. In the muddy station, the number of leaves missing for the three colors were the same (2). In coralline areas, yellow leaves had two missing leaves (2) compared to the others, one for the green (1) and none for the brown (0). For sandy areas, green and yellow leaves had the same number of missing leaves (6) while brown leaves had the lowest number (5) (Figure 5 B).

DISCUSSION

Females invested more time feeding and fed 50% faster than males. For example, *Uca vocans* (Rumphius, 1705) was the most dominant fiddler crab species on sandy beaches and was particularly active, feeding at approximately twice the rate of other species (Weis and Weis 2004). Composition of the substrate is also significantly altered by foraging and burrowing activities (Posey 1987) and could affect biological processes like meiofauna reproduction (Ólafsson and Ndaro 1997) and growth of young mangrove plants (Macusi and Tipudan 2021). Foraging activity was the most frequently performed activity by female fiddler crabs compared to males, followed by walking. To increase the size of their arms out of proportion to the growth of their bodies, large male fiddler crabs engage in grabbing and pinching structures. Even crab mating can be utilized

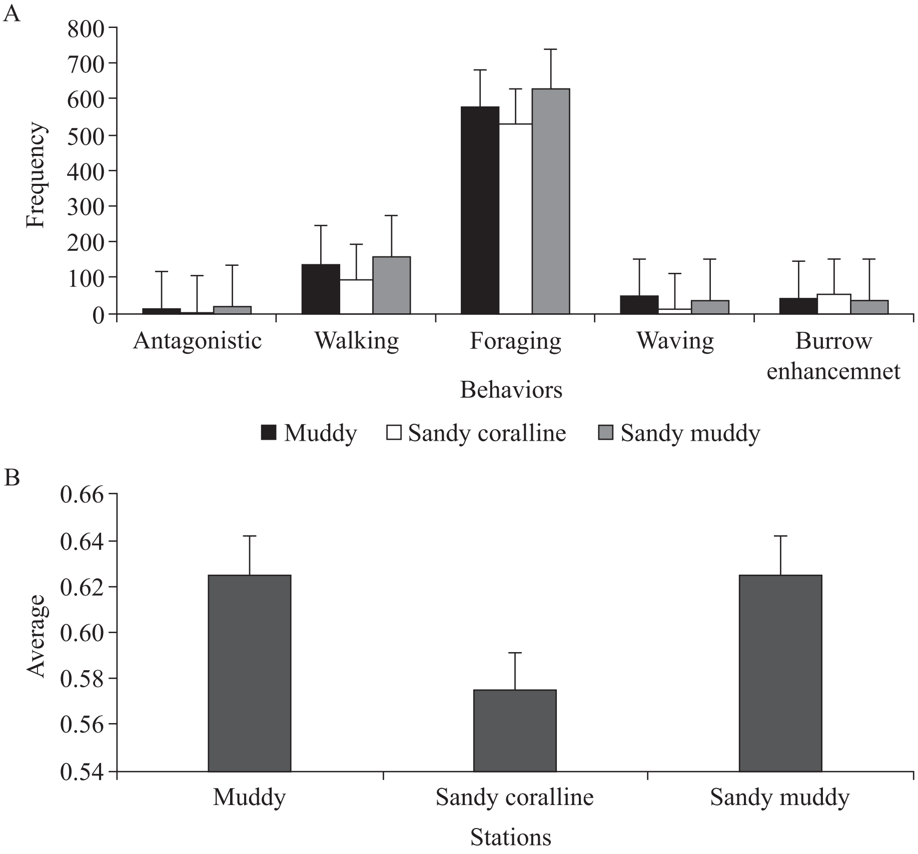

Figure 3. Total count of various behaviors of fiddler crabs observed in the three different substrates (A). Male fiddler crabs performed both antagonistic and waving activities more actively. Percentage of stomach contents of fiddler crabs (B).

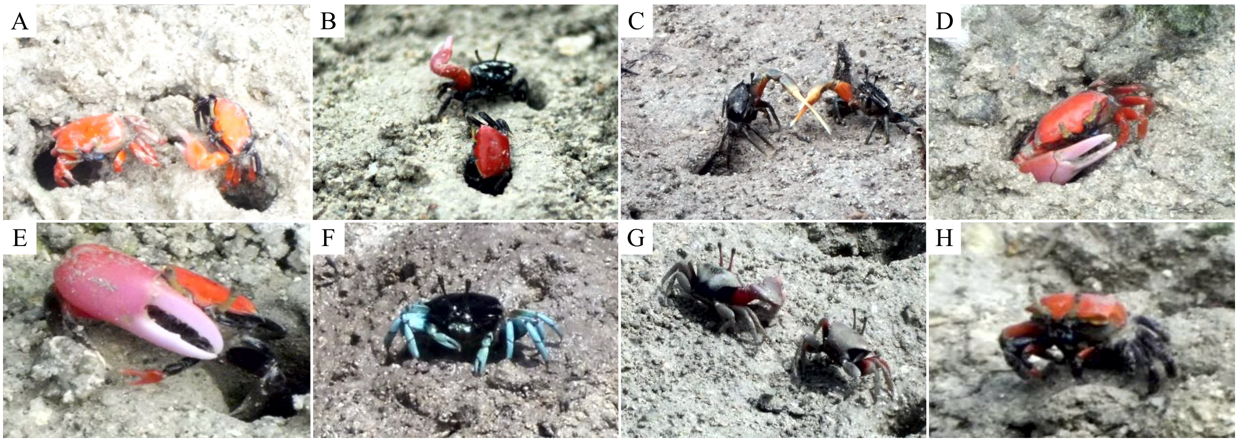

Figure 4. The various behaviors of fiddler crabs displayed in the three stations (muddy, sandy, and coralline). A, D, and E) *Paraleptuca crassipes*. B) *P. boninensis*. C) *Tubuca dussumieri*. F) *T. capricornis*. G) *Gelasimus tangeri*. H) *P. chlorophthalmus*.

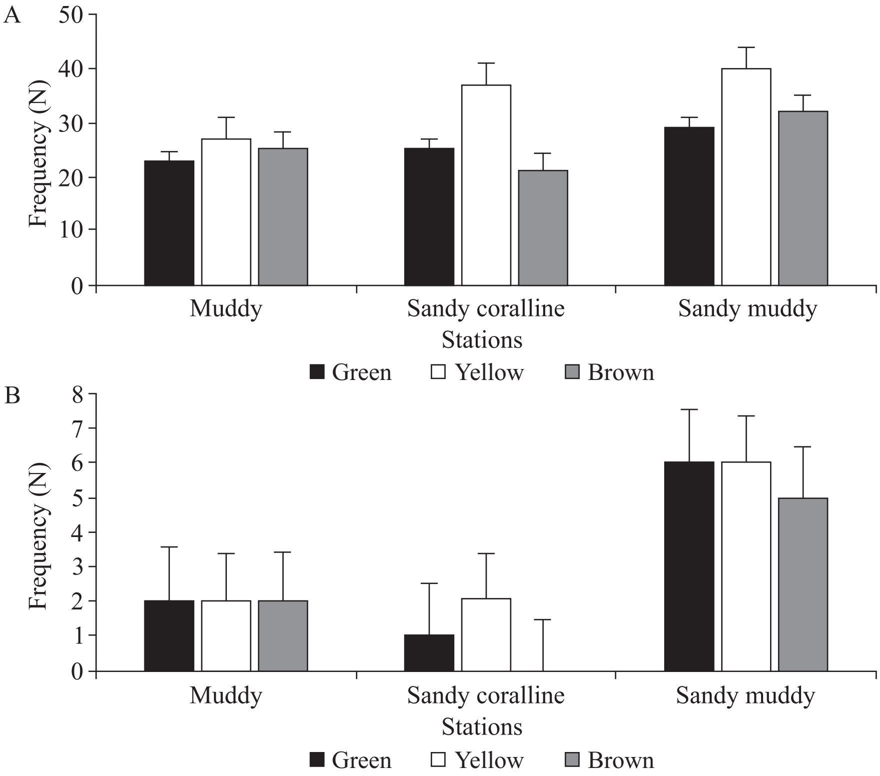

Figure 5. Total count of eaten (A) and missing (B) mangrove leaves.

as a predation technique. Males of 'directing' or 'herding' fiddler crab species trap stressed females between their body and their major claw before pushing and pulling them into burrows (Zucker 1986). The bioturbation carried on by fiddler crabs through burrowing, feeding and ventilation is crucial for coastal wetlands worldwide (Stieglitz et al. 2013; Xiao et al. 2017). Crab burrows become waterlogged occasionally as a result of tidal flushing, which results in material exchange between the burrow water and overlying water across the sediment-water interface (Xie et al. 2019). Burrow flushing creates asymmetric distributions of dissolved oxygen along burrow walls and surrounding sediments, and bioturbation can significantly increase dissolved oxygen uptake (Liu et al. 2019).

Stomach contents of fiddler crabs consisted of sediments, chum, and leaf particles. When observed under the microscope, sediments and chum were consistently more prevalent than leaf particles in the stomach of fiddler crabs. At each station, some leaves were tied near their burrows and after some time they disappeared, while some leaves bore a scratch mark and others were eaten, indicating that leaves were also part of the diet of the species. Since energy is much more readily available in plants than in animals, the low nitrogen concentration of plants can prove to be a significant limiting nutrient for herbivores (Boyd and Goodyear 1971). Although having a greater expected mass and availability than animal meals, plants are less nutrient-dense than those used for food by herbivores (Wolcott and O'Connor 1992).

Mangrove forest sediments contain large numbers of active bacteria (Alongi et al. 2005). These bacterial communities break down organic debris, including leaf litter, and incorporate remineralized nutrients into mangrove sediments, making them available to plants and detritivores (Koch and Wolff 2002). Fiddler crabs, together with other detritivores, consume between 20% and 80% of the carbon from mangrove leaf litter. They are the most active and noticeable detritivores in the mangrove forest (France 1998; Bouillon et al. 2008; Kristensen et al. 2008). By utilizing these resources, detritivores contribute more to the cycling of nutrients in mangrove systems than any other trophic group by mass per unit of time (Koch and Wolff 2002). This concept, however, had been questioned, and even pointed out that partially degraded mangrove leaves are likely insufficient to support crab growth (Bouillon et al. 2004). When gut samples of fiddler crabs were viewed under the microscope and analyzed, 60% of their content was sediment. Fiddler crabs are specialized sediment consumers. They use their mouthparts to extract organic material from the sand or mud sediments. Excess inorganic sediments are later released as tiny pellets, which typically cover the ground near burrows. Because male crabs only have one feeding claw, it is helpful to identify crab species by its gender. Therefore, they feed longer and scoop more quickly than female crabs. After the primary claw reaches a particular size, it becomes useless as a feeding instrument (Moruf and Ojetayo 2017).

CONCLUSIONS

This study was conducted due to the lack of information about the behavior and diet composition of fiddler crabs. Subsequent studies could benefit from additional data collection to better understand their roles in the mangrove ecosystem. Firstly, a similar study involving the recording of digital video cameras for their various behaviors ought to be carried out. Secondly, Rose Bengal staining should have been used to determine the gut contents of the fiddler crabs and additional burrow sampling should have been used to assess the diets of fiddler crabs. Lastly, identifying the species of fiddler crabs could be done at the molecular level.

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ORIGINAL RESEARCH

Biodiversity of forage fishes in the Lower Laguna Madre, southernmost Texas

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ABSTRACT. Coastal estuarine ecosystems serve as nursery habitats for many commercially and recreationally important fishes. Biodiversity is a structural indicator and has been used as a metric for conservation and management. In the hypersaline Lower Laguna Madre of Texas, a variety of organisms makes their living in and around the dominant seagrass vegetation. This study provides a general assessment of forage fishes biodiversity collected seasonally with bag seines in two sites: Holly Beach (HB) and South Bay (SB) within the most southern Texas bay system as part of a broader study on fish biology. A total of 15,880 fishes representing 32 species were collected during four quarterly samplings through a year (11,795 from HB and 4,085 from SB). Both sites are interconnected as no fishes similarities difference were found, nonetheless, the sites' variable characteristics (i.e. basin area, seagrasses coverage, connection to the Gulf of Mexico) resulted in significant greater species richness, relative abundances, and diversity in HB than SB for most of the year, suggesting differences in habitat quality or at the very least variation in the availability of habitat types, which are known to contribute to differences in fish diversity attributes.

Key words: Fishing gear, estuaries, coastal fishes, baitfish, nursery habitat.

Biodiversidad de peces de forraje en la Laguna Madre Inferior, en el extremo sur de Texas

RESUMEN. Los ecosistemas de estuarios costeros sirven como hábitats de crianza para muchos peces de importancia comercial y recreativa. La biodiversidad es un indicador estructural y se ha utilizado como métrica para la conservación y la gestión. En la hipersalina Laguna Madre Inferior de Texas, una variedad de organismos vive en y alrededor de la vegetación de pastos marinos dominante. Este estudio proporciona una evaluación general de la biodiversidad de peces de forraje recolectados estacionalmente con redes de cerco en dos sitios: Holly Beach (HB) y South Bay (SB) dentro del sistema de bahías al sur de Texas, como parte de un estudio más amplio sobre la biología de peces. Durante cuatro muestreos trimestrales a lo largo de un año, se recolectaron un total de 15.880 peces (11.795 de HB y 4.085 de SB) que representan 32 especies. Ambos sitios están interconectados, ya que no se encontraron diferencias en las similitudes de peces; sin embargo, las características variables de los sitios (es decir, área de la cuenca, cobertura de pastos marinos, conexión con el Golfo de México) dieron como resultado una riqueza de especies, abundancias relativas y diversidad significativamente mayores en HB que en SB durante la mayor parte del año, lo que sugiere diferencias en la calidad del hábitat o, al menos, variación en la disponibilidad de tipos de hábitat, que se sabe que contribuyen a las diferencias en los atributos de diversidad de peces.

Palabras clave: Artes de pesca, estuarios, peces costeros, carnada, hábitat de cría.

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INTRODUCTION

Coastal estuaries usually consist of a variety of structured and productive ecosystems such as marshes, mangroves, seagrasses, and reefs (Beck et al. 2001) that act as a habitat for a variety of organisms and create a nursery system for many commercially important fish species all over the coastal world (Hampel et al. 2005; Whitfield 2016; Breaux et al. 2019), many spawning offshore and using these areas as larvae and juveniles (Heck et al. 1997). Economically, these ecosystems are incredibly important locally, regionally, and nationally. In the United States of America (USA), the Texas coast alone brings in about USD 2 billion for recreational fishing, USD 5.4 million from tourism, and USD 250 million for seafood production (Rosen 2013).

Smaller and lower trophic level schooling fishes, known as forage fish, are usually found to be prey items to larger predatory fishes within the estuary. Forage fishes populate these ecosystems playing an important role within the community and trophic web as they make up a large part of the diet of many higher-level predators that use the estuary to feed and grow (Pikitch et al. 2012; Faletti et al. 2019). Many of these forage fishes will stay within the estuary their entire life, whereas others will travel offshore to spawn (Murphy and Taylor 1989; Wilson and Nieland 1994; Brown-Peterson et al. 2002; Faletti et al. 2019).

On the Gulf coast of Texas, which stretches about 644 km, there are about 10,522 km^2 of estuary habitat and seven major bay systems (Rosen 2013). Along the Texas coast, many of the estuaries have a high presence of seagrass that allows for sediment stabilization, nutrient cycling, protection, and detrital production and export (Heck et al. 2003). The most southern bay system of the Texas Gulf coast is the Laguna Madre. The most southern portion of the Laguna Madre, the Lower Laguna Madre (LLM), has been considered as hypersaline due to little freshwater inputs, few inlets to the Gulf of Mexico (GOM), and high evaporation (Tunnell and Judd 2002; Rosen 2013; Kowalski et al. 2018). The LLM has a high presence of seagrasses mostly including Turtle Grass (*Thalassia testudinum* K. D. Koenig, 1805) and Shoal Grass (*Halodule wrightii* (Ascherson, 1868)), but other species such as Manatee Grass (*Syringodium filiforme* Kützing, 1841), Widgeon Grass (*Ruppia maritima* Linnaeus, 1753), and Clover Grass (*Halophila engelmannii* Ascherson, 1875) can be found (Sheridan and Minello 2003). It is expected to find a higher number of fishes residing in areas of the estuary that have higher densities of seagrasses and other plant structures, which was shown in the LLM by Sheridan and Minello (2003). Though with changing climatic conditions, anthropogenic disturbances, and the increase of cold fronts and storm surges, many organisms are seeing declines, mass mortalities, or displacement (Sheridan and Minello 2003; Kowalski et al. 2018).

Due to the high productivity within these ecosystems, a high diversity of species (fishes and invertebrates) is usually found (Beck et al. 2001) which leads to interactions among different species using the same resources (Whitfield 2016). This creates biotic interactions that may affect local species distributions and abundances. An ecosystem's productivity is largely attributed to the area's biodiversity, making biodiversity a crucial metric for conservation and management (Pawluk et al. 2021). Fish diversity within the marine environment is constantly changing and will continue to fluctuate with changing environmental conditions. Habitat heterogeneity, basin area, physicochemistry of the water, primary productivity, resources availability and historical factors are known drivers of fishes diversity (Tonn 1990; Ricklefs and Schluter 1993; Gelwick et al. 2001; Ricklefs 2004; Auber et al. 2017; Thompson et al. 2020). As Pawluk et al.

(2021) pointed out, it is important to assess the patterns in fish abundances and species richness within marine systems in order to better understand community dynamics given changing temperatures and environmental conditions and point out what potential vulnerabilities there are. Given the importance of biodiversity and their connection with productivity and conservation, it is crucial to characterize these low-studied areas (as is the case in the southernmost Texas coast) and understand the dynamics of the forage fish community that can have a major impact on the local and state economies.

This study is derived from a broader one (to be published elsewhere) focusing on the age, growth, diet, and trophic web reconstruction of *Sciaenops ocellatus* and looks at forage fishes' diversity to better understand if there are any changes due to shifting environmental factors that are continually increased by climate change. Objectives of this study were: (1) compare forage fishes' biodiversity between two sites within the LLM, a bay and a lagoon, and (2) identify variations within a single year as a driver of any changes in forage fishes biodiversity by using netting to capture and record species along the shoreline of both sites. Because of differences in basin area (the lagoon site being smaller as detailed in methods), connection to the GOM, and seagrass coverage, it is hypothesized that the bay system will have greater fishes diversity than the lagoon system. Furthermore, fishes biodiversity is expected to fluctuate throughout the year due to a combination of factors including fishes migration cycles (e.g. Livingston et al. 1976; Timmerman et al. 2021), spawning and recruitment, juveniles survivorship (Livingston et al. 1976; Morin et al. 1985; Meffe and Berra 1988; Yoklavich et al. 1991), movement and dispersal of fishes that might be affected by home ranges, and degree of connectivity as well as physical barriers (Livingston et al. 1976; Yoklavich et al. 1991; Gelwick et al. 2001).

MATERIALS AND METHODS

Study sites

Study sites are South Bay (SB) and Holly Beach (HB), both located in Cameron County, southern Texas, USA. This area has several knowledge gaps including baseline studies as compared to other geographic locations in the country. Both sites are part of the LLM, which is one of the six largest hypersaline estuarine systems in the world (Tunnell and Judd 2002; Marquez et al. 2017). The climate is categorized as semiarid and subtropical (Tunnell and Judd 2002; Marquez et al. 2017). Estuaries of the LLM are connected to the GOM at the Brazos-Santiago Pass which was created in the 1930's (Tunnell and Judd 2002; Marquez et al. 2017).

South Bay (26° 01′ 20.6″ N-97° 11′ 03.8″ W) is classified as a bay system by name only, as it is an enclosed lagoon which only connects to the Brownsville Ship Channel through a narrow opening (Figure 1). It is located south of the Brazos-Santiago Pass. It is a shallow body of water and connects to the Rio Grande River on the south end. It has an average depth of 0.85 ± 0.15 m with an area of about 14.2 km^2 (Marquez et al. 2017). Holly Beach (26° 07′ 30.5″ N-97° 17′ 48.4″ W) is classified as a lagoon system and is located north of SB and the Brazos Santiago Pass (Figure 1). It lies between the Laguna Atascosa National Refuge and the LLM with the Laguna Vista Cove on the south end (Murphy et al. 2021). It has an average depth of about 1 m and has a great seagrass bed presence. As HB is part of the LLM aquatic system, for the purposes of this study, an area of ~ 42 km^2 was estimated using Google Earth (2022). Both study sites are popular bodies of water for fishing and birding as they provide a variety of ecosystem services and a habitat for many fishes of commercial and recreational importance.

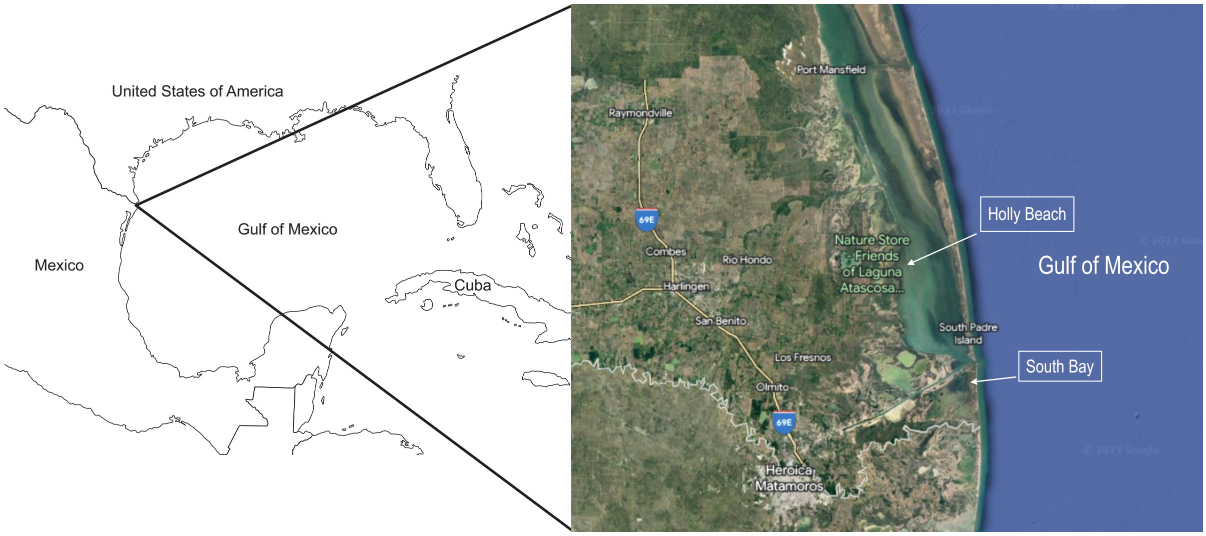

Figure 1. Gulf of Mexico map and study sites Holly Beach and South Bay located within the Lower Laguna Madre, Texas, United States of America. Map modified from Google Earth.

Sampling

Sampling procedure for this study followed the protocol from the Texas Parks and Wildlife Department (TPWD), which uses bag seines as part of their survey efforts. Bag seines utilized were made to replicate those from TPWD, which are 18.3 m long with 1.3 cm stretched nylon # 5 multifilament mesh in the bag, and 1.9 cm stretched nylon # 5 multifilament mesh in the wings and were used along the shore of both sites. Sampling effort goal was five bag seine replicates per site for a total of 20 replicates per quarter (Q), given four overall visits to each site. Due to restricted access to SB by SpaceX during rockets testing, unpredictable weather, and a set limit of 300 individual *S. ocellatus* each Q under the University of Texas Rio Grande Valley, Institutional Animal Care and Use Committee (IACUC, AUP-19-40). Bearing in mind that, in order to comply with the approved protocol under AUP-19-40, no further sampling occurred once the set number of *S. ocellatus* was achieved on each Q (i.e. 300 between both sites); hence, a balanced sampling effort was not achievable. This resulted in variable numbers in replicates per site visit, as well as sample area covered. Nonetheless, the sampling effort goal was exceeded every Q as follows: Q1 21 samples (n), Q2 n = 35, Q3 n = 36, and Q4 n = 30. For future comparison purposes to the TPWD database, sampling was diurnal and occurred during high tides. A total area of about 720 m^2 was covered at both sites. Fishes were counted and identified for each bag seine replicate. All fishes (other than *S. ocellatus*) and their count were noted and then released back into the water. For identification purposes, when needed two voucher specimens of each species were kept and taken back to the laboratory.

Statistical analyses

Fishes' data were analyzed in Primer v7, before any routine a log (abundance + 1) was necessary as determined by a shade plot as per Clarke et al. (2014), which down-weighted contributions by highly abundant species and allow low-and-mid-range species to also influence assemblage similarities calculations (Clarke and Warwick 2006). The following Primer routines and tests allowed comparisons between fish assemblages from both sites throughout the year on a quarterly basis. Natural groups of fishes at each site for every Q were identified with group-averaged cluster analysis based on Bray-Curtis similarities and non-metric multidimensional scaling (nMDS), only the latter was presented graphically (Figure 2), followed by a similarity profile (SIMPROF) test to identify genuine groups. A similarity percentage (SIMPER) test was performed to determine fishes that contributed to assemblages' dissimilarities among Qs and sites. Because there are only two sites, a one-way ANOSIM was performed on Qs. The DIVERSE routine was utilized to obtain species richness, Shannon-Wiener diversity (H' hereafter), and Jaccard evenness (J' hereafter). These metrics as well as the overall abundance (abundance hereafter) per Q at each site were compared with a model 1 two-way analysis of variance (ANOVA) unless otherwise noticed (see below). Fishes' dominance ratios (DRs) were estimated by locality for each Q and were compared graphically using descriptive statistics (mean ± standard deviations), as no further statistical analyses were deemed appropriate because of the effect of highly abundant taxa in a given Q, which skewed the fishes' dominance ratio distributions.

Prior to performing any ANOVA, fish species richness, abundance, H', and J's at each site were subjected to Q-Q plots and Kolmogorov-Smirnov tests to verify normality, while homoscedasticity was evaluated with Levene's test (Zar 1996). Fishes' abundance violated both assumptions and were subjected to a $\log_{10} + 1$ transformation (Zar 1996). Species richness was not normally distributed, but the ANOVA was deemed robust enough for such violation (Underwood 1997) and was performed on non-transformed values. Diversity was heteroscedastic and the $\log_{10} + 1$ transformation made data even less homoscedastic but as the variances difference was < 3 times, the ANOVA was deemed robust for this violation and was performed on non-transformed values. Evenness was not complaint to either assumption (i.e. normality or homoscedasticity) and $\log_{10} + 1$ transformation made it worst. In this case, the ANOVA could have been still performed as ANOVA is based on

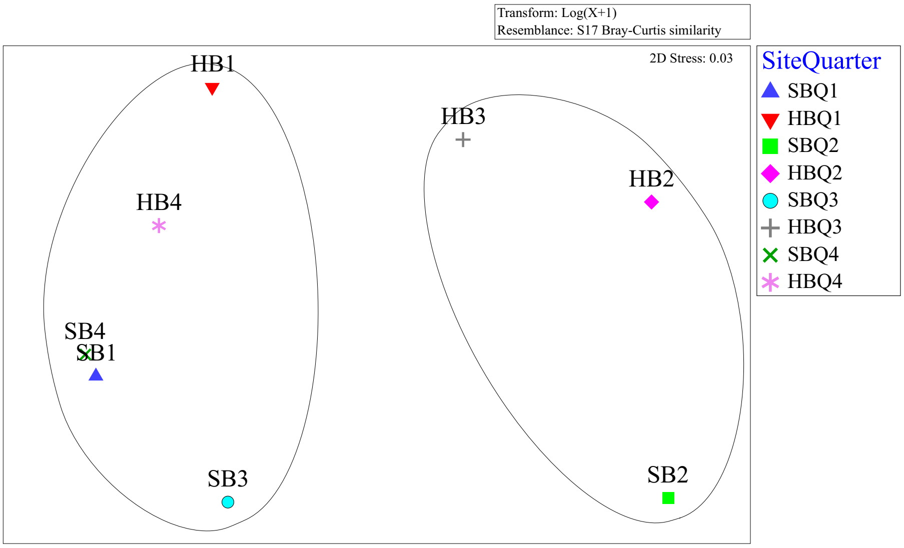

Figure 2. Non-metric multidimensional scaling plot of fishes' assemblages similarities. Ovals indicate 50% resemblance levels. Holly Beach = HB, South Bay = SB, quarter = Q. Q1 = October-December 2020; Q2 = January-March 2021; Q3 = April-June 2021; Q4 = July-September 2021.

means which conforms to the Central Limit Theorem making the assumption of normality not too critical, and the same reasoning used for H’ might have been applied to the J’ lack of homoscedasticity compliance. Hence, the non-parametric option (i.e. Kruskal-Wallis) was performed as an academic exercise only, because it is sensitive to departures from homoscedasticity (Underwood 1997). Noteworthy, Kruskal-Wallis runs only as a one-way therefore two tests were performed one for Qs and the second one for sites. A Tukey Honest Significant Difference (Tukey hereafter) test was performed when ANOVA indicated significant differences to identify the Qs responsible for them (Zar 1996). Note as there are only two sites the software does not perform this test for that variable and issues a warning, but the difference indicated by the ANOVA remains and therefore can be determined from the mean values. All parametric statistics were performed with SPSS v27.

RESULTS

A total of 32 fishes (Table 1) yielded 15,880 individuals collected during the year of sampling, 74.3% of them captured at HB. *Anchoa mitchilli*, *Cyprinodon variegatus*, *Lagodon rhomboides*, and *Micropogonias undulatus* were present year-round at both sites (Table 1). Fishes’ richness in HB was 29 with ten species only present there, while SB had 22 species, three occurring only at SB (Table 1). Species richness varied also by Q ranging from 12-16 fishes at HB with 12 species occurring in a single Q, while the range for SB was 8-14 fishes with also 12 species occurring in a single Q (Table 1).

Similarity of fishes yielded two major clusters separating at 40.2%, one cluster included Q2 from both sites as well as Q3 at HB, all other similarities occurred in the second cluster (figure not shown); however, both clusters were not significantly different from one another. Quarters were not significantly different from one another as per ANOSIM ($R = 0.417$, $p = 0.114$) supporting the SIMPROF test. Separation of Q2 was also depicted by the nMDS, with Q3 at HB in between the remaining groups (Figure 2). Similarity among samples ranged from 24.4 to 77.4%, with Qs 1 and 4 at SB being the more similar to one another; and Qs 2 and 4 at SB being more dissimilar from each other. Overall, seven or 12 fishes were needed to explain > 90% of the similarities: *L. rhomboides*, *A. mitchilli*, *M. undulatus*, *S. ocellatus*, *Eucinostomus gula*, *Lutjanus griseus*, and *Brevoortia patronus* explained the similarities between Qs 1 and 4 at SB, while *L. rhomboides*, *A. mitchilli*, *C. variegatus*, *B. patronus*, *Hippocampus* sp., *Mugil cephalus*, *Lutjanus griseus*, *Bairdiella chrysoura*, *Opsanus beta*, *Synodus foetens*, *Hemiramphus brasiliensis*, and *Fundulus grandis* explained similarities between Qs 2 and 4 at SB.

Mean ± standard deviation fishes’ richness at HB ranged from 3.27 ± 1.94 to 6.75 ± 1.81, while at SB the range was from 2.75 ± 1.04 to 3.47 ± 1.46. There were significant differences between sites ($F_{0.05\,(1,121)} = 60.66$, $p < 0.001$) with HB having greater richness than SB, and among Qs ($F_{0.05\,(3,121)} = 6.47$, $p < 0.001$) (Figure 3 A). The Tukey test indicated Q4 at HB was significantly lower than the other 3 Qs, which were not different from one another; while at SB Q4 was significantly larger than all other Qs, which were not significantly different among (Figure 3 A). However, but as expected, the interaction effect was also significant ($F_{0.05\,(3,121)} = 8.86$, $p < 0.001$).

Fishes’ abundances (mean ± standard deviation) ranged from 84.73 ± 95.24 to 268.00 ± 248.33 at HB, and from 29.00 ± 25.80 to 93.80 ± 38.26 at SB (Figure 3 B). Holly Beach had a significantly larger number of individuals ($\log_{10}$ transformed) than SB ($F_{0.05\,(1,121)} = 19.25$, $p < 0.001$), significant differences also occurred among Qs ($F_{0.05\,(3,121)} = 5.79$, $p = 0.001$), and the interaction between sites and Qs ($F_{0.05\,(3,121)} = 14.00$, $p < 0.001$). At both sites, Qs 1, 2, and 4 were not significantly different from one another,

Table 1. Fishes' richness by site and quarter (Q) presented in alphabetical order. Holly Beach = HB; South Bay = SB; Q1 = October-December 2020; Q2 = January-March 2021; Q3 = April-June 2021; Q4 = July-September 2021; Freshw. = freshwater.

Species	HB	SB	Environment[1]
Anchoa mitchilli (Valenciennes, 1848)	Q1, Q2, Q3, Q4	Q1, Q2, Q3, Q4	Euryhaline
Archosargus probatocephalus (Walbaum, 1792)	Q3, Q4		Marine/brackish
Bairdiella chrysoura (Lacepède, 1802)		Q1	Marine/brackish
Brevoortia patronus Goode, 1878	Q3	Q4	Euryhaline
Chaetodipterus faber (Broussonet, 1782)	Q3		Marine/brackish
Cynoscion nebulosus (Cuvier, 1830)	Q1, Q4		Marine/brackish
Cyprinodon variegatus Lacepède, 1803	Q1, Q2, Q3, Q4	Q2, Q3, Q4	Euryhaline
Elops saurus Linnaeus, 1766	Q2		Marine/brackish
Eucinostomus gula (Quoy and Gaimard, 1824)	Q1, Q4	Q1, Q4	Euryhaline
Fundulus grandis Baird and Girard, 1853	Q1, Q2, Q3, Q4	Q2, Q4	Freshw./brackish
Fundulus majalis (Walbaum, 1792)	Q2, Q3	Q2	Marine/brackish
Hemiramphus brasiliensis (Linnaeus, 1758)	Q1	Q4	Marine
Hippocampus sp.	Q1	Q1, Q2	
Kathetostoma albigutta Bean, 1892	Q3	Q4	Marine
Lagodon rhomboides (Linnaeus, 1766)	Q1, Q2, Q3, Q4	Q1, Q2, Q3, Q4	Euryhaline
Lucania parva (Baird and Girard, 1855)		Q3	Marine/brackish
Lutjanus griseus (Linnaeus, 1758)	Q1, Q4	Q1, Q4	Euryhaline*
Micropogonias undulatus (Linnaeus, 1766)	Q1, Q2, Q3, Q4	Q1, Q2, Q3, Q4	Marine/brackish
Mugil cephalus Linnaeus, 1758	Q1, Q2, Q3, Q4	Q2, Q3, Q4	Euryhaline*
Mugil curema Valenciennes, 1836	Q3	Q4	Euryhaline*
Oligoplites saurus (Bloch and Schneider, 1801)	Q1		Euryhaline*
Opsanus beta (Goode and Bean, 1880)	Q1, Q2, Q3, Q4	Q1, Q3	Marine
Orthopristis chrysoptera (Linnaeus, 1766)		Q4	Marine/brackish
Paralichthys lethostigma Jordan and Gilbert, 1884	Q1, Q2, Q3	Q3	Euryhaline*
Pogonias cromis (Linnaeus, 1766)	Q3, Q4		Marine/brackish
Sciaenops ocellatus (Linnaeus, 1766)	Q2, Q3	Q2	Marine/brackish
Scomberomorus maculatus (Mitchill, 1815)	Q4		Marine
Strongylura marina (Walbaum, 1792)	Q1, Q3, Q4		Euryhaline
Syngnathus louisianae Günther, 1870	Q2, Q3		Marine
Syngnathus sp.	Q1		
Synodus foetens (Linnaeus, 1766)	Q3	Q1	Euryhaline
Trachurus trachurus (Linnaeus, 1758)	Q4	Q4	Marine

[1] From Froese and Pauly (2022).

*Reported as occasional in freshwater or penetrating rivers, and thus considered euryhaline.

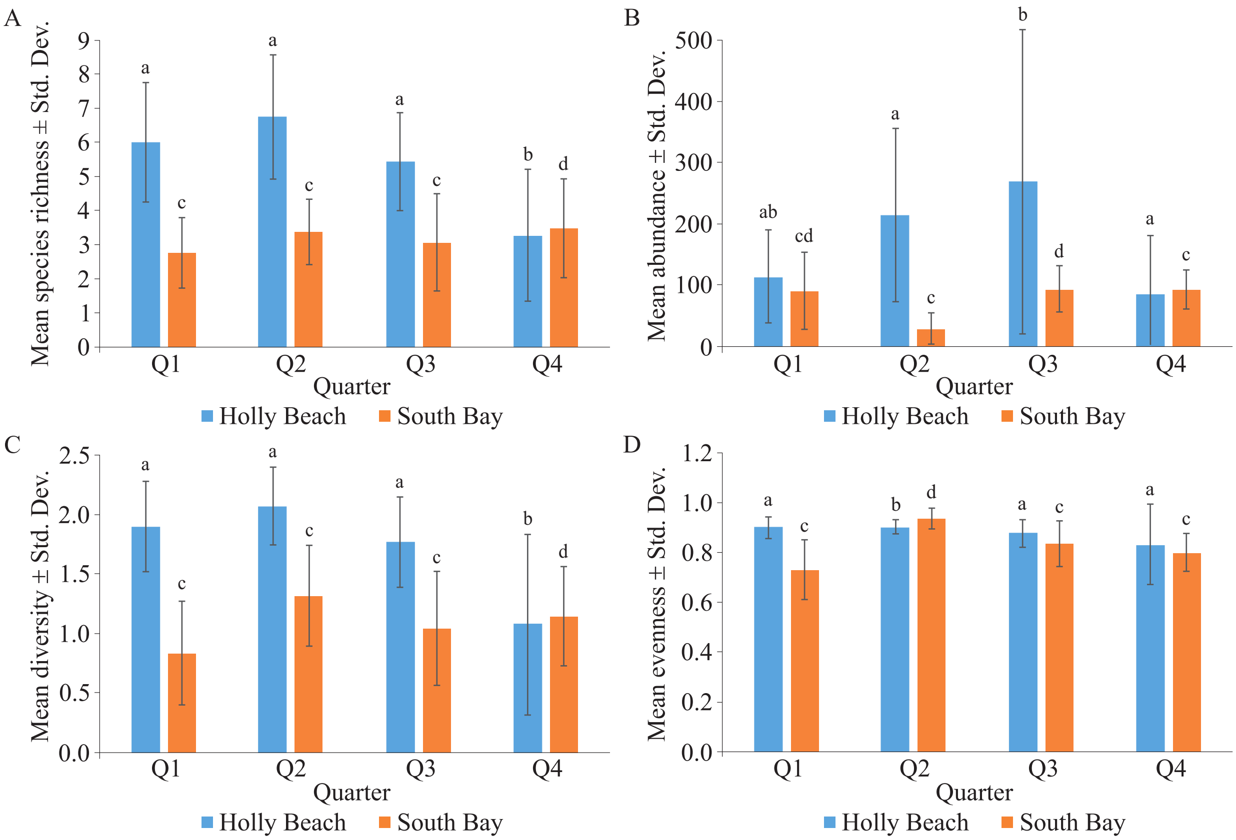

Figure 3. Mean ± standard deviation (Std. Dev., bars) metrics for each quarter (Q) in the study sites. A) Species richness, B) abundance, C) diversity, and D) evenness. Holly Beach = HB, South Bay = SB. Sample size (n) as follows: HBQ1 n = 13, SBQ1 n = 8, HBQ2 n = 16, SBQ2 n = 19; HBQ3 n = 21; SBQ3 n = 15; HBQ4 n = 15; SBQ4 n = 15. Q1 = October-December 2020; Q2 = January-March 2021; Q3 = April-June 2021; Q4 = July-September 2021.

but Q3 was significantly different than Qs 2 and 4 (Figure 3 B) as per Tukey's test.

Fishes' H' (mean ± standard deviation) at HB ranged from 0.88 ± 0.62 to 1.70 ± 0.27, while in SB ranged from 0.68 ± 0.36 to 1.09 ± 0.35 (Figure 3 C). As for the previous two metrics, there were significant differences in H' between sites ($F_{0.05\ (1,121)} = 46.55$, $p < 0.001$), among Qs ($F_{0.05\ (3,121)} = 8.32$, $p < 0.001$), and their interaction ($F_{0.05\ (3,121)} = 7.40$, $p < 0.001$) (Figure 3 C). Holly Beach once more had higher values than SB for most Qs, while the Tukey test indicated Q4 was significantly different from the other Qs, which were not different from one another at both study sites (Figure 3 C).

Mean ± standard deviation fishes' J' range at HB was 0.83 ± 0.16 to 0.90 ± 0.03, and at SB 0.73 ± 0.12 to 0.94 ± 0.04 (Figure 3 D). Fishes' J' was significantly larger at HB than at SB ($H_{0.05\ (1)} = 4.08$, $p = 0.043$), and among Qs ($H_{0.05\ (3)} = 24.28$, $p < 0.001$) (Figure 3 D). Regarding J' Q2 was significantly different than the others, which were not different from one another at both sites (Figure 3 D) as per the pairwise comparisons.

Lagodon rhomboides were overwhelmingly the more abundant fish in SB during Qs 1, 3, and 4 DR = 0.93, 0.90, and 0.93, respectively); while Q2 in SB was dominated by *M. undulatus* (DR = 0.37). In HB, the same two species were also dominant during the same Qs with *L. rhomboides*

DR = 0.69, 0.76, and 0.85 in Qs 1, 3, and 4, respectively; the DR in Q2 for *M. undulatus* was 0.39. The second highest DR (0.03) in SB for Q1 was for *E. gula* followed by *A. mitchilli* (DR = 0.02); for Q2 *A. mitchilli* had the 2nd highest DR (0.32), and *S. ocellatus* occupied the 3rd position with a DR of 0.16. *Anchoa mitchilli* had the 2nd highest DR (0.06) during Q3 in SB followed by *C. variegatus* (DR = 0.02), while the 2nd and 3rd place in the last Q were occupied by *E. gula* and *C. variegatus*, respectively. *Eucinostomus gula* also occupied the 2nd highest position with a DR of 0.14 in HB during Q1 followed by *F. grandis* (DR = 0.08); 2nd and 3rd place during Q2 were occupied by *F. grandis* (DR = 0.29) and *L. rhomboides* (DR = 0.13). Dominance was 2nd highest for *Mugil cephalus* (0.13) in HB for Q3 while *A. mitchilli* occupied 3rd place (DR = 0.007), and for the last Q *E. gula* had the 2nd highest DR (0.06) and *M. cephalus* the 3rd one (DR = 0.05). Quarter 2 was the more evenly divided in terms of fishes' dominance as the highest abundances of *L. rhomboides* resulted in high mean dominance ratio values for the other three Qs, particularly in SB (Figure 4).

DISCUSSION

In general, HB showed greater species richness, relative abundances, and H' than SB for Qs 1-3; while in Q4 SB had greater values than HB. This opposite result is likely one cause for the significant interaction effect for relative abundances and H'. As SB and HB have different habitat characteristics (e.g. basin area, connection to the GOM, seagrasses coverage, among others), the observed significant differences between sites are not surprising as HB was expected to host a greater number of fishes than SB.

Another cause for the interaction effect between sites and Qs is the expected changes in fishes' presences throughout the year, which also helps explain the significant differences observed in time. Twelve species were present only during one Q at each site. Such differences are explained by a combination of factors, e.g. fishes migration cycles (Livingston et al. 1976; Timmerman et al. 2021), spawning, recruitment, and juvenile survivorship (Livingston et al. 1976; Morin et al.

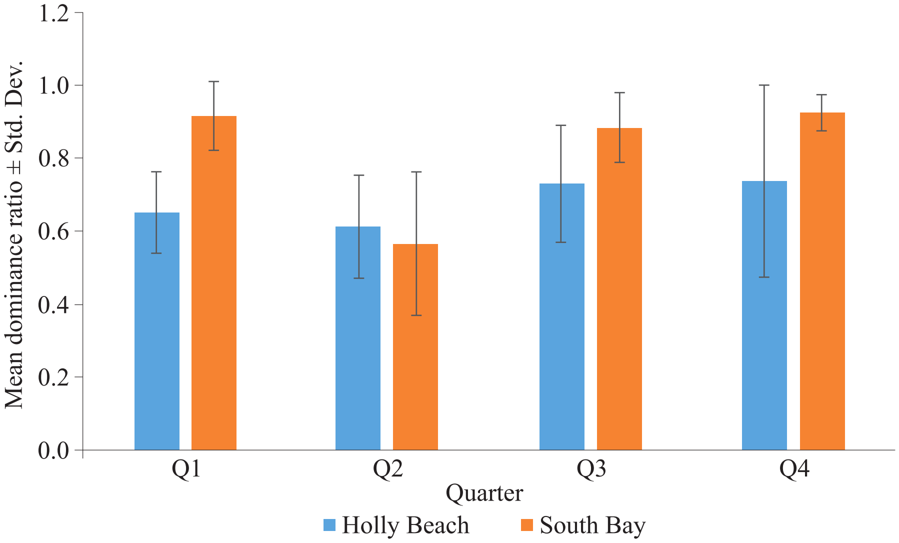

Figure 4. Mean ± standard deviation (Std. Dev., bars) fishes dominance ratio for each quarter (Q) in the study sites. Abbreviations and sample sizes as in Figure 3.

1985; Meffe and Berra 1988; Yoklavich et al. 1991), movement and dispersal of fishes which might be affected by physical barriers, home ranges, and degree of connectivity (Livingston et al. 1976; Yoklavich et al. 1991; Gelwick et al. 2001).

As HB is not only more open to the GOM but also has a larger area than SB, it is able to support a more diverse ichthyofauna with the following species only occurring there: *Archosargus probatocephalus*, *Chaetodipterus faber*, *Cynoscion nebulosus*, *Elops saurus*, *Oligoplites saurus*, *Pogonias cromis*, *Scomberomorus maculatus*, *Strongylura marina*, *Syngnathus louisianae*, and *Syngnathus* sp. Out of these ten fishes, five were present during a single Q. Three of them were reef-associated species: *Chaetodipterus faber* occurred only during the spring (i.e. Q3) and it is known to be present in estuaries, particularly as juveniles (Froese and Pauly 2022); while *E. saurus* present in winter (i.e. Q2) are known to occur in shallow onshore areas with common occurrence of juveniles in lagoons (Cervigón et al. 1992); in fall (i.e. Q1) *O. saurus* was found, and are known to prefer turbid waters when entering estuaries (Fischer et al. 1995). *Syngnathus* sp. was also present in Q1. Organisms in this genus are associated with aquatic vegetation including seagrasses, noteworthy its congeneric (*S. louisianae*) occurred in the two subsequent Qs and only at HB. For summer (i.e. Q4) the presence of *S. maculatus* was recorded. They are known to be moving along the Mexican coast (which is very nearby the study sites) between August and November (Froese and Pauly 2022).

The three fishes that only occurred at SB were present in a single Q: *Bairdiella chrysoura* (Q1), *Lucania parva* (Q3), and *Orthopristis chrysoptera* (Q4). The former species likely was using the enclosed system as a nursery and/or feeding area, as they are known to move into estuaries during the summer months (Froese and Pauly 2022); while *L. parva* benefitted from the presence of seagrasses, which are denser than at HB but were not quantified for the purposes of this study. Both species might have been present but not captured in other Qs. This possibility is less likely for *O. chrysoptera* which are mainly nocturnal and apparently avoid low water temperatures as they seasonally migrate to deeper waters during winter (Darcy 1983). While for *B. chrysoura*, the possibility is very feasible as it is known not only to feed but also to mature and reproduce within estuaries, and hence considered an estuarine resident (Grammer et al. 2009). *Lucania parva* is also categorized as an estuarine species, known to prefer areas with high seagrasses canopies that may provide protection from predators and perhaps a larger amount of epibenthic prey items that attach to the seagrasses surface areas (Tomoleoni 2007). Many studies have shown that vegetated habitats tend to rear higher densities of forage fishes and other organisms than those that are non-vegetated sandy or muddy bottoms (Summerson and Peterson 1984; Connolly 1994; Jenkins et al. 1997; Rozas and Minello 1998; Sheridan and Minello 2003), but as the goals of the present study were not to contrast vegetated versus non-vegetated sites neither to estimate seagrasses densities at the studied sites, the subject is not further discussed.

Aside from the aforementioned factors associated with fishes movements (migration, dispersal), ontogenetic (reproduction, growth), survivorship, or diel habits, one other cause for not capturing the eight fishes (five in HB and three in SB) in other Qs could be related to the fishing gear (i.e. bag seine) used. Rozas and Minello (1997) suggested that enclosure devices have a greater catch efficiency of small nekton than towed nets in shallow estuarine habitats. However, see Layman and Smith (2001) for a different perspective. Noteworthy, gear was selected as part of the larger study focused on the age, growth, diet, and trophic web reconstruction of *S. ocellatus* and adopted from the TPWD sampling protocol, which uses bag seines as part of their survey efforts. As the present results will serve as a baseline study to compare outcomes to TPWD presented elsewhere, it was necessary to sample with this gear. Nonetheless, even with the inherent bag seine sampling bias and limitations, four species (*A. mitchilli*, *C. variegatus*, *L. rhomboides*, and *M. undulatus*) use both studied sites as their permanent home by being present year-round. Three of these fishes are generally euryhaline.

In terms of fishes' relative abundances, 11,795 and 4,085 individuals were captured at HB and SB, respectively. Temporally, the greater abundances occurred in Q3 at both sites, then changed depending on location with the 2nd largest abundances at HB during Q2 and Q4 at SB. Thus, the spring (i.e. Q3) seems to be the more beneficial season at both sites but as this is a single-year study such a statement may not hold when multiple years are accounted for. Nonetheless, for the purposes of the results here presented, 47.7% and 34.4% of the fishes' abundances occurred at HB and SB respectively during the spring. *Lagodon rhomboides* was mainly responsible for this pattern with 4,271 individuals at HB and 1,267 at SB. Noteworthy, the species was least abundant during Q2 (~ winter), and as mentioned before occurred year-round at both sites. Hence, *L. rhomboides* had higher abundances during spring-summer, which was also reported for the Mad Island estuary in Texas (Akin et al. 2003), and in Tampa Bay, Florida (Chacin et al. 2016).

Lagodon rhomboides post-larvae arrive in the GOM and southeastern USA estuaries during winter as they reproduce offshore (Darcy 1985), hence the higher abundances during spring to fall (i.e. ca. Qs 3, 4, and 1) of one of the most widely distributed and common fishes in the USA (Hoese and Moore 1998), which follows such ontogenetic cycle. This also explains its lesser abundances during winter (Q2). Furthermore, Stoner (1980) indicated *L. rhomboides* as important mesograzers in the Laguna Madre seagrass beds being abundant from early spring to fall, while Hoss (1974) observed a minimal overwintering of the *L. rhomboides* population in North Carolina's estuarine waters as the majority of the fish migrated offshore upon the onset of colder water temperatures.

Fish assemblages similarities formed two clusters (not shown), but there was no significant difference between them. Nonetheless, the group formed in Q2 for both sites with Q3 at HB in the nMDS is likely the result of greater variability in the abundances of taxa, with the two higher abundances at HB and the least abundance at SB. This exchange of abundance values among seasons is complementary to the more abundant fishes which might have contributed to the lack of significant difference found and helps to also explain the interaction effect in abundances and diversity (discussed above) resulting in the generally observed equitability. However, winter conditions should not be disregarded and likely allowed some degree of grouping of both sites during Q2.

Although DRs were variable throughout the year and between sites, *L. rhomboides* was overwhelmingly more abundant from spring to fall at both sites, while *M. undulatus* was more dominant in winter (Q2) with a DR of 0.37 at SB and 0.39 at HB. As mentioned in the results, the 2nd and 3rd positions based on DRs varied among species and might have resulted from resource partition throughout the year. Likely migration offshore for reproduction purposes, decreasing temperatures, or both factors combined, *L. rhomboides* (see above) allowed the rise of another year-round resident to become dominant in Q2. Akin et al. (2003) also found seasonal changes in estuarine fishes assemblages in Mad Island Marsh, Matagorda Bay, Texas with *M. undulatus* being more abundant from December-April when temperatures were low, while *L. rhomboides* was abundant during spring and summer. Resource partitioning could also be exemplified by *A. mitchilli* and *L. rhomboides*, regarding the DRs of the former species tended to be the 2nd most abundant in half of the Qs at SB. Although habitat zonation was not the focus of this study, Gelwick et al. (2001) identified zones based on depth, salinity, and dissolved oxygen gradients also in Matagorda Bay and indicated *A. mitchilli* occupied a different zone than *L. rhomboides*.

Lastly, six of the eight more dominant species are important for fisheries (*A. mitchilli*, *C. variegatus*, *L. rhomboides*, *M. undulatus*, *M. cephalus*, and *S. ocellatus*) and were present year-round highlighting the importance of both study sites as important in their life cycle, although *M. cephalus*, and *S. ocellatus* were not always captured by the bag seines. According to Froese and Pauly (2022) these species as fishery resources have the following uses: 1) major relevance as bait *A. mitchilli*, *C. variegatus* and *L. rhomboides*; 2) considered game fishes *L. rhomboides*, *M. undulatus*, *M. cephalus* and *S. ocellatus*; 3) commercial *M. undulatus* and *M. cephalus*, while *L. rhomboides* and *S. ocellatus* are used in minor extent; 4) aquarium fishes' exploitation *C. variegatus* and *S. ocellatus*; and 5) used in aquaculture *M. undulatus*, *M. cephalus*, and *S. ocellatus*.

Although the present study only encompassed one-year, it was evident that both sites are interconnected as no fishes similarities difference was found, nonetheless their multiple differences (i.e. basin area, seagrasses coverage, connection to the GOM, etc.) resulted in significant differences in fishes richness, abundances, H', and J' suggesting differences in habitat quality, or at the very least variation in the availability of habitat types, which are known to contribute to differences in fish diversity attributes (Meffe and Berra 1988). It also highlights the importance of HB and SB as a permanent residency for several species that were present year-round, including six fishes relevant to fisheries. This calls for further studies in this relatively abandoned area (compared to other USA GOM ones), particularly as global warming and increasing sea-level are expected to impact the coastal areas likely impacting not only resources useful to feed the increasing human population but also affecting forage fishes which should be managed at the very least as a group because of their relevance as an energy source within any marine food web.

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ORIGINAL RESEARCH

Assessing the ecological vulnerability of Western Atlantic marine benthic gastropods

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ABSTRACT. Assessing the extinction risk in marine invertebrates poses serious challenges to conservation biology, due to the magnitude of marine biodiversity, the inaccessibility of most of the marine realm, and the lack of appropriate data on population dynamics and ecology for most species. However, simple life history traits have a huge potential for preliminary screening criteria for assessing large numbers of species whose status is harsh or impossible to evaluate. Body size and trophic position could be strong predictors of extinction risk providing a general framework for the assessment of species vulnerability. We analyzed the Body Size-Trophic Position (BS-TP) relationship along 1,067 genera representing 4,256 nominal species of western Atlantic benthic gastropods. We found that a carnivore diet characterizes 67% of the genera and that, supporting theoretical predictions, the probability of being carnivores as a function of size showed a unimodal trend. For species with adult body sizes larger than 5 cm, a negative association between trophic position and body size was detected. This result points to an energetic restriction for the viability of large species, implying that organisms placed near the BS-TP boundary are extremely vulnerable to environmental changes. With this result, 109 genera from 42 families of carnivore gastropods and 33 genera from 19 families of herbivore gastropods that may be more vulnerable from the analyzed perspective were identified and ranked. Supporting these results, while the most vulnerable genera are not represented in global IUCN assessments, all our 'top 10' vulnerable families are being considered in National or Regional Red Lists. Prior to conducting regional or global conservation assessments for invertebrate taxa, screening methods should be strongly considered.

Key words: Extinction risk, body size-trophic position relationship, conservation biology.

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Evaluación de la vulnerabilidad ecológica de los gasterópodos bentónicos marinos del Atlántico Occidental

RESUMEN. Evaluar el riesgo de extinción de los invertebrados marinos plantea serios desafíos para la biología de la conservación, debido a la magnitud de la biodiversidad marina, la inaccesibilidad de la mayor parte del ámbito marino y la falta de datos apropiados sobre la dinámica de población y la ecología de la mayoría de las especies. Sin embargo, los rasgos simples de la historia de vida tienen un gran potencial como criterios preliminares de selección para evaluar un gran número de especies cuyo estado es difícil o imposible de evaluar. El tamaño del cuerpo y la posición trófica podrían ser fuertes predictores del riesgo de extinción proporcionando un marco general para la evaluación de la vulnerabilidad de las especies. Analizamos la relación Tamaño Corporal-Posición Trófica (BS-TP) a lo largo de 1.067 géneros que representan 4.256 especies nominales de gasterópodos bentónicos del Atlántico Occidental. Encontramos que una dieta carnívora caracteriza al 67% de los géneros y que, apoyando las predicciones teóricas, la probabilidad de ser carnívoros en función del tamaño mostró una tendencia unimodal. Para especies con tamaños corporales adultos mayores de 5 cm, se detectó una asociación negativa entre la posición trófica y el tamaño corporal. Este resultado apunta a una restricción energética para la viabilidad de las especies grandes, lo que implica que los organismos ubicados cerca del límite BS-TP son extremadamente vulnerables a los cambios ambientales. Con este resultado, se identificaron y clasificaron 109 géneros de 42 familias de gasterópodos carnívoros y 33 géneros de 19 familias de gasterópodos herbívoros que pueden ser más vulnerables desde la perspectiva analizada. Respaldando estos resultados, mientras que los géneros más vulnerables no están representados en las evaluaciones globales de la UICN, todas nuestras “10 principales” familias vulnerables están siendo consideradas en las Listas Rojas Nacionales o Regionales. Antes de realizar evaluaciones de conservación regionales o globales para taxones de invertebrados, se deben considerar seriamente los métodos de detección.

Palabras clave: Riego de extinción, relación tamaño corporal-posición trófica, biología de la conservación.

INTRODUCTION

Despite the widespread global threats to marine ecosystems (Halpern et al. 2007), rates of registered marine neo-extinctions have been so far relatively low, with a 9-fold lower marine extinction rate compared to terrestrial systems (Webb and Mindel 2015). In fact, only five marine mollusc species or subspecies have been mentioned as possible extinct in recent historical times (Dong et al. 2015). However, the pace of marine habitat deterioration is accelerating, thus increasing already apparent threats to marine biodiversity, with nearly 66% of the ocean and 77% of national jurisdictions showing increased human impact (Halpern et al. 2015). Further, it should be noticed that only a small number of marine animals has been evaluated by the IUCN, and many assessed species were determined to be data deficient. Thus, reported numbers of extinct and endangered marine fauna should be considered as conservative (Régnier et al. 2009; Pimm et al. 2014).

Gastropods are an incredibly diverse and widespread group, with representatives found in virtually all aquatic and terrestrial environments, ranging from shallow to deep regions of the ocean, freshwater, and most land areas. Nevertheless, the ocean remains their predominant habitat, with the highest number of species concentrated in marine benthic environments. Gastropod species have a variety of different feeding styles. Some species are seaweed-eating herbivores or suspension feeders, while others are predatory carnivores or internal parasites (Todd 2001). Most aquatic gastropods spend adult life in the benthic realm, from intertidal rocky shores to abyssal plains and hydrothermal vents. The evolutionary success of gastropods can be largely attributed to the structural and functional plasticity of the feeding apparatus (Purchon 1977; Kohn 1983).

To date, only 11,2% species of gastropods in the IUCN red list are marine. Most of these species are represented in the Red List owing to the first comprehensive global assessment of a marine taxon, namely the 632 valid species of the tropical marine gastropod Genus *Conus* (Peters et al. 2013). However, there is a huge potential for simple life history traits to be used as preliminary screening criteria for the assessment of large numbers of species whose status is harsh or impossible to evaluate, such as the 32,000-40,000 known described species and the estimated 85,000-105,000 undescribed species in marine Gastropoda (Appeltans et al. 2012).

In this vein, body size is closely and predictably related to a wide array of species traits, thus synthesizing a large amount of biological information (Brown et al. 2004). Larger animals live longer, expend more energy, and have higher metabolic rates, affecting resource demands and population growth rate and density (McNab 2002; Brown et al. 2004; White et al. 2007). Additionally, the hierarchy in trophic interactions, in which free-living predators consume smaller prey, is a well-reported empirical pattern and a main determinant of food web structure

(Brose et al. 2006a, 2006b). Congruently, it was found that extinction threat for molluscs in modern oceans is strongly associated with large body size, whereas past extinction events were non-selective or preferentially affected smaller-bodied taxa (Payne et al. 2016). In addition, whereas habitat zone and feeding mode do not appear to be associated with threats in the modern ocean, previous mass extinctions have disproportionately removed pelagic species. This suggests that organisms that live in the benthic realm may face the same threats as their open sea nektonic and planktonic counterparts.

When the phylogenetic, temporal or spatial scales are large enough, a hump-shaped relationship between trophic position and body size is expected (Arim et al. 2007a) and reported (Burness et al. 2001, 2016; Segura et al. 2015a, 2016). Despite this, there have been numerous reports of positive relationships within taxonomic groups. (Arim et al. 2010; Romanuk et al. 2011). The BS-TP relationship would be positive as morphological restrictions on consumption disappear at larger sizes; however, the relationship would be negative because high trophic positions have increased energetic demands and decreased resources (Arim et al. 2007a). Positive correlations arise since larger sizes can provide several advantages, including scape from predation and/or the ability to engage in more ‘daring’ behaviours, which can expand the range of available prey. With body size comes an increase in the ability to capture and dominate prey, the maximum distance between meals (in space or time), and the length of the digestive tract (resulting in longer digestion times and more resources extracted per gram of prey consumed), which translates into greater processing opportunities. (McNab 2002). This may be enhanced by the also increasing absolute size of the organs associated with prey (and predator) identification and thus the species ability to differentiate between resources and distances and detection thresholds in the environment (Pawar 2015). All these factors led to an important expansion of the quantity and quality of resources that can be exploited. However, the negative relationship often found at the extreme of body-size distributions may imply that species placed near the boundary are extremely vulnerable to any shift in resource availability, which could drive these species to extinction. This is of utmost importance for conservation biologists, since most processes related with biodiversity loss (e.g. fragmentation, pollution, overfishing, etc.) produce said shifts in resource availability and quality (Segura et al. 2015b, 2016). In this sense, there may be important conservation applications for identifying species and/or clades that are susceptible to energetic constraints.

Most of the published examples on BS-TP focus on taxonomically restricted assemblages, typically freshwater or marine fishes (e.g. Layman et al. 2005; Akin and Winemiller 2008; Lucifora et al. 2009; Arim et al. 2010; Romanuk et al. 2011; Segura et al. 2015b; Burress et al. 2016; Ou et al. 2017; Dantas et al. 2019). Further, BS-TP curves may show non-trivial idiosyncratic patterns according to clade identity, feeding ecologies and the broader environmental setting. However, no study has analysed the BS-TP relationship for marine gastropods to date. Gastropods span four orders of magnitude in linear dimensions and eight orders in mass (volume). From Triphoridae, presenting adult sizes generally ranging between 2-10 mm, with a few species exceptionally reaching 40-50 mm (Albano et al. 2011), to *Srynx aruanus*, the largest living gastropod (more than 90 cm maximum adult size), marine gastropods are a remarkably well suited group to study the BS-TP relationship. Further, gastropods exploit a wide array of feeding ecologies, often very conserved at genus, family, or even superfamily level. This implies that a feeding strategy may be more that reasonably inferred given the taxonomic identity of a given species. In the present study, we evaluated the relationship between body size and trophic position along genera of western Atlantic marine benthic gastropods. By detecting a hump-shaped pattern that support energetic constraints, species prone to be affected by the ongoing change in the energetic scenario, e.g. productivity, resource diversity and distribution, temperature, pollutants, among others, were identified. Finally, results were contrasted to the existing conservation assessments for marine gastropods.

MATERIAL AND METHODS

Database structure

Species-level data and associated taxonomy for western Atlantic benthic gastropods were obtained from Malacolog 4.1.1, a database created for research on the systematics, biogeography and diversity of molluscs (Rosenberg 2009). Malacolog geographical coverage ranges from Greenland to Antarctica, attempting to document all names that have ever been applied to marine molluscs in the western Atlantic and providing species identity and taxonomy, maximum adult length (hereafter body size), bathymetric and geographic ranges and relevant references supporting each assignment. However, there is no currently available dietary information in this database.

Dietary information

Species-level information derived from Malacolog was later combined with dietary information based on Todd (2001), derived and modified from the trophic classifications of Hughes (1980) and Taylor and Reid (1984) for Neogene Neotropical Gastropds. This trophic classification recognizes seven categories: Predatory carnivores, browsing carnivores, herbivorous omnivores, herbivores, herbivores on rock, rubble or coral substrates, herbivores on plant or algal substrates, and suspension feeders (Table 1). Each species in the Malacolog database was assigned to one of the above-described categories combining them on the general categories of Carnivore-Non Carnivore (Arim et al. 2007b, 2010; Segura et al. 2016).

Data analysis

Considering that the feeding ecology is highly conserved at generic level, the BS-TP analysis was analysed at this taxonomic resolution. The trophic position of each genera (carnivorous versus non-carnivorous) was linked to the mean body size of the genera. The occurrence of carnivorous genera was related to the average body size using a logistic regression (Zuur et al. 2009). Three logistic models were fitted to: i) a model considering only a constant intercept, in which diet and body size are independent; ii) a model that included the effect of body size, reflecting a monotonic association between variables; and iii) a model with body size and its quadratic value as independent variables, considering the theoretical expectation of a humped association between the probability of being carnivorous and body size (Arim et al. 2007a). Models were ranked from their AIC values and the weight of evidence: $w_i = \exp(-0.5 \cdot (AIC_i - \min(AIC))/\sum \exp(-0.5 \cdot (AIC_i - \min(AIC))$ (Burnham and Anderson 2002). Model weights indicate the probability that the model is the best for the data in comparison to the other models considered.

Priorities for conservation

Genera were ranked in order to identify conservation priorities. The first component of the ranking was based on the difference between the maximum body size in the dataset and the mean body size for each genus. Specifically, the calculation involves subtracting the mean body size from the maximum body size, resulting in a numerical value that represents the difference between the two measurements. This difference was calculated for each genus, allowing for comparisons of the size variation within and between different genera. Thus, the largest carnivorous or non-car-

Table 1. Diet categories for Gastropoda used in this study, based in Hughes (1980), Taylor and Reid (1984), and Todd (2001).

Non carnivores	Carnivores
Herbivorous omnivores: browsing macroherbivores with unselective omnivory, typically of epifauna attached to macroalgae.	Predatory carnivores: predators that consume entire sedentary or mobile macro-organisms, killing them in the process and also selective foraminifera ingesters (foraminiferivores). Include scavengers which, with scant exceptions, display predatory characteristics. These organisms possess the ability to modulate their feeding behaviour in response to the availability of carrion.
Herbivores on fine-grained substrates: microalgivores, detritivores, microphages and unselective deposit feeder. Also included here is a miscellany of herbivorous non-HR and HP categories, including those living on wood or mangrove substrates.	Browsing carnivores: predators that consume sedentary, clonal animals such as corals and cnidarians, sponges, and ascidians, without causing their immediate death, fall under this category. Additionally, the group includes ectoparasites that live on larger sedentary or mobile prey.
Herbivores on rock, rubble or coral substrates: microalgivores.	
Herbivores on plant or algal substrates: micro-and macroalgivores and detritivores on macroalgal and seagrass substrates.	
Suspension feeders: includes taxa feeding solely or dominantly upon suspended particles, including mucociliary feeders.	

nivorous genus was assigned a rank value of 1. The ranking then proceeds with the assumption that the number of species within genera is negatively correlated with extinction risk and takes into account the species richness within each genera. As a result, less speciose genera will be ranked higher at any given body size. The analysis was done for both carnivores and non-carnivores separately.

Online search on conservation status

Finally, the overlap between genera/families here identified was assessed 1) on a global scale with the IUCN red Lists Global Assessment, and 2) on a regional scale with other non-IUCN national or regional assessments or national red lists from countries within the western Atlantic Ocean, when available.

RESULTS

The database included data on maximum reported adult body size and dietary information for 4,256 species belonging to 1,067 genera of western Atlantic benthic gastropods. Once the holoplanktonic gastropods were removed, the database consisted of 1,047 genera, with 350 genera (33%) classified as non-carnivores and 697 genera (67%) classified as carnivores. The distribution of species richness within genera was highly skewed, with approximately 43% of the genera being monospecific, while the maximum generic diversity corresponded to *Conus*, with some 121 species.

Both carnivorous and non-carnivorous species covered a large range of overlapping body sizes (Figure 1 A). However, the probability density of carnivorous genera surpassed that of herbivorous at intermediate body sizes. This trend is particularly evident in the logistic regression analysis (Figure 1 B). A quadratic model in which carnivorous incidence is maximum at intermediate body sizes was the one that best matched the data. This model presented the lower AIC values and it associated weight of evidence outperformed alternative lineal or monotonic models ($w_{quadratic} = 0.999$; $w_{linear} = 7.2e\text{-}06$; $w_{intercept} = 5.9e\text{-}26$). This result supports the existence of an association between the incidence of carnivorous genera and body size, and also that this association involves a hump-shaped relationship (Figure 1 B).

Once identified the theoretical threshold after which energetic constraints operate (around 5 cm maximum adult body size) and ranked species as previously described, 109 genera from 42 families of carnivore gastropods and 33 genera from 19 families of herbivore gastropods that may be more vulnerable from the analyzed perspective were classified. Among the overall ranking, seven out of 10 genera assigned top priorities were carnivorous, the exception being *Titanostrombus*, *Aliger* and *Syphonota* (Table 2). *Titanostrombus*, *Syphonota, Aliger*, *Lentigo*, *Cittarium*, *Bursatella*, *Macrocypraea*, *Dolabrifera*, *Entemnotrochus* and *Aplysia* were the most vulnerable of the herbivorous genera (Table 3). *Triplofusus*, *Charonia*, *Zidona*, *Pachycymbiola*, *Turbinella, Adelomelon*, *Cassis, Pugilina*, *Platydoris* and *Pleuroploca* species ranked amongst the more threatened carnivorous genera.

Online search on conservation status

The IUCN currently lists 643 species of marine gastropods. From these, as mentioned above, 617 species belong to the Genus *Conus* (Peters et al. 2013). Data deficient and least concern species

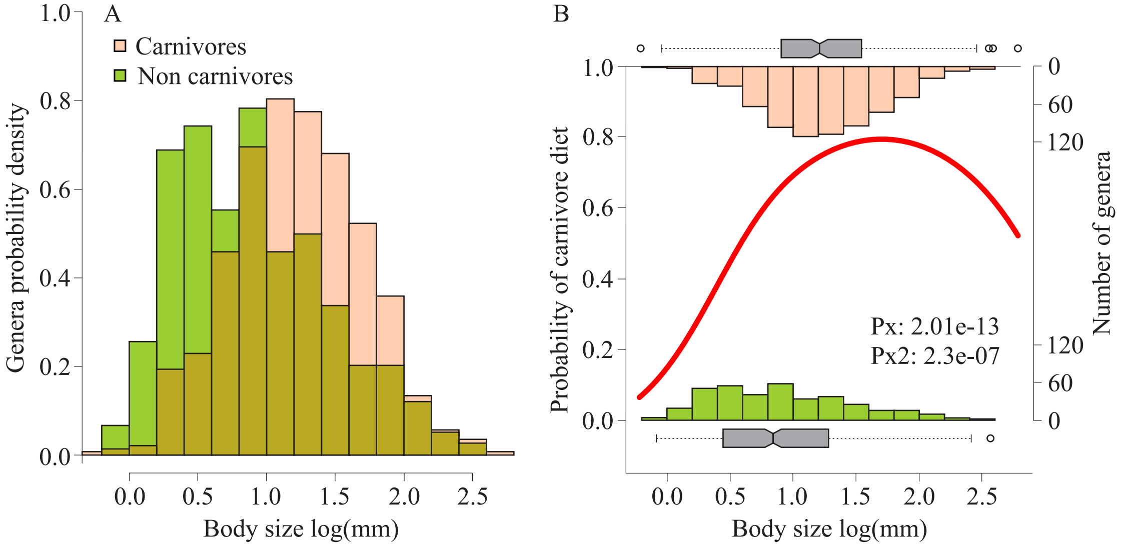

Figure 1. Size-frequency distribution for carnivorous and non-carnivorous gastropod genera (A) and the probability density of a carnivorous diet from logistic regression analysis (B).

Table 2. Marine gastropod genera most affected by energetic constraints, based in species richness (SR) within genera and average maximum adult size. C = carnivores; H = non-carnivores.

Family	Genus	Species richness	Mean size (cm)	Diet	Rank
Fasciolariidae	*Triplofusus*	1	609	C	1
Strombidae	*Titanostrombus*	1	380	H	2
Charoniidae	*Charonia*	2	382	C	3
Volutidae	*Zidona*	1	270	C	4
Volutidae	*Pachycymbiola*	2	200	C	5
Volutidae	*Adelomelon*	3	362	C	6
Turbinellidae	*Turbinella*	2	280	C	7
Cassidae	*Cassis*	3	288	C	8
Aplysiidae	*Syphonota*	1	170	H	9
Strombidae	*Aliger*	2	274	H	10

Table 3. Non-carnivore marine gastropod genera most affected by energetic constraints.

Higher clade	Number of families	Family	Genus	Species richness
Aplysioidea	2	Aplysiidae	*Syphonota*	1
			Bursatella	1
			Aplysia	6
		Dolabriferidae	*Dolabrifera*	1
Cypraeoidea	1	Cypraeidae	*Macrocypraea*	2
Pleutotomarioidea	1	Pleurotomariidae	*Entemnotrochus*	2
Stromboidea	1	Strombidae	*Titanostrombus*	1
			Aliger	2
			Lentigo	1
Trochoidea	1	Trochidae	*Cittarium*	1
Total	6			18

accounts for ca. 90% of the assessed species. Taxonomically, nine families are represented (Table 4), although most of the families include mainly freshwater and/or brackish species (e.g. Stenothyridae and Hydrobiidae). However, 39 species from 16 families are represented in regional and/or national assessments (Table 5). Results were retrieved from Rio Grande do Sul, Brazil (ICMBio 2018), Guatemala (CONAP no date), Colombia (Ardila et al. 2002) and Venezuela (Rodríguez et al. 2015). Scientific names provided in Table 5 were updated using the latest nomenclature available in the World Register of Marine Species WORMS (Ahyong et al. 2023), and some names may differ from those utilized in the original publication.

Table 4. Families of marine gastropods represented in the IUCN Red List as data deficient (DD), least concern (LC), near threatened (NT), vulnerable (VU), endangered (EN), and critically endangered (CR).

Family	DD	LC	NT	VU	EN	CR	Total
Assimineidae	2	2	0	0	0	0	5
Conidae	85	465	25	25	11	3	617
Ellobiidae	3	0	0	0	0	0	3
Haliotidae	0	0	0	0	0	1	1
Hydrobiidae	0	1	0	0	0	0	1
Iravadiidae	0	1	0	0	0	0	1
Neritidae	1	7	0	0	0	0	8
Stenothyridae	1	4	0	0	0	0	5
Thiaridae	0	2	0	0	0	0	2
Total	92	482	25	25	11	4	643

Table 5. Western Atlantic Marine Gastropods species included in available national assessments as data deficient (DD), least concern (LC), near threatened (NT), vulnerable (VU), endangered (EN) and critically endangered (CR). Scientific names may differ from those originally published. See references in the text.

Family	Species	Red list category	Country
Cassidae	*Cassis flammea*	VU	Colombia
Cassidae	*Cassis madagascariensis*	VU	Colombia
Cassidae	*Cassis madagascariensis*	EN	Guatemala
Cassidae	*Cassis tuberosa*	VU	Colombia
Charoniidae	*Charonia variegata*	DD	Brazil
Charoniidae	*Charonia variegata*	VU	Colombia
Columbellidae	*Anachis coseli*	VU	Colombia
Cypraeidae	*Muracypraea mus*	VU	Venezuela
Cypraeidae	*Propustularia surinamensis*	VU	Colombia
Fasciolaridae	*Fasciolaria tulipa*	EN	Guatemala
Melongenidae	*Melongena melongena*	VU	Guatemala
Melongenidae	*Melongena patula*	VU	Guatemala
Melongenidae	*Pugilina morio*	LC	Brazil
Olividae	*Olivancillaria contortuplicata*	CR	Brazil
Olividae	*Olivancillaria teaguei*	CR	Brazil
Olividae	*Olivancillaria vesica vesica*	NT	Brazil
Olividae	*Olivancillaria auricularia*	DD	Brazil
Olividae	*Olivella formicacorsii*	DD	Brazil
Cymatiidae	*Cymatium femorale*	DD	Brazil

Table 5. Continued.

Family	Species	Red list category	Country
Strombidae	*Aliger gallus*	DD	Brazil
Strombidae	*Aliger gigas*	VU	Colombia
Strombidae	*Aliger gigas*	VU	Guatemala
Strombidae	*Aliger gigas*	VU	Venezuela
Strombidae	*Titanostrombus goliath*	VU	Brazil
Strombidae	*Macrostrombus costatus*	VU	Brazil
Strombidae	*Macrostrombus costatus*	VU	Guatemala
Strombidae	*Macrostrombus costatus*	VU	Brazil
Strombidae	*Strombus pugilis*	VU	Guatemala
Strombidae	*Titanostrombus goliath*	VU	Brazil
Tegulidae	*Cittarium pica*	VU	Colombia
Tegulidae	*Cittarium pica*	VU	Venezuela
Terebridae	*Hastula cinerea*	LC	Brazil
Tonnidae	*Tonna galea*	LC	Brazil
Tonnidae	*Tonna pennata*	DD	Brazil
Turbinellidae	*Turbinella angulata*	EN	Guatemala
Turbinellidae	*Turbinella laevigata*	DD	Brazil
Vermetidae	*Petaloconchus myrakeenae*	CR	Brazil
Volutidae	*Adelomelon beckii*	DD	Brazil
Volutidae	*Adelomelon riosi*	DD	Brazil
Volutidae	*Adelomelon ancilla*	NA	Brazil
Volutidae	*Odontocymbiola americana*	LC	Brazil
Volutidae	*Odontocymbiola simulatrix*	DD	Brazil
Volutidae	*Pachycymbiola brasiliana*	LC	Brazil
Volutidae	*Voluta ebraea*	DD	Brazil
Volutidae	*Voluta musica*	VU	Venezuela
Volutidae	*Zidona dufresnei*	LC	Brazil

DISCUSSION

The present study contributes to both applied marine conservation initiatives and food web theory. A complementary approach useful for the identification and prioritization of a number of gastropod genera was derived from the empirical evidence supporting the predicted humped trend between organism trophic position and body size in benthic marine gastropods.

Theoretical implications

The expected trophic position trend along the body size gradient was significant and covered a large variation in the proportion of carnivorous species. However, it has to be noted that carnivorous diets do not reach a zero incidence among larger gastropods, as reported for other taxa as mammals, birds, and fishes (Arim et al. 2011; Segura et al. 2016). This suggests that in spite of being a strategy that became progressively more difficult to sustain, it represents a frequent strategy even among the larger gastropod species.

It was concluded that larger species were considered as particularly vulnerable to extinction. The claim that large consumer at higher trophic position are particularly vulnerable to extinction is not new (May et al. 1995). However, trophic position and body size were considered as positively related, thus providing redundant information for vulnerability assessments. Still, the detection of a humped trophic position-body size association supports the opposite pattern, showing a negative association between trophic position and body size among large and vulnerable species. This implies that large herbivorous could be equally or more vulnerable to environmental change than carnivorous species (Segura et al. 2016). More generally, the negative trophic position-body size association along intermediate to lager body sizes involves an explicit mechanistic understanding of the energetic constrain, potentially affecting species local persistence or extinction susceptibility (Burness et al. 2001; Valkenburgh et al. 2004; Arim et al. 2007a).

So far it is known, the negative association between trophic position and body size emerge from the balance between energetic population demands and the available energy in the environment for each population (Brown et al. 1993; Marquet and Taper 1998; Burness et al. 2001; Arim et al. 2007a, 2016). This balance is affected by environmental variables such as temperature due to its effects on metabolism (Arim et al. 2007a). Similarly, since more energy has to be incorporate into the population to reach the minimum viable population size, predation rates are expected to increase energetic constrains (Arim et al. 2011). The total amount of local energy in the food web is determined by the interaction between area and productivity at the community or ecosystem level (Schoener 1989), and landscape features determines how individuals move among local populations, integrating spatial patches of resources (Urban and Keitt 2001; McCann 2005, 2012). Finally, pollutants negatively affect individual's metabolism, energetic demands and resource allocation (Garay-Narváez et al. 2013). Consequently, the negative association between trophic position and body size herein reported is likely to encompass multiple drivers of energetic imbalance at individual, population, community and ecosystem levels. The observed pattern is therefore connecting ongoing environmental trends with the persistence of particular species close to the 'boundary' of energetic constraints. However, it should be noticed that these mechanisms cannot be equally invoked if there is no positive association between trophic position and body size (Dantas et al. 2019).

Practical implications

This being said, we found a poor match between the genera identified here as being close to the energetic imbalance and the IUCN Red List marine gastropods. Not only is none of the families currently assessed by the IUCN present in our 'top 10' assessment, but our analysis suggests that most species listed may not be affected by energetic constraints. In contrast, all of our 'top 10' vulnerable families and genera are much often represented on the national or regional list. We are not saying, in any case, that species listed in the IUCN are not genuine conservation targets, yet rather suggesting new avenues for identifying endangered species. In this line, a new addition to the IUCN Red List, the scaly-foot snail or sea pangolin (*Chrysomallon squamiferum*), exemplifies how Red List criteria can be applied to organisms in deep water, poorly known habitats without baseline population data (Sigwart et al. 2019). However, it is worth noting that several species included in national or regional Red Lists does not rank high in our vulnerability assessment, such as the olivid gastropods *Olivancillaria teaguei* and *O. contortuplicata* (see e.g. Scarabino 2004), highlighting that the causes of species declines are complex and often interconnected, and encouraging more local or regional assessment of gastropod species.

Caveats

This approach aims to provide an initial screening for a large number of species and therefore it is beyond the scope of this paper to carefully review the nomenclature provided in the database. This may have important implications, since the establishment of a new genera, the description of new species, and the identification of synonymies may modify our ranking. Further, taking into consideration that most species are probably microgastropods (Albano et al. 2011), the database can be regarded as biased towards large-sized species. For example, in an unprecedented massive collecting effort involving 400 person-days at a single site in New Caledonia, SW Pacific, 2,738 species of marine molluscs were recorded (Bouchet et al. 2002). Small-sized species made up the majority of the diversity, while over 50% of the species had adult sizes below 10 mm. Top five families in terms of species richness were 'Turridae' (specialist polychaete hunters), Eulimidae (echinoderm parasites), Pyramidellidae (invertebrate ectoparasites), Triphoridae and Cerithiopsidae (specialist feeders on sponges). These five families together accounting for 29.5% of the mollusc diversity at the study site. There are thus reasons to expect that any in-depth study of the diversity of gastropods in the western Atlantic should also follow this pattern. However, even taking into account the large number of unreported small gastropods and associated taxonomic uncertainties (e.g. genus or family-level assignment of species), our results should be robust since no changes in the shape of the curve are expected unless a large number of previously unknown large carnivore gastropods species is discovered.

CONCLUSIONS

Mechanistic theories provide a better framework for the management of applied problems with comparatively less demand of empirical information. The humped trend in trophic position with body size support the existence of both morphological restriction to trophic position among smaller species and an energetic constrain for large species. It is interesting to note that few empirical evidence support the humped association when was originally proposed. However, the analysis at large taxonomic and spatial scale is progressively supporting its occurrence in different ecosystems. Equally or more important, when the humped pattern is not observed, the operation of additional mechanisms become evident. In this sense, a theory based on basic principle provides a mechanist understanding of biodiversity patterns, even when it fails. The taxonomic biases in the analysis of the TP-BS relationship and more generally on the environmental determinants of food chain length are a matter of concern. The bulk of evidence about the trophic position-body size relationship is based on fishes. The analysis of different organisms, with different traits and inhabiting different environment is essential for the validation of general mechanisms and/or the identification of novel mechanisms to be included on theory. Our analysis of the trophic position-body size relationship for marine gastropods attempts to be a step in this direction, which provide in this case, mechanistic based suggestions for the identification of species of conservation concern.

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NOTE

Side effects for batoids' conservation in the vacuum of fishery management

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ABSTRACT. A shift verified in batoid landings by artisanal fisheries during 2017-2021 is interpreted as a potential consequence of legal measures set by the Brazilian government in 2014. In this five-year period, the increasing landings of stingrays concomitant with a decrease in the landings of guitarfish might be a result of fishing bans established for the Brazilian guitarfish *Pseudobatos horkelii* and the Shortnose guitarfish *Zapteryx brevirostris*, which are both endemic to the coasts of Southern Brazil, Uruguay, and Argentina and listed as threatened at national and global levels. In 2022, more batoids became protected, so it is expected that shifts in captures will continue, reaching species whose stocks have not yet been evaluated and for which conservation measures are not foreseen. Considering the sociocultural and economic relevance of artisanal fisheries in the country, the observed shift is discussed here as it relates to batoids' effective conservation and adherence to legal measures by the fishery sector in Southern Brazil.

Key words: Guitarfish, stingrays, artisanal fisheries, Brazil, Southwestern Atlantic Ocean.

Consecuencias del vacío en la gestión pesquera para la conservación de los batoideos

RESUMEN. El cambio verificado en los desembarques de batoideos en las pesquerías artesanales durante 2017-2021, se interpreta como una posible consecuencia de las medidas legales establecidas por el gobierno brasileño en 2014. En este período de cinco años, los crecientes desembarques de rayas concomitantes con una disminución en los desembarques de pez guitarra podrían ser el resultado de las prohibiciones de pesca establecidas para el pez guitarra brasileño *Pseudobatos horkelii* y el pez guitarra de pico corto *Zapteryx brevirostris*, que son endémicos de las costas del sur de Brasil, Uruguay y Argentina, y figuran como amenazados a nivel nacional y mundial. En 2022, se protegieron más batoideos, por lo que se espera que continúen los cambios en las capturas, llegando a especies cuyos *stocks* aún no han sido evaluados y para las cuales no se prevén medidas de conservación. Teniendo en cuenta la relevancia sociocultural y económica de la pesca artesanal en el país, el cambio observado se analiza aquí en relación con la conservación efectiva de los batoideos y el cumplimiento de las medidas legales por parte del sector pesquero en el sur de Brasil.

Palabras clave: Pez guitarra, rayas, pesquerías artesanales, Brasil, Océano Atlántico Sudoccidental.

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With growing concern about guitarfish conservation (Dulvy et al. 2017, 2021), the precarious situation these animals have been facing has become increasingly evident, with high rates of unreported catches and poor management across their home range (Sherman et al. 2022). This urgent matter was first raised by Moore (2017), with solid evidence that guitarfish were following the same path as sawfish –another group of elasmobranchs at high risk of extinction. Since then, the situation has worsened, as now Rhino Rays (i.e. guitarfish and wedgefish) are the most threatened vertebrates, with about 76% of species listed under an extinction risk category globally. In the Parana coast, Southern Brazil, elasmobranch commercial fishery is a tradition, with several families depending on their capture as a source of income. Elasmobranch commercial capture is now an urgent matter at the global level, as population declines can be high as 90% in certain regions for some species. In Brazil, some species receive legal protection from the federal government since 2014. However, fisheries management in the country is still an enormous challenge, as there are many socio-ecological aspects which are rarely taken into account when fishing bans are set.

When detached from the alternatives for fishery production maintenance, are capture bans effective for conservation? On the Southern Brazilian coast, data showed that capture bans on the Brazilian guitarfish *Pseudobatos horkelii* (Müller and Henle, 1841) (Rhinobatidae) in 2014 was followed, for at least five years, by a gradual and expressive increase in the landings of Dasyatidae rays. As this was possibly not a coincidence, in 2022 more batoids were protected. This gives rise to one important question: for whom will the fishing gears work from now on?

Protecting the guitarfish

Although the batoid production by commercial fisheries in Brazil is small, it is growing. In the early 21st century, landings totaled 6,000 t year^{-1}, equivalent to 40% of the shark production (MMA 2003), which increased to 7,200 t year^{-1} and 50%, respectively, by 2009-2011 (MPA 2011). This was the last national survey performed and included batoid families such as Rhinobatidae, Dasyatidae, Myliobatidae, Gymnuridae, Narcinidae, and Rajidae without species distinction (MPA 2011).

The trend is slightly different on the Parana coast, at approximately 25° S-48° W (Figure 1). Among elasmobranchs, batoid production has grown from < 30% to > 40% in the past 50 years, exceeding that of sharks in 2019. However, batoid production fell from 12-80 t year^{-1} in the 1970s (Loyola e Silva and Nakamura 1975) to < 5 t year^{-1} in 2021 (FUNDEPAG 2022), along with a reduction in shark production, from 30-200 t year^{-1} to < 5 t year^{-1} (Figure 2).

Landing surveys in Brazil are not continuous, but the natural history of batoids and sharks has received progressive attention. Studies have focused on reproductive biology, age structure, and population dynamics, because of the demands highlighted in the National Plan for Conservation of Threatened Marine Elasmobranchs (Lessa et al. 2021). For example, the high extinction risk of *P. horkelii* led Brazil to ban its capture in 2014 (Portaria MMA 445 2014). This guitarfish occurs in shallow waters from Southeast Brazil to Argentina (Alemany et al. 2021; Cardoso et al. 2021; Froese and Pauly 2022), and it was the first elasmobranch targeted by Brazilian fisheries (Lessa et al. 2021). In the southern region of Brazil, catches reached 1,800 t year^{-1} during 1975-1987, making *P. horkelii* the most landed and marketed batoid (Vooren et al. 2005). The conservation-driven nature of fishing ban has resulted in conflicts between the government, conservationists, and fishery sectors. Two key facts hindered its efficacy in areas from Southern Brazil, including the Parana coast: (1) the shared vulnerability with its sympatric species to the same fishing gear, particularly bottom trawling and gillnets with 18 cm opposite knots (Chaves and Silva 2019; Afonso and Chaves 2021); and (2) challenges to properly distinguish the guitarfish with permitted capture from the one with bans set. The sympatric guitarfish is *P. percellens* (Walbaum, 1792), also found in shallow waters but distributed from Caribe to Southern Brazil (Froese and Pauly 2022). External similarities between *P. horkelii* and *P. percellens* were ana-

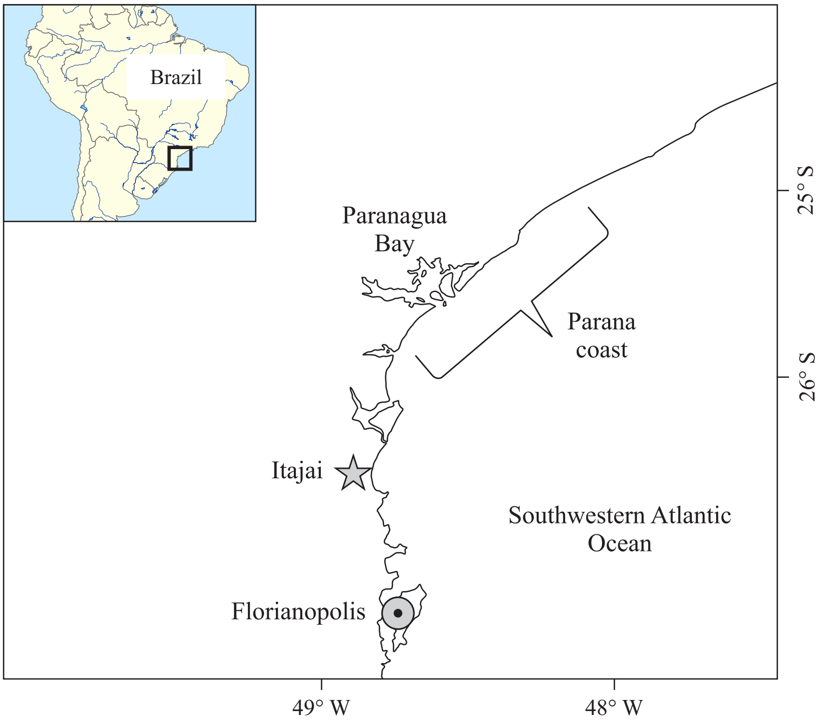

Figure 1. Map of the Parana coast in Southern Brazil, Southwestern Atlantic Ocean. Small square shows a section ranging from 25.29° S-48.09 W to 25.98° S-48.57° W. Grey star: Itajaí, the main national fishery port. Small circle: Florianópolis (both cities in Santa Catarina State).

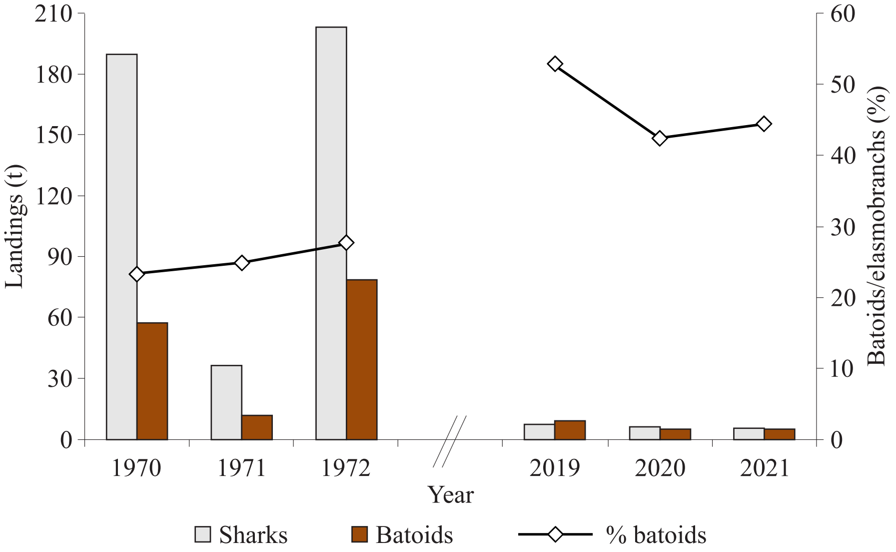

Figure 2. Annual artisanal landings of sharks and batoids on the Parana coast comprising two periods: 1970-1972 (Loyola e Silva and Nakamura 1975) and 2019-2021 (data: FUNDEPAG 2022). The % batoids refers to the percentage of batoids landed in relation to the total amount of elasmobranchs.

lyzed by genetic, physiological and population studies aimed at better understanding their similarities and differences (Franco 2010; Cruz et al. 2021; Leite 2022).

Concerns on other batoids

On the Parana coast, fisheries are mostly artisanal, with a predominance of two fishing gears: shrimp trawling, where batoids, mainly *Pseudobatos* spp., *Zapteryx brevirostris* (Müller and Henle, 1841), *Narcine brasiliensis* (Olfers, 1831), and Dasyatidae species, corresponding to 1% of the total production, are also captured as bycatch; and gillnets, where the above mentioned batoids plus *Rhinoptera* spp. and *Rioraja agassizii* (Müller and Henle, 1841), corresponding to 2-3% of the total production, are captured too (Robert 2012; Afonso and Chaves 2021; Chaves 2021). Other fisheries include bottom longline, which for the 2017-2021 period the Dasyatidae (hereafter: stingrays) catch accounted for up to 80% of the total elasmobranch volume, and 20% when considering all species caught (FUNDEPAG 2022).

Recently, the conservation status of other batoids has been evaluated, resulting in new restrictions on commercial fisheries in Brazilian waters and reactions from stakeholders. In June 2022, the Sindicato dos Armadores e das Indústrias de Pesca de Itajaí e Região (the largest Brazilian fishery syndicate, based in Southern Brazil; Figure 1) expressed their discontent, stating that comprehension challenges would limit compliance with legal restrictions (SINDIPI 2022). The new bans (Portaria MMA 148 2022) now include two stingrays, *Hypanus americanus* (Hildebrand and Schroeder, 1928) and *H. marianae* (Gomes, Rosa and Gadig, 2000), along with *P. percellens*, all of which have historic landings in Southern Brazil (Vooren et al. 2005; Costa and Chaves 2006; Robert 2012; Santos et al. 2016). The new ban on *P. percellens* has the potential to neutralize the challenges of co-occurrence mentioned above, as no *Pseudobatos* species can be landed. However, the fishery sector will face another challenge: which fish to land.

Regional data on fishery production (FUNDEPAG 2022) reveal that the landings of *Pseudobatos* spp. by artisanal fleets in Parana are decreasing. The total production decreased from 3 t in 2017 to 0.5 t in 2021. Landings may not have reached zero, as until 2021 *P. percellens* capture was allowed. Simultaneously, however, the total non-guitarfish batoid production has grown from < 0.5 t in 2017 to > 4 t in 2021, an increment mostly from stingrays (Figure 3).

There is a possible cause-effect relationship between legal restrictions for certain species –guitarfishes– and the increasing landings of others –stingrays. The capture effort is not measured, nor is the status of the stocks, but it is known that between 2017 and 2021 gillnetting production decreased in Parana, from > 400 t year^{-1} to < 150 t year^{-1} (Figure 4). This decrease reflects teleost production, whose total volume exceeds 15 times both elasmobranch and crustacean production (FUNDEPAG 2022). At the same period, longline production also decreased (Figure 4), despite the increment in stingray landings observed from 2019. This indicates a greater interest in this resource as well as greater availability, and/or retention onboard. The commercial use of non-targeted elasmobranchs is common worldwide, and batoid retention or non-retention is usually decided onboard (as reported by Tamini et al. 2006 for bottom trawling in Argentina). By comparison, in the China Sea, 28 shark species listed as NT, VU, and EN (IUCN list) are caught in drift gillnets, bottom trawl nets, and hook-and-line fisheries, all of which are retained and marketed (Araí and Azri 2019).

There are approximately sixty fishing communities along the Parana coast (Robert 2012). As batoids are a common and (supposedly) welcomed bycatch, conservation measures can limit fishing activities, but their acceptance depends on the alternatives offered to the sector. The

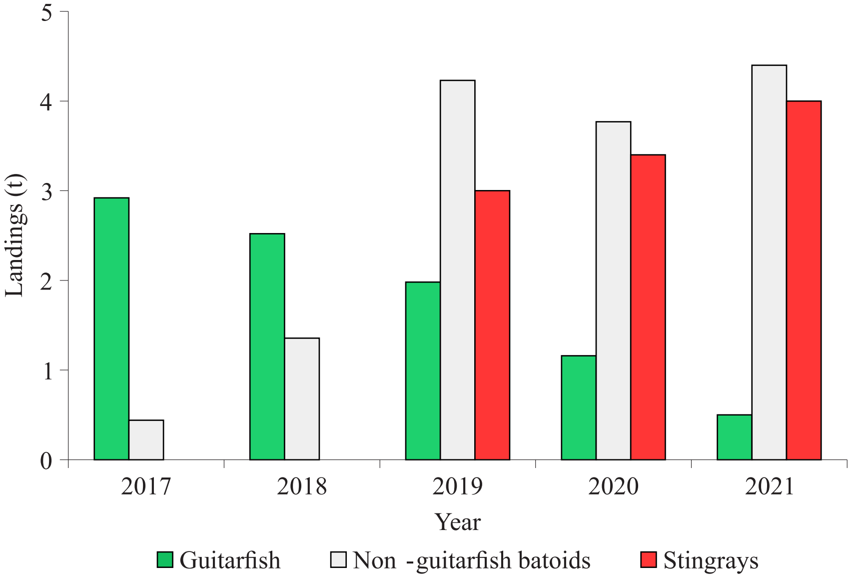

Figure 3. Annual landings of guitarfish (*Pseudobatos* spp.), non-guitarfish batoids, and stingrays only (Dasyatidae) by artisanal fleets in the Parana coast, Southern Brazil, between 2017 to 2021. Data source: FUNDEPAG (2022).

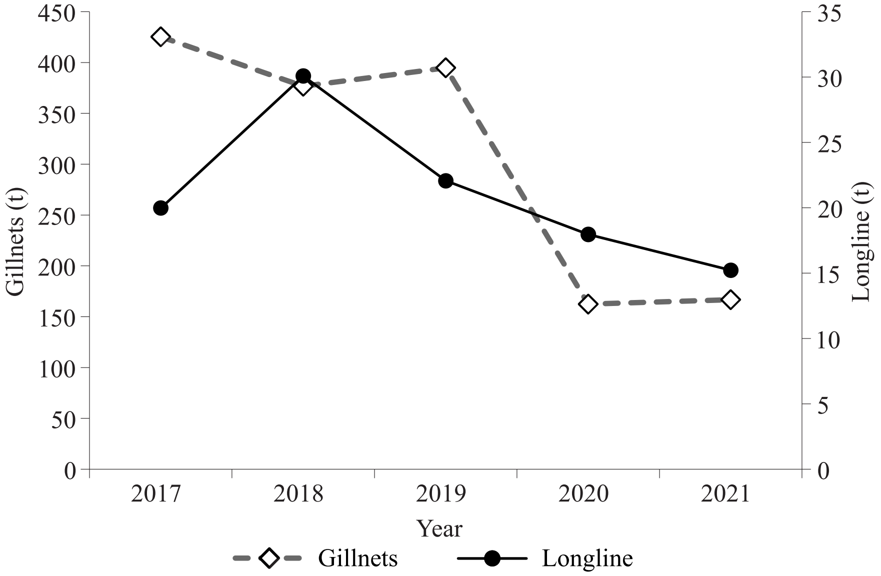

Figure 4. Annual landings of artisanal fisheries performed in the Parana coast, Southern Brazil, from 2017 to 2021. All fishery resources are summed according to the fishing gear employed. Data source: FUNDEPAG (2022).

Brazilian law 11959/2009, Art. 3, requires the government 'to calculate, authorize, and plan access regimes, and fix allowed catches; indeed, it is the government's obligation to consider fisheries' particularities and fishers' needs, aiming to assure the permanence and continuity' of artisanal fisheries. The most recognized and suggested labor activity shift model (i.e. extractive activities for ecotourism) can be restrictive in some regions, in addition to imposing changes in family structures and traditions that are not always well accepted (Das and Chatterjee 2015). In Brazil, there is a lack of prospecting for sustainable exploitation, which creates a gap between fishing bans and proper redirection to alternatives that do not impose a new lifestyle on fishers, without their consent.

RECOMMENDATIONS AND CONCLUSIONS

Considering the influence of stakeholders on species conservation, socio-ecological systems, assuming the need to integrate biodiversity management with people, are particularly relevant (Refulio-Coronado et al. 2021). This approach recognizes the complexity, unpredictability, dynamics, and non-linearity of fishing activities, assuming that decisions need to evolve towards strategies adapting to the distinct reality of traditional communities. In this context, the mitigation hierarchy model integrates biological and operational aspects of fisheries, considering the socioeconomic context to manage potential trade-offs between conservation initiatives and human needs (Booth et al. 2019). Such an approach can be applied to develop holistic and adaptive measures for batoid fishery management.

Hence, participatory management is a promising conservation measure for threatened species, concomitant with the coordinated exploitation of new resources, aimed at sustainable fisheries (Cota-Nieto et al. 2018). Management plans for stocks not yet overexploited should thus consider biological variables allowing the establishment of minimum and maximum capture sizes, in addition to quotas and seasonal bans for batoids. Furthermore, measures to mitigate overexploitation must be presented to fishers (Gupta et al. 2020), to develop conservation initiatives without affecting the financial gains of traditional communities.

Altogether, an artisanal landing shift on the Parana coast has been noted, which might be a reflex of the slow yet progressive fulfillment of the conservation measures proposed by the federal government in 2014. Despite the population collapse being a possibility, onboard monitoring and access to fisher ecological knowledge in the past four years provide strong evidence that the number of captured individuals remains constant (Wosnick et al. in preparation). Moreover, the reduction in landings might also be a result of a conservation initiative based on the release of live animals performed in Parana for over a decade (Wosnick et al. 2020), at least for *Z. brevirostris*. It is also important to consider that the decrease in guitarfish landings might also be a result of fewer fishers turning their efforts to fisheries that catch them, possibly because of bans turning landing into a great risk. Thus, monitoring efforts must be intensified in the region, aiming to understand the putative causes (or a combination of them) of the reduction in landings retracted in regional fisheries statistics.

It is also imperative that fisheries management be directed towards the economic-viable stingrays, along with monitoring efforts to understand drivers behind this shift in catches in the region. Finally, fishers must be included and consulted at every stage of the development of conservation measures to ensure that socio-cultural values are recognized and preserved. This will result in management plans fully adopted and, most importantly, supported by the fishery sector.

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NOTE

Length-weight relationship of mangrove clam (*Pegophysema philippiana*) in different sites within the Baganga, Davao Oriental Province, Philippines

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ABSTRACT. Mangrove clam *Pegophysema philippiana* Reeve, 1850, is common to mangroves muddy substrate in Baganga, Davao Oriental, particularly in barangay Kinablangan, Lucod, Salingcomot and Bobonao. Sampling was done on May 2-7, 2022, during high tide. Mangrove clam length-weight relationship was calculated using the exponential equation $W = aL^b$. A total of 769 mangrove clams were collected during sampling. The biggest (4.4 ± 0.81 cm) and heaviest (43.4 ± 25.3 g) clams were recorded at Bobonao, the smallest was measured at Lucod (3.7 ± 0.65 cm), and the lightest clam was found at Kinablangan (26.8 ± 16.28 g). ANOVA detected significant differences ($p < 0.05$) in length and weight of mangrove clams between sites. Length-weight relationship of mangrove clam exhibited a strong positive relationship between length and weight; however, different values of slopes were noted. This is very common in bivalves because they are very sensitive to environmental changes. In general, the length-weight relationship of mangrove clam in Baganga, Davao Oriental, revealed allometric growth pattern.

Key words: Davao, exploitation, gleaning, invertebrates, mangrove ecosystem.

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Relación longitud-peso de la almeja de manglar (*Pegophysema philippiana*) en diferentes sitios dentro de Baganga, Provincia Oriental de Davao, Filipinas

RESUMEN. La almeja de manglar *Pegophysema philippiana* Reeve, 1850, es común en los sustratos fangosos de los manglares en Baganga, Davao Oriental, particularmente en los barangays de Kinablangan, Lucod, Salingcomot y Bobonao. El muestreo se realizó del 2 al 7 de mayo de 2022, durante la marea alta. La relación longitud-peso de las almejas de manglar se calculó mediante la ecuación exponencial $W = aL^b$. Se recolectaron un total de 769 almejas de manglar durante el muestreo. Las almejas más grandes (4,4 ± 0,81 cm) y más pesadas (43,4 ± 25,3 g) se registraron en Bobonao, las más pequeñas se midieron en Lucod (3,7 ± 0,65 cm), y las almejas más ligeras se encontraron en Kinablangan (26,8 ± 16,28 g). El ANOVA detectó diferencias significativas ($p < 0{,}05$) en la longitud y el peso de las almejas de manglar entre los distintos sitios. La relación longitud-peso de la almeja de manglar exhibió una fuerte relación positiva entre la longitud y el peso; sin embargo, se observaron diferentes valores de pendientes. Esto es muy común en los bivalvos porque son muy sensibles a los cambios ambientales. En general, la relación longitud-peso de la almeja de manglar en Baganga, Davao Oriental, reveló un patrón de crecimiento alométrico.

Palabras clave: Davao, explotación, espigueo, invertebrados, ecosistema de manglar.

Mangrove clam *Pegophysema philippiana* Reeve, 1850, is a highly sought bivalve species in the Philippines because of its flavor and size, and is considered as a local seafood delicacy in the region (Primavera et al. 2002). Mangrove clam is a burrowing bivalve and one of the most valued invertebrate species in the Davao Region. It is considered as the main source of proteins, vitamins and minerals for the poorest social communities living on the coast since most of them rely on artisanal fishery catch (Dejarme et al. 2015). Due to the large population of the Philippines, growing coastal settlement drives increasing fishing pressure on certain commodities, and the mangrove clam is not exempted from this problem since it is very susceptible for exploitation (Araneta 2016). A study in biology, ecology, genetics, and early life stages of *P. philippiana* was already conducted (Adan 2000; Primavera et al. 2002; Araneta 2016); however, the study of its morphometric measurement was limited (Sajol-Degamon and Fernandez-Gamalinda 2021). Hence, only taxonomic investigation was conducted in the Davao Region and no morphometric relationship study was carried out (Lumogdang et al. 2022).

Morphometric measurements of the association between length and weight were computed in the current investigation. In fisheries biology and population dynamics, the length-weight relationship (LWR) is crucial and many stock assessment models suggested the use of LWR parameters (Jamabo et al. 2009). LWR is basic for evaluating the growth of any edible and economically significant invertebrate species since it may directly represent the organism's general health by providing an evaluation of its weight in relation to its length (Aban et al. 2017).

Mangrove clam was reported to be depleted in Baganga, Davao Oriental according to the Municipal Agriculturist and observation of gleaners during the pre-sampling visit (Bacaltos et al. 2010). Although mangrove clams could still be harvested in the mangrove areas of Baganga, Davao Oriental, a need for scientific data is essential and this paper aims to fill in this gap. This paper focuses only on the morphometric relationship (LWR) of *P. philippiana* in different barangay[1] of Baganga, Davao Oriental, as this municipality is one of the major exporters of mangrove clams in Davao City (Bangkerohan and Agdao Public Markets) with reported 1,000 to 3,000 kg of mangrove clam sold every day (Bacaltos et al. 2010). Thus, the data generated from the current study provides a first reference for the study of mangrove clam fishery management and ecological monitoring in the area.

Mangrove clam (*P. philippiana*) was collected in barangay Kinablangan, Lucod, Salingcomot and Bobonao, within the Baganga, Davao Oriental province (Figure 1). Field sampling was done during daytime on May 2-7, 2022, with the assistance of three hired gleaners. Within the mangrove forest, gleaning was done during high tide as preferred by the gleaners to facilitate easy maneuver in the mud at 1 m depth. Using their toes, they locate the mangrove clam by doing rhythmic movement, which is termed locally as *hinol-hinol*. Shell length was measured using a Vernier caliper (± 0.1 mm), while weight was obtained using a digital weighing scale (± 0.2 g) *in situ*. Collected clams were partially drained before weighing in order to minimize the influence of water.

Analysis of Variance (ANOVA) was used to establish the significant difference in length and weight of mangrove clams ($p = 0.05$). Further, Tukey test was used to identify significant difference between study sites. The relationship between length and weight was also calculated using the exponential equation $W = aL^b$, where W stands for weight, a stands for the intercept, which represents the initial growth coefficient, L stands for length, and b stands for the slope, which represents the relative growth rates of the

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[1] Barangay is the lowest territorial and political boundary in the Philippines.

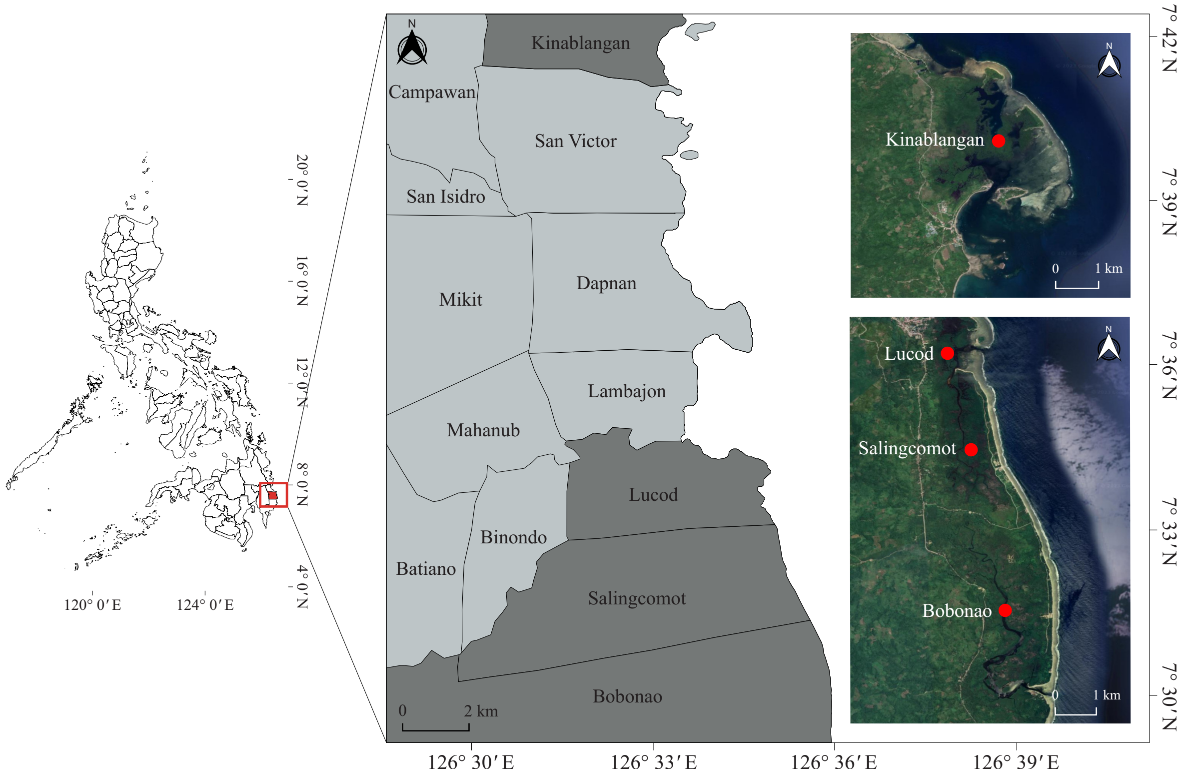

Figure 1. Collection sites (red spots) of mangrove clam in Baganga, Davao Oriental province, Philippines.

variables and provides growth information (Aban et al. 2017). The value of the slope was analyzed using the t-test to determine the growth exhibited by the mangrove clam (López-Rocha et al. 2018). Growth is isometric when $b = 3$, allometric when b substantially differs from 3 (positive if $b > 3$ and negative if $b < 3$) (Sajol-Degamon and Fernandez-Gamalinda 2021). The analysis was carried out through SPSS 20 and Microsoft Excel 365.

A total of 769 mangrove clam *P. philippiana* specimens were collected in Baganga, Davao Oriental. Results indicated that Bobonao had biggest clams with a mean length of 4.4 ± 0.81 cm ($n = 176$) followed by Salingcomot with 4.1 ± 0.71 cm ($n = 120$), Kinablangan with 3.8 ± 0.67 cm ($n = 251$), and lastly Lucod with 3.7 ± 0.7 cm ($n = 222$). In terms of mean weight, the heaviest individual was found in Bobonao (43.4 ± 25.3 g), followed by Salingcomot (37 ± 20.57 g), Lucod (29.8 ± 17.77 g) and Kinablangan (26.8 ± 16.28 g). The Tukey test found that mangrove clams from Kinablangan and Lucod showed no significant difference ($p > 0.05$) in length and weight, while significant differences were observed when comparing Bobonao and Salingcomot ($p < 0.05$). One factor that might affect the size differentiation (length and weight) of clams between study sites is the magnitude of harvest of the resource (Elvira and Jumawan 2017). Moreover, comparable results from barangay Lucod and Kinablangan might be due to the accessibility of both areas in which no gleaning restrictions were instituted and as a result gleaners could harvest clams freely and gleaning pressure increased. In addition, according to the office of Municipal Agriculture, the majority of the gleaners were from Lucod, so it is safe to assume that the harvest in Kinablangan and Lucod was comparable compared to other study site (Sadino 2022 pers. comm.). High exploitation pressure on resources in mangrove wetlands of Butuan (Philippines) may be found in Elvira and Jumawan (2017), where they found out that exploitation due to gleaning of mud clam *Polymesoda erosa* was a contributing factor of its size variability. So, different sizes observed in mangrove clam in the current study might also be influenced by the gleaning activity in different barangays. In addition, mangrove clam has high market value in Baganga, Davao Oriental, with reported values of 2.2-2.7 USD kg^{-1} (Sunstar 2018), which may drive an increase in gleaning pressure on some study sites considering there is no gleaning restrictions to increase their income (Table 1).

Mangrove clams in this study ranged from 3.7-4.4 cm shell length and 26.8-43.4 g weight, indicating that mangrove clam population was in good condition based on its size structure. Clams reached first sexual maturity at 3 cm shell length before being harvested (Primavera et al. 2002; Araneta 2016). Therefore, growth exploitation was not observed since bigger clams were gleaned in the area (> 3 cm shell length). In consonance, recruitment exploitation was also not observed since mangrove clam collected across study sites were smaller compared to the ideal brood stock size of 5.7-7.3 cm and weights of 60-125 g since recruitment exploitation only existed when the brood stock of a certain fishery were heavily harvested (Adan 2000). Moreover, results from the present study are comparable to those of Kilatong and Bruckner (2010) in which mean length of mangrove clams collected outside the protected area of Oikull, Airai Strair, Republic of Paluau, ranged from 4.45-4.75 cm. However, bigger mangrove clam also collected in an unprotected area in Panay, Philippines by Adan (2000) reported 4.3-5.1 cm mean length and 21-170 g weights.

Mangrove clam is a commercially important bivalve collected for consumption and sold to local markets and restaurants by the local gleaners (Yahya et al. 2020). Due to their size, taste, and supposed aphrodisiac powers, mangrove clams are sold in other regions to generate more income to support daily needs of families (Primavera et al. 2002). Given its economic value and dependence of gleaners to mangrove clam to sustain their regular necessities, fishing pressure might increase as competition among gleaners arouse during harvest which could influence a decline in mangrove clam size and stocks.

The result from morphometric analysis showed that shell length and total weight of mangrove clam *P. philippiana* in all study sites had strong positive relationship, since all values of correlation coefficients (r^2) were close to 1.0 (Table 2). Thus, shell length and total weight of mangrove clam *P. philippiana* were closely related to each other and could be used to estimate total weight based on shell length. Values of the slope from different study sites varied and no isometric growth was observed. In Kinablangan, a positive allometric growth pattern (b = 3.052) was observed indicating that the weight of mangrove

Table 1. Mean (± SD) length (cm) and weight (g) of mangrove clams (*Pegophysema philippiana*) collected in different areas of Baganga, Davao Oriental. Different superscript denotes significant different using ANOVA ($p < 0.05$).

	Kinablangan (n = 251)	Lucod (n = 222)	Salingcomot (n = 120)	Bobonao (n = 176)
Mean length	3.8 ± 0.65^{b}	3.7 ± 0.7^{b}	4.1 ± 0.71^{ab}	4.4 ± 0.81^{a}
Mean weight	26.8 ± 16.28^{b}	29.8 ± 17.77^{b}	37.0 ± 20.57^{ab}	43.4 ± 25.3^{a}

Table 2. Summary of the relationship between shell length and weight and growth patterns of mangrove clam *Pegophysema philippiana* in Baganga, Davao Oriental.

Sampling sites	n	r^2	Intercept (a)	Regression coefficient (b)	t-test	Growth pattern
Kinablangan	251	0.929	0.401	3.052	$P < 0.05$	Allometric (+)
Lucod	222	0.963	0.675	2.811	$P < 0.05$	Allometric (–)
Salingcomot	120	0.886	0.685	2.749	$P < 0.05$	Allometric (–)
Bobonao	176	0.932	0.525	2.913	$P < 0.05$	Allometric (–)

Note: n = sample size, r^2 = coefficient of determination, $b > 3$ = positive allometry, $b < 3$ = negative allometry.

clam increases superiorly compared to its shell length. This growth pattern could be influenced by the existing aquaculture pond in the area which increased organic materials beneficial to clams nourishment (Lebata 2001; Sarà et al. 2009). On the other side, negative allometric growth patterns were observed in Lucod ($b = 2.811$), Salingcomot ($b = 2.749$) and Bobonao ($b = 2.913$) suggesting that the rate of shell length increase was higher compared to weight increase. This negative growth pattern may be driven by multiple factors such as fluctuating environmental parameters and the consequent mangrove clam physiology (Thomas 2013; Singh 2017). The analysis of the slope was also done to establish significant difference between the b values and isometric values (3) using t-test and the result showed significant difference in all study sites ($p < 0.05$).

The result of the analysis conforms to the study of Aban et al. (2017) in which the growth of organisms proceeds with different factor differing from the measurement of the length. It was also noted that the slopes of the paired morphometric parameters were greater or lesser than 3.0, meaning that the increase in shell length was not proportional to the weight gained of mangrove clam *P. philippiana*. Different findings for length and weight relationship in the selected study sites maybe influence by ecological or physiological factors (Ramesha et al. 2009; Malathi and Thippeswamy 2011) though it was a limitation in the study. As clams were particularly sensitive to environmental changes, further studies comparing its state and heterogeneity in different locations will be needed.

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NOTE

Stranding of blue button jelly *Porpita porpita* (Cnidaria: Hydrozoa) on the beaches of Visakhapatnam, India (Western Bay of Bengal)

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ABSTRACT. *Porpita porpita* occurs in the tropical and sub-tropical waters of the Pacific, Atlantic, and Indian Oceans, and the mass numbers of stranded colonies seem to be increasing. Although its presence in Indian waters is minimal, this is the first record ever made of *P. porpita* in Visakhapatnam coastal waters. The present study provided a detailed description of the species and its global distribution. Further, the perceived increase in gelatinous zooplankton blooms in the observed area indicates that jellyfish can negatively affect fisheries because they compete with zooplanktivorous fish, prey upon fish eggs and larvae, and indirectly compete with higher trophic levels by reducing the plankton available to planktivores. Conversely, jellyfishes also play a vital role in regulating global marine plankton food webs, spatio-temporal dynamics, and biomass, which is a role that has been generally neglected so far.

Key words: Jellyfish, Porpitidae, fisheries, gelatinous zooplankton, food web.

Arribazón de medusa azul *Porpita porpita* en las playas de Visakhapatnam, India (Bahía occidental de Bengala)

RESUMEN. *Porpita porpita* se encuentra en las aguas tropicales y subtropicales de los océanos Pacífico, Atlántico e Índico, y el número masivo de colonias varadas parece estar aumentando. Aunque su presencia en las aguas de la India es mínima, este es el primer registro de *P. porpita* en las aguas costeras de Visakhapatnam. El presente estudio proporcionó una descripción detallada de la especie y su distribución global. Además, el aumento percibido en las floraciones de zooplancton gelatinoso en el área observada, indica que las medusas pueden afectar negativamente a las pesquerías porque compiten con los peces zooplanctívoros, se alimentan de huevos y larvas de peces, e indirectamente compiten con niveles tróficos más altos al reducir el plancton disponible para los planctívoros. Por el contrario, las medusas también juegan un papel vital en la regulación de las redes alimentarias del plancton marino global, la dinámica espacio-temporal y la biomasa, un papel que generalmente se ha descuidado hasta ahora.

Palabras clave: Medusa, Porpitidae, pesquerías, zooplancton gelatinoso, trama trófica.

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Porpita porpita (Linnaeus, 1758), commonly known as 'blue button jelly', is a colony of Hydrozoa belonging to the Order Anthoathecata, Family Porpitidae, which includes three genera: *Porpema* Haeckel, 1888; *Velella* Lamarck, 1801 and *Porpita* Lamarck, 1801. It is an open ocean species found globally in tropical and sub-tropical waters of the Pacific, Atlantic, and Indian oceans (Zhang 1999; Kirkendale and Calder 2003; Bouillon et al. 2004;

Kubota and Tanase 2007; Fisner et al. 2008; Gravili et al. 2008; Calder 2010; Pandya et al. 2013; Gul and Gravili 2014). The species was first described by Linnaeus (1758) as *Medusa porpita.* Numerous nominal species of *Porpita* Lamarck, 1801, have been described over the years, but all are now synonymised for a single species, *P. porpita* (Calder 1988; Schuchert 2013). It is inhabiting the ocean surface although habitats of larvae and medusae may extend up to 200 m depth. This species is the dweller of the uppermost layer of the marine environment and is easily carried to shore by water currents and wind (Pandya et al. 2013).

The species *P. porpita* actively feeds on diverse zooplanktonic prey, including copepods, cladocerans, larval forms of small crustaceans and molluscs (Ganapati and Subba Rao 1959). In addition, *P. porpita* colonies and medusae host symbiotic zooxanthellae that may provide nutrition. It is predated by a diverse vertebrate predator and specially gastropods, mostly *Glaucus* spp. and *Janthina* spp. (Chowdhury et al. 2016; Lepoint et al. 2016; Phillips et al. 2017).

Porpita porpita is notable for forming huge rafts at sea and for massive beach strandings and aggregations that have been reported in various parts of the world's oceans (Chowdhury et al. 2016; Madkour et al. 2019; Mamish et al. 2019; Gurlek et al. 2020; Sahu et al. 2020; Boukhicha and Tilg-Zouari 2021). A total of 2,039 records from the Indian Ocean can be found in the Ocean Biogeographic Information System (OBIS) and the Global Biodiversity Information Facility (GBIF), of which 1,005 occurrences have been reported so far, though other records may be scattered throughout the literature and other biogeographic databases. This observation represents the blue button jelly *P. porpita* washed ashore at Bheemunipatnam beach, and it is the first record in Visakhapatnam coastal waters. In addition, the present study discussed a detailed description of the species, its distribution and the negative impact of fishers.

On March 16th, 2021, a cluster of twenty colonies of *P. porpita* were observed in Bheemunipatnam village, Visakhapatnam (Western Bay of Bengal). Out of twenty colonies, two *P. porpita* specimens were transported for laboratory analysis; later in the collection, specimens were examined visually and photographed. Specimens were preserved in a 4% formaldehyde solution for further anatomical studies. Anatomical details were observed with a dissection microscope and described following Ruppert et al. (2004) and Fox (2007). Specimens were stored in separate glass containers and deposited in the referral Museum of Fishery Survey of India, Visakhapatnam.

The animal is a round, bright blue colour, floating hydroid colony having a large, gas-filled flat disc with a prominent central pore and numerous minute pores radiating from the centre, no free-floating sail, a single mouth beneath the float and tentacles. The lower side of the disc has a small, central gastrozooid with a terminal mouth and is surrounded by many gonozooids, and dactylozooids extending towards the periphery (Figure 1).

The hydroid colony has a large, disc-shaped mantle and it floats on water's surface. Polyps and tentacles are finger-like projections that are submerged on the underside of the water. The upperside is slightly convex, without tubercles, and the central portion has a round elevation where a small central pore (stigmata) is present. Upper float and hanging polyps are present; there is a large central mass made up of mesoglea penetrated by tubular, gastrodermal extensions. The central region is hardened due to an internal chitinous float (pneumatophore) containing a series of concentric air chambers with pores on the upper side. The central part of the organ is covered by ectodermal tissue and filled with cnidoblasts, which are located between the upper and lower portion of the central mass. The cnidoblasts drift to tentacles and polyps, where they become stinging cells. The colony is divided into three sections: a large central gastrozooid, a median band of numerous gonozooids, and a peripheral band of dactylo-

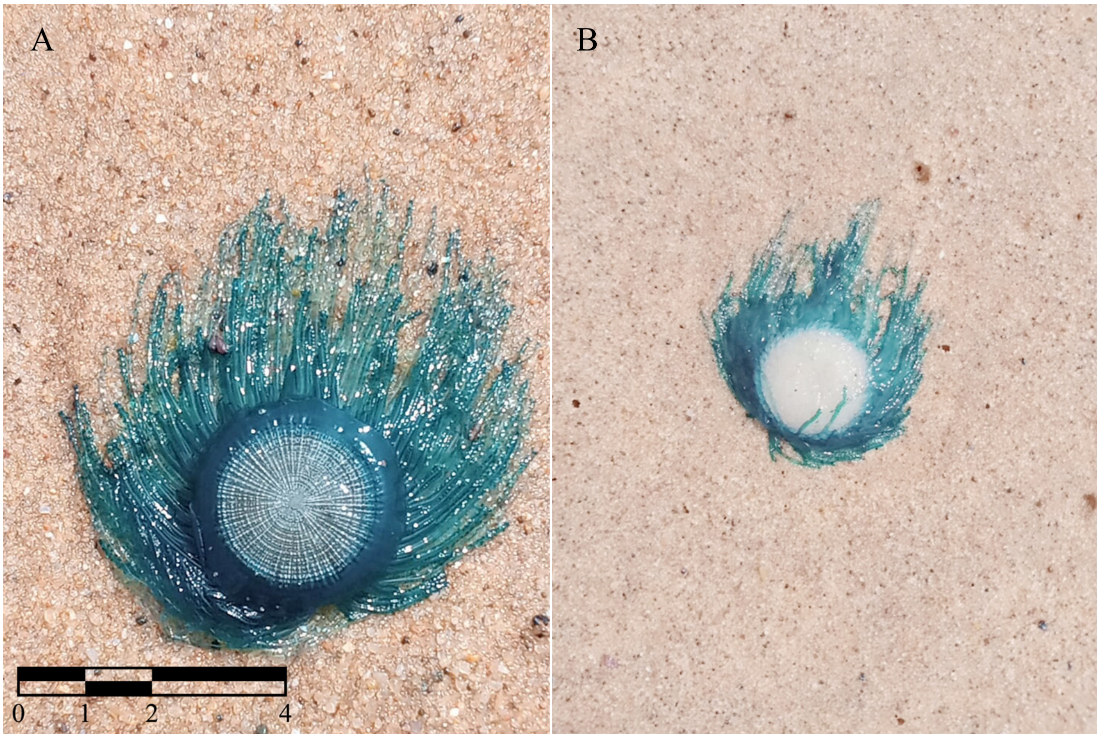

Figure 1. *Porpita porpita* stranding in Bheemunipatnam beach (A), lower disc of the animal (B).

zooids. The central gastrozooid is circular, short, and broad with a terminal mouth and prominent nematocyst clusters. Gonozooid is a reproductive organ, and tentacles are absent. Instead of the tentacles, wart-like nematocyst clusters are developed in the medusae and are scattered over the body. Dactylozooids with three longitudinal rows and a distal whorl of four capitate tentacles are found on the floats oral surface and outer margin; the mouth absent. The mantle and dactylozooids are bright blue, while the central float region is silvery white due to the attached gas or basal tissues, which glow yellow to brown. In the Bay of Bengal, India, *P. porpita* occurs during the March-May period (Sahu et al. 2020), while in the Arabian sea in June-September (CMFRI 2010).

Porpita porpita was distributed throughout the tropical, sub-tropical, Indian, Pacific, Atlantic and Mediterranean seas (Moser 1925; Totton 1954; Brinckmann-Voss 1970; Daniel 1979; Bouillon 1984; Pages et al. 1992; Schuchert 1996; Bouillon et al. 2004; Gravili et al. 2008) (Figure 2).

Blue button jellies may cause a slight sting in humans since they contain bioactive compounds, which have antibacterial and antimicrobial effect (Fredrick and Ravichandran 2010). Its abundance and distribution in tropical and temperate waters and its importance as a predator and/or competitor of fish suggest that this species in Indian waters should be monitored. In fact, a mass occurrence and swarming are serious effects on fish stocks, which are already subject to high fishing pressure by thousands of peoples who rely on the sea as their only source of livelihood (Davies et al. 2009). Many researchers reported that the aggregated swarm of *P. porpita*, in association with other species such as *Janathina*, *Physalia* and *Glaucus*, were found on the east coast of Guam in the Western Pacific (Kirkendale and Calder 2003). Also, in Veraval (Arabian sea) a

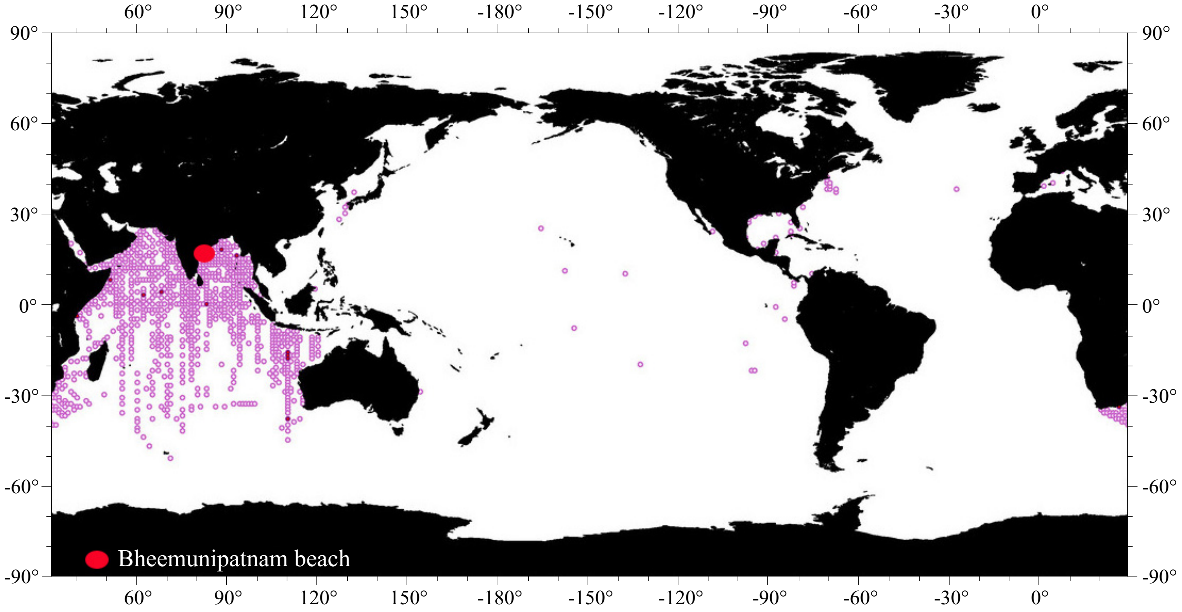

Figure 2. Global distribution of *Porpita porpita* (based on the data obtained from Copepedia, https://copepedia.org/?id=T4014367). The red dot indicates present location.

large number of *P. porpita* appeared ashore during monsoon season (CMFRI 2010). Similarly, on the Odisha coast, Sahu and Panigrahy (2013) observed a swarming of jellyfish in the summer. The present study noticed *P. porpita* washed ashore in summer, which coincides with the findings of Sahu and Panigrahy (2013).

The distribution and abundance of gelatinous zooplankton are determined by physical parameters such as winds, water currents and tides; these supporting factors cause them to drift or swarm near to shore (Zavodnik 1987; Graham et al. 2003). Another possible reason for swarming is due to the availability of food. Predominant food items for *P. porpita* are calanoid copepods and crab megalopa larvae, as well as fish larvae, though the latter in lower quantities (Bieri 1970). It is highly likely that phytoplankton abundance and distribution during February and March will induce sufficient food for *P. porpita* and lead to large aggregations and swarming. The jellyfish blooms were mostly observed during the summer season (March-May), so it might be an optimal temperature for the species. In conclusion, the aggregation or swarming is a once-a-year event, which occurs on the summer season (March-May) on the Bay of Bengal.

Finally, it can be hypothesized that the beach stranding of *P. porpita* was due to physical and oceanographic parameters, i.e. wind (16 km h^{-1}), currents and tides. These factors might be a possible reason for offshore aggregation and swarming of the species. Furthermore, their occurrence was associated with higher water temperature (28.1 °C) and salinity (32.1) during the summer and monsoon seasons, which made Indian waters a favourable environment for the species aggregation or swarming.

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NOTE

First occurrence of juvenile *Sargocentron rubrum* (Forsskål, 1775) from South-Eastern Mediterranean, Turkey

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ABSTRACT. In the present study, one juvenile specimen of redcoat *Sargocentron rubrum* (Forsskål, 1775) was first reported from the Mediterranean coast of Turkey with a visual record during an underwater survey conducted from the coast of Arsuz (Konacik), Iskenderun Bay, at a depth of 3 m, on September 11, 2018. The Family Holocentridae is currently represented in the Mediterranean by seven species, all exotic, six of them originate in the Red Sea (Lessepsian migrants) and one originates from the Atlantic.

Key words: Holocentridae, visual record, Lessepsian migrant, Iskenderun Bay.

Primer registro de un juvenil de *Sargocentron rubrum* (Forsskål, 1775) del Mediterráneo Sudoriental, Turquía

RESUMEN. En el presente estudio, un espécimen juvenil de candil rojo *Sargocentron rubrum* (Forsskål, 1775) fue reportado por primera vez en la costa mediterránea de Turquía, mediante un registro visual durante un estudio submarino realizado desde la costa de Arsuz (Konacik), bahía de Iskenderun, a una profundidad de 3 m, el 11 de septiembre de 2018. La Familia Holocentridae está representada actualmente en el Mediterráneo por siete especies, todas exóticas, seis de ellas originarias del Mar Rojo (migrantes lessepsianos) y una originaria del Atlántico.

Palabras clave: Holocentridae, registro visual, migrante lessepsiano, bahía de Iskenderun.

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The opening of the Suez Canal in 1869 resulted in the introduction of many Red Sea species to the Mediterranean Sea. This ongoing process is termed 'Lessepsian migration' (Por 1978). Since the penetration of the first Lessepsian migrant *Atherinomorus forsskali* in 1902, at least 115 fish species have been recorded and substantiated as migrants from the Red Sea into the Mediterranean Sea via the Suez Canal (Kovačić et al. 2021).

Redcoat *Sargocentron rubrum* (Forsskål, 1775) (Holocentridae) was first documented from the Mediterranean by Haas and Steinitz (1947) recording an adult specimen from Palestine and then in Greece, Rhodes (Laskaridis 1948), Cyprus (Demetropoulos and Neocleous 1969) and Libya (Stirn 1970). Recently, it has been reported from the southwestern Aegean Sea and Peloponnose (Zenetos et al. 2013), Tunisia (Amor et al. 2016), Malta (Deidun et al. 2016). *Sargocentron rubrum* was first recorded in Turkish marine waters from the Mediterranean Sea and the Aegean Sea (Kosswig 1950) and later this species was also reported from the Marmara Sea by Artüz and Golani (2018).

S. rubrum is widespread in the West Pacific Ocean (Randall et al. 2003). This species is also known as the spotfin squirrelfish or soldierfish. *S. rubrum* is one of the most commonly encountered species in its genera. It is frequently seen in the Red Sea, southern Japan to New Caledonia, Vanuatu and New South Wales, Australia (Williams and Greenfield 2016; Froese and Pauly 2022). This fish species is nocturnal, inhabiting caves and cracks, crevices during the daytime (Kuiter and Tonozuka 2001).

In the present paper, we reported the first visual record of juvenile *S. rubrum* from Iskenderun Bay, southeastern Mediterranean, Turkey. Besides, we also believe that reporting the existence of this juvenile specimen will help scientists and public authorities working in this field determine the juvenile stage of this species.

A single juvenile specimen of *S. rubrum* was photographed at a depth of 3 m during a SCUBA diving expedition in Konacik/Arsuz (Iskenderun Bay, 36° 21′N-35° 49′E) on September 11, 2018 (Figure 1). The surface water temperature was 29° C. This specimen was photographed on a rocky habitat, partially covered with algae and sea grass (Figure 2). Morphological and colour descriptions used for the identification followed Randall (1998).

Some of the visible features of the specimen of *S. rubrum* observed with a camera in SCUBA diving were as follows. Body compressed and covered with coarsely scales. Head scaly and slightly convex. Mouth terminal and sharp nose.

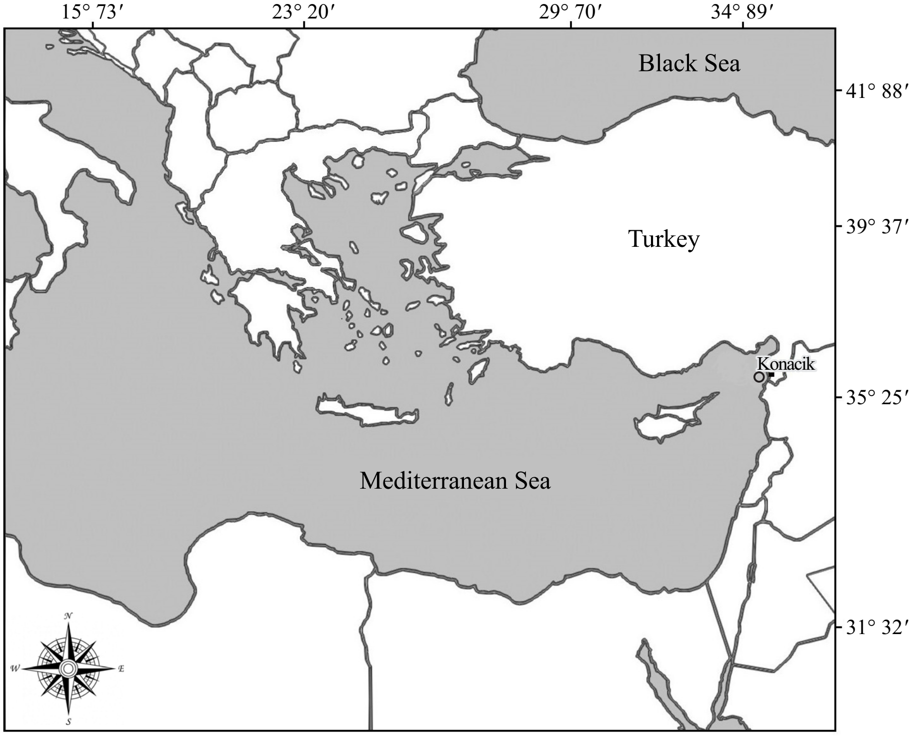

Figure 1. Map showing the capture site (○) of juvenile *Sargocentron rubrum* in the Mediterranean Sea.

Figure 2. A) Underwater observation of *Sargocenton rubrum* (Forsskål, 1775) in Konacik (Arsuz), Iskenderun Bay. B) Dark patch on the anterior dorsal fin of juvenile specimen of *S. rubrum* (photo: Necdet Uygur).

Very large eye (Allen and Swainston 1988; Golani et al. 2021). The colour of the juvenile specimen was silvery with bluish upper parts, silvery flanks and dark large black spots on dorsal rays. Tip of membranes of spinous dorsal fin translucent. Caudal lobes and anterior soft rays of anal fins whitish. Pectoral fins and pelvic fins light white.

The Family Holocentridae includes 83 species all inhabiting tropical and subtropical seas (Nelson et al. 2016). Seven species of Holocentridae have been recorded in the Mediterranean Sea (Vella et al. 2016; Mehanna and Osman 2022; Deef 2021; Ghanem et al. 2022). All of them non-indigenous. Six originating from the Red Sea (Lessepsian migrants): *Neoniphon sammara*, *Sargocentron caudimaculatum* (Rüppell, 1838), *Sargocentron rubrum* (Forsskål, 1775), *Sargocentron spiniferum* (Forsskål, 1775), *Sargocentron spinosissimum* (Temminck and Schlegel, 1843), and *Sargocentron tiereoides* (Bleeker, 1853); and one of Atlantic origin: *Holocentrus adscensionis* (Osbeck, 1765) (Woods and Greenfield 1978; Greenfield 2002).

Another species, *Sargocentron praslin* (Lacepède, 1802), was mentioned in the literature as occurring in the Mediterranean, but this is evidently a misidentification of *S. rubrum* (Golani et al. 2021). However, Bariche et al. (2015) claimed that molecular evidence highlighted that more than one species of *Sargocentron* could occur in the Mediterranean Sea.

Sargocentorn rubrum is a benthopelagic species, usually seen alone or in small groups. It feeds on benthic crabs, small fishes and shrimps at night (Golani et al. 1983; Randall et al. 1990; Göthel 1992). The recorded maximum total length was 32 cm (TL) for this species (Fischer et al. 1990). This species commonly inhabits seagrass beds and hard-bottomed habitats from the reef flats and on lagoons, bays, and seaward reefs, sometimes sheltering in branching corals (Lieske and Myers 1994; Randall and Greenfield 1999).

In the present study, the redcoat *S. rubrum* was observed at 3 m depth in the Arsuz coast (Turkey). The determined juvenile specimen was discovered while diving between crevices on the rock. Holocentrids in their pelagic stage are typically silver-blue (Lies and Carson-Ewart 2000), thus matching the coloration of the photographed specimen. Upon settlement, they change to adult coloration. The black blotch on the anterior dorsal fin distinguishes juvenile *S. rubrum* from other Mediterranean holocentridae (Golani and Ben-Tuvia 1985). It naturally occurs at depths of 1-84 m (Randall 1998). The depth range of the discovered juvenile (3 m) specimen was also in accordance with the literature (Froese and Pauly 2022).

Sargocentron rubrum is a venomous species. It has a strong venomous spine at the corner of its preopercle (Randall and Greenfield 1999). It is a common species in the aquarium trade in India (Gopakumar 2008). This species is also used as a baitfish in tuna fisheries (Blaber et al. 1993).

Our finding in Iskenderun Bay was the first occurrence, and hence the first evidence of the juvenile specimen of redcoat on the southeastern Mediterranean coast of Turkey. Data presented here are important in terms of the current status of the species and the biodiversity in the region. Additionally, this study can be useful in the field of fisheries and can contribute to both fisheries management and the knowledge of the juvenile stage of *Sargocentron* spp.

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TECHNICAL PAPER

Can commercially available mosquito nets be used for rearing sandfish (*Holothuria scabra*) juveniles in floating ocean nursery?

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ABSTRACT. This study investigates the potential of locally available mosquito nets as an alternative material for sandfish ocean nurseries. Mosquito nets (~ 2 mm mesh) were designed into single (SL), double (DL), and triple-layered (TL) to approximate the conventional hapa (CH) with ~ 1 mm mesh normally used in sandfish ocean nurseries. The study was conducted in Maliwaliw island and in a cove in Buyayawon both located in Eastern Samar, Philippines. Results showed that TL had the highest juvenile survival (35.93 ± 10.56%) in Maliwaliw, which was significantly different ($p < 0.05$) from SL and DL. The DL design showed the highest survival (25.23 ± 17.15%) in Buyayawon by day 60, followed by TL (21.37 ± 3.11%), although not statistically significant. On the other hand, average growth rate was highest in SL in both sites where survival was also the lowest. Biomass, however, was the highest in DL in Buyayawon (1,014 ± 266 g m^{-2}) followed by TL in Maliwaliw (925 ± 107 g m^{-2}). Sandfish juvenile survival in DL and TL were higher than those in the CH in both sites suggesting that mosquito nets can indeed be used as an alternative material for rearing early-stage sandfish juveniles in floating ocean nurseries.

Key words: Ocean nursery, post-settled sandfish, growth, survival, Philippines.

¿Se pueden utilizar redes mosquiteras disponibles en el mercado para criar juveniles del pepino de mar (*Holothuria scabra*) en jaulas oceánicas flotantes?

RESUMEN. Este estudio investiga el potencial de los mosquiteros disponibles localmente como un material alternativo para los criaderos de pepinos de mar en el océano. Los mosquiteros (malla de ~ 2 mm) se diseñaron en una sola (SL), doble (DL) y triple capa (TL), para aproximarse al hapa convencional (CH) con malla de ~ 1 mm que normalmente se usa en los criaderos de pepinos de mar en el océano. El estudio se realizó en la Isla de Maliwaliw y en una cala en Buyayawon, ambas ubicadas al Este de Samar, Filipinas. Los resultados mostraron que el TL tuvo la supervivencia de juveniles más alta (35,93 ± 10,56%) en Maliwaliw, significativamente diferente ($p < 0,05$) de los diseños SL y DL. La DL obtuvo la mayor supervivencia (25,23 ± 17,15%) en Buyayawon al día 60, seguido de TL (21,37 ± 3,11%), aunque no fue estadísticamente significativa. Por otro lado, la tasa de crecimiento promedio fue más alta en SL en ambos sitios, en donde la supervivencia también fue la más baja. La biomasa, sin embargo, fue más alta en DL en Buyayawon (1.014 ± 266 g m^{-2}) seguida de TL en Maliwaliw (925 ± 107 g m^{-2}). La supervivencia de juveniles de pepinos de mar en DL y TL fue mayor que la de CH en ambos sitios, lo que sugiere que las redes mosquiteras pueden usarse como un material alternativo para criar juveniles de pepinos de mar en etapa temprana en jaulas oceánicas flotantes.

Palabras clave: Criadero oceánico, pepino de mar bentónico, crecimiento, supervivencia, Filipinas.

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INTRODUCTION

Holothuria scabra, commonly known as sandfish, are high-value sea cucumber species cultured in the Philippines and other countries. The success of sandfish grow-out culture largely depends on the supply of sandfish juveniles. Fortunately, the technology for juvenile sandfish production in land-based hatcheries are well established (Agudo 2006; Gamboa et al. 2012; Juinio-Meñez et al. 2012). Post-settled hatchery-produced sandfish juveniles (< 5 mm in length) are transferred to ocean nursery systems (Agudo 2006; Gamboa et al. 2012; Juinio-Meñez et al. 2012; Mills et al. 2012) for further rearing. Sandfish culture techniques in nursery systems vary in different countries. In Vietnam, and northern Australia, pond nursery systems employ hapa nets stocked with sandfish juveniles measuring 1-2 mm (Pitt and Duy 2004; Bowman 2012). In New Caledonia, nursery systems follow two phases (Agudo 2006). Early-stage juveniles (< 5 mm) are maintained in bare (without sand) tanks until they reach a size of about 10-20 mm (1 g). Then, they are transferred to tanks lined with a thin layer of sand enriched with mud or food supplement. While this hatchery-based nursery system has shown good results, this is not practical in the Philippines because of the high operating cost and space limitations (Juinio-Meñez et al. 2012). Marine ponds with sandy substrate are also not common in the country. To address these bottlenecks in sandfish juvenile production, the floating ocean nursery system was developed (Juinio-Meñez et al. 2012).

Ocean nursery rearing of early-stage sandfish juveniles (~ 3 mm) uses a conventional hapa made from fine nylon net with ~ 1 mm mesh size (Gamboa et al. 2012; Sinsona and Juinio-Meñez 2019; Altamirano and Noran-Baylon 2020). Juveniles are reared for 30-60 d before released to sea ranch or enhancement sites.

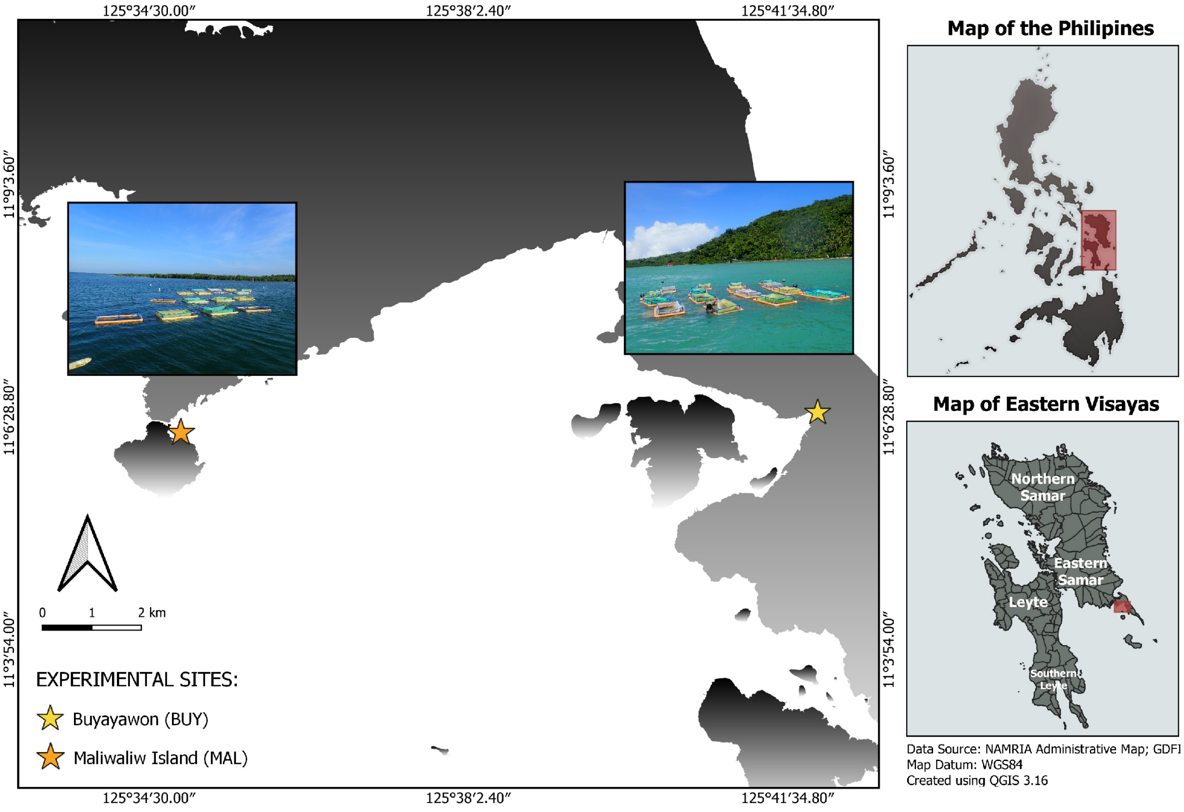
A study conducted in Bolinao (Pangasinan province) comparing the growth and survival of sandfish in ocean floating hapas and hapas in ponds found that survival rates of juveniles in both hapa systems were similar albeit with lower average growth rates in ocean nursery (Juinio-Meñez et al. 2012). Likewise, a study by Cabacaba and Campo (2019) in Guiuan, Eastern Samar, comparing the growth and survival of sandfish juveniles in floating hapas and those in rearing tanks, showed better growth of juveniles in the floating hapas but lower survival rate. However, the difference in the survival rate was not significant. Same authors recorded 64.88% survival of 1,000 early sandfish juveniles stocked per hapa in floating ocean nursery after 45 d of rearing, while Altamirano and Noran-Baylon (2020) recorded 70.5% survival after 60 d. According to Juinio-Meñez et al. (2012), ocean nurseries using floating hapas are cost-effective and strategic for community-based grow-out and sea ranching. However, the fine nylon mesh net (~ 1 mm) used in ocean nursery systems is not readily available in local stores in Eastern Samar nor in Eastern Visayas. They came from Western Visayas and are rather expensive for small-scale fishers who want to go into sandfish rearing. One piece of locally available mosquito net costs only about USD 3.00, whereas fine mesh nets cost USD 30.00 a piece, including handling and delivery costs. Hence, this study was conducted to investigate the potential of using locally available mosquito nets as an alternative material for rearing early-stage sandfish juveniles in floating ocean nurseries.

MATERIALS AND METHODS

Field experiments were conducted from March to May 2021 in the nearshore waters of Barangay (smallest political unit in the Philippines) Maliwaliw, Salcedo (Site 1), and in Barangay Buyayawon, Mercedes (Site 2) in Eastern Samar, Philippines (Figure 1). Site 1 (11.10513° N-125.58088° E) is adjacent to a mangrove and seagrass bed and exposed to moderate to strong wave action. Site 2 (11.10886° N-125.69852° E) is a cove with minimal wave exposure, and water flow/circulation is constrained by a provincial road cutting through and made possible only through a short bridge. Some houses are situated along the coastline of the cove which could be a potential source of nutrient inputs into the water.

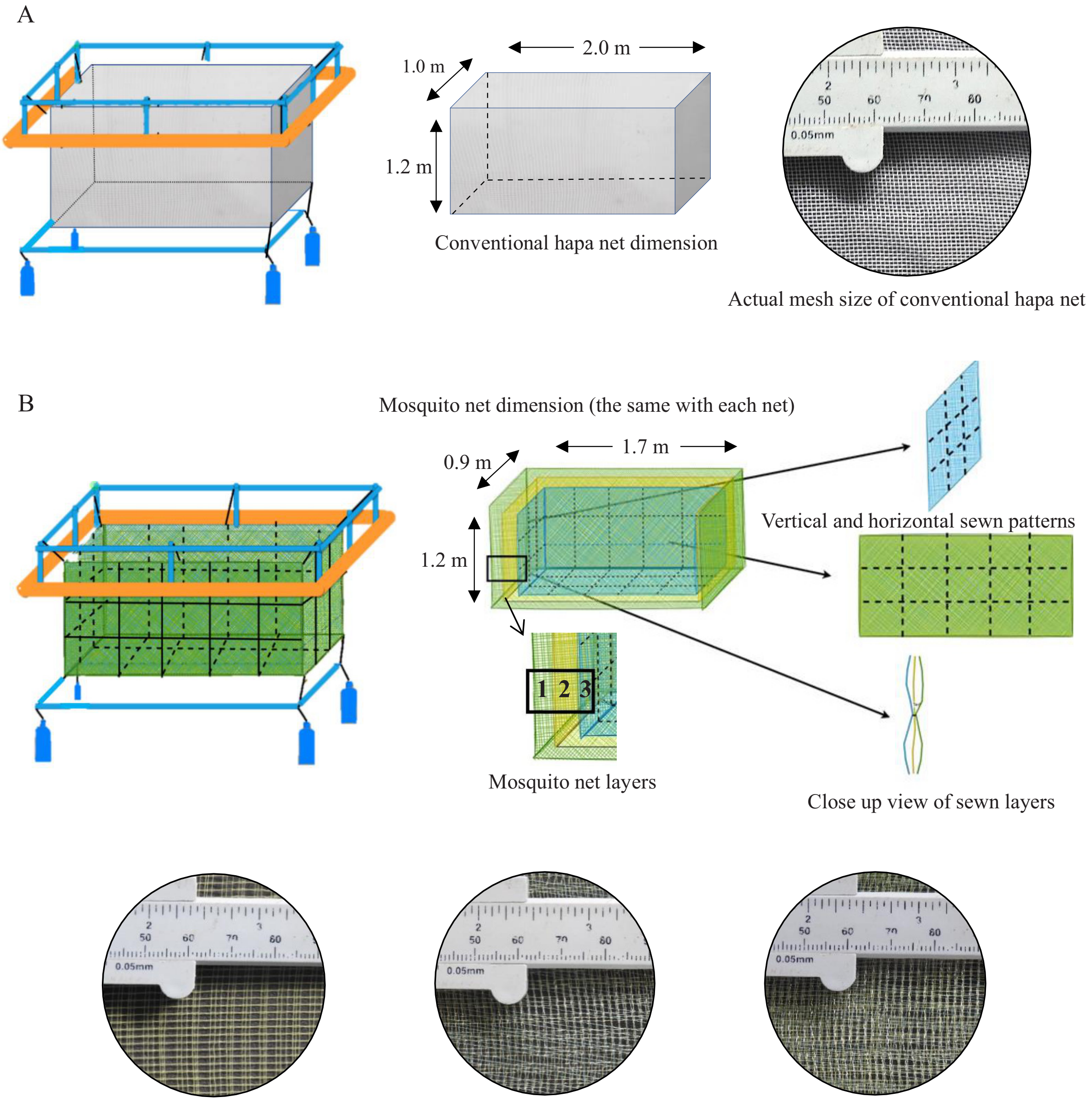
Mosquito nets used has a dimension of 1.7 m × 0.9 m × 1.2 m (length × width × height) and do not have uniform mesh size. Because of the mesh size, three designs were tried: single-layer (SL), double-layer (DL), and triple-layer (TL) alternating bigger and smaller mesh sizes. The DL and TL were made by overlaying 2 and 3 mosquito nets, respectively. To prevent flapping of the overlayed nets while at sea, the bottom and sides of nets were sewed horizontally and vertically (Figure 2). For each site, 12 hapas were installed consisting of triplicate of each mosquito hapa net design, and the conventional hapa. Each hapa net is attached to a rectangular frame (2 m × 1 m) made from PVC pipe (4" diameter). To maintain the rectangular shape of the bottom, a rectangular perforated (2 m × 1 m) frame made from 3/4" blue PVC pipe were also attached to each hapa net. Improvised sinkers made from re-used plastic bottles (~ 1 l) filled with sand were also attached to the four corners of the hapa net.

Prior to stocking juveniles, nets were pre-conditioned for three days, following nursery culture



Data Source: NAMRIA Administrative Map; GDFI
Map Datum: WGS84
Created using QGIS 3.16

Figure 1. Location of experimental sites in Eastern Samar, Philippines. Data Source: NAMRIA Administrative Map, GDFI 2022.WGS84. QGIS 3.16.



B1. Actual mesh size of single-layer (SL) mosquito net design

B2. Actual mesh size of double-layer (DL) mosquito net design

B3. Actual mesh size of triple-layer (TL) mosquito net design

Figure 2. Diagram of experimental set-up: conventional hapa, dimension, and actual image of mesh size (A); and mosquito net design, dimension, layering, sewn patterns, and actual image of mesh sizes of different layers (B).

protocols (Gorospe et al. 2019; Sinsona and Juinio-Meñez 2019; Altamirano and Noran-Baylon 2020). Pre-conditioning allows colonization of periphyton biofilm, which will serve as food source for sandfish juveniles. Twenty-four thousand early stage (50 d post-settlement) sandfish juveniles were obtained from the Bureau of Fisheries and Aquatic Resources-Guiuan Marine Fisheries Development Center (BFAR-GMFDC) sea cucumber hatchery facility. To get the initial weight, juveniles were photographed with scale reference and length was measured using CPCE V4.1 software. Body weight values were then derived using the equation, $W = 0.000614*L^{2.407}$ (Purcell and Agudo 2013). Juveniles were then packed in transparent polyethylene plastic bags filled with seawater at 1,000 juveniles per bag. Oxygen was pumped into each bag before closing it tightly with a rubber band, and then transported in a boat to the study sites in Maliwaliw Island, and Buyayawon. Maliwaliw and Buyayawon are approximately 8.74 and 6.15 nm away from the BFAR-GMFDC hatchery, respectively. Juveniles were acclimatized *in situ* for 5 min before they were slowly poured out of the plastic bags into each hapa net. Each net was stocked with 1,000 juveniles.

Mean weight, average growth rate (AGR), and survival of stocked juveniles were monitored on day 30 (D30) and 60 (D60). Average growth rate (AGR) was calculated as the difference in the final average weight and initial average weight divided by the number of rearing days (Altamirano and Noran-Baylon 2020). Biomass was computed as the ratio of the product of the number of survival and mean weight divided by the bottom area of the hapa. Survival of juveniles was monitored by counting all surviving juveniles on D30 and D60. To avoid biofouling, nets were cleaned every 15 d. Nets were replaced with preconditioned nets on D30.

Growth and survival data among net designs were analyzed using IBM* SPSS* Statistics Version 21. Prior to analysis, all measurements and computed data (e.g. AGR, biomass) were tested for normality using Shapiro-Wilk Test ($p > 0.05$). The effect of site and hapa net layers on sandfish mean weight, AGR, survival, and biomass on D30 and D60 were analyzed using two-way ANOVA. Where significant differences were found, Tukey HSD was used as post-hoc test. Where there is a statistically significant interaction effect found ($p < 0.05$), a simple main effects analysis was carried out using the SPSS Statistics syntax. Data on the conventional hapa for both sites were excluded from the analysis since Maliwaliw has missing hapa replicates due to Typhoon Surigae.

RESULTS

On D30, DL had the highest mean wet weight at Site 1 (2.38 ± 0.69 g) and Site 2 (1.01 ± 0.02 g) (Figure 3). In contrast, SL recorded the lowest mean weight at Site 1 (1.84 ± 0.17g) and in TL at Site 2 (0.89 ± 0.11 g). However, results did not significantly differ among net designs ($p = 0.458$). At D60, SL recorded the highest mean weight in both Sites 1 (11.68 ± 4.78 g) and 2 (9.87 ± 9.15 g), while TL recorded the least in both Sites 1 (4.23 ± 1.53 g) and 2 (4.71 ± 0.55 g). Statistical analysis did not show significant differences among net designs (two-way ANOVA, $p > 0.05$). The mean weight of the surviving juveniles in CH was 2.02 g, but from 1 hapa net only as two of the CH nets were overturned during typhoon Surigae (*Bising*) prior to D30 monitoring. At Site 2, the mean weight of juveniles in CH (0.93 ± 0.14 g) was second highest to DL, but differences were not significant to all mosquito net designs. With respect to location, Site 1 had significantly bigger sandfish (2.04 ± 0.46 g) on D30 regardless of net design ($p < 0.05$), but did not significantly differ from Site 2 on D60.

Similar to the mean weight, significant differences of AGR between sites were found on D30 only. At Site 1, AGR of juveniles was highest in DL followed by CH, while SL and TL had same values. At Site 2, all mosquito net designs including CH had the same AGR values (0.03 g day^{-1}). At D60, SL and DL had the highest AGR (0.19 g day^{-1}), while TL (0.07 g day^{-1}) recorded the low-

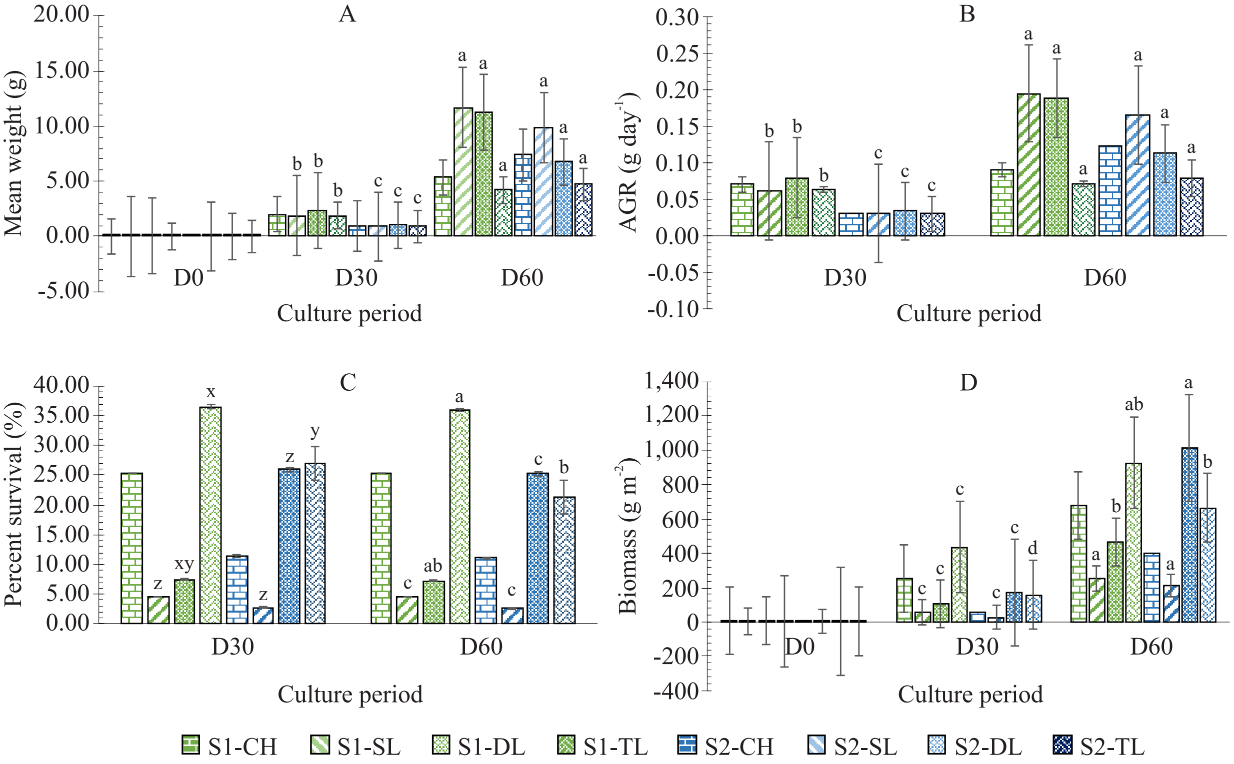


Figure 3. Mean weight (A), average growth rate (B), percent survival (C), and biomass (D) of sandfish (*Holothuria scabra*) reared in different sites (S1 = Maliwaliw, Salcedo, Eastern Samar; S2 = Buyayawon, Mercedes, Eastern Samar) using different net designs (CH = conventional hapa; SL = single layer mosquito net; DL = double layer mosquito net; and TL = triple layer mosquito net) from March to May 2021. Means with the same lower case indicate homogeneous groups as determined by two-way ANOVA and Tukey HSD post-hoc test ($p < 0.05$).

est at Site 1. Similarly, SL (0.16 g day^{-1}) had the highest AGR at Site 2 followed by CH (0.12 g day^{-1}), while TL (0.08 g day^{-1}) had the lowest. However, values were not statistically different between sites nor among net designs ($p > 0.05$).

Significantly differing results in survival of sandfish juveniles between sites and among net designs were found during the culture period ($p < 0.05$). At D30, highest survival was recorded in TL in both sites (36.53% and 27.07%, respectively), while SL consistently had the lowest. At D60, best survival was still observed in TL (35.93%) at Site 1 while DL (25.23%) surpassed the TL (21.37%) at Site 2, albeit not significantly ($p = 0.607$). The juvenile survival in DL was significantly higher ($p < 0.05$) at Site 2 than Site 1 at D30 and D60. Interestingly, sandfish juveniles in CH had low percentage survival with 25.30% for one net only at Site1 and 11.13% at Site 2 on D60.

Biomass (g m^{-2}) were significantly different ($p < 0.05$) between the SL, DL, and TL ($p = 0.001$). Moreover, there is a statistically significant difference between the biomass of sandfish reared at Site 1 and Site 2 for TL ($p = 0.002$). At D30, TL biomass at Site 1 was highest (433.88 ± 126.01 g m^{-2}) among all net designs and between sites. At Site 2, DL had the highest biomass at (172.77 ± 123.34 g m^{-2}) but did not significantly differ from TL and SL at 159.18 ± 41.77 g m^{-2} and 28.22 ± 43.20 g m^{-2}, respectively. At D60, biomass in DL (1014.17 ± 455.14 g m^{-2}) at Site 2 surpassed TL (924.66 ± 107.13g m^{-2}) at Site 1, albeit not significantly ($p > 0.05$). Similar to growth and survival, biomass produced in CH on D60 at Sites 1 and 2 (679.31 g m^{-2} and 398.20 g m^{-2}, respectively) was lower than that of TL in both sites.

DISCUSSION

This is a preliminary study on the potential of using mosquito nets as an alternative material for rearing early-stage sandfish juveniles in floating ocean nurseries. Sandfish growth performance on D30 at Site 2 was lower compared to those reared at Site 1. Though food plays a vital role in the growth and development of any organism, food availability may not be a problem as Site 2 had more food available indicated by the high chlorophyll-*a*, and ash-free dry weight (unpublished data) of periphyton, which measures microalgae and total biomass, respectively. Factors that may have affected the growth performance of juveniles might be related to environmental parameters in each site. According to Magcanta et al. (2021), water salinity affects the growth of sandfish juvenile. High precipitation brought by heavy rains and typhoon Surigae during the first 30 d of rearing could have lowered the water salinity at Site 2 which has restricted water movement. During this period, low surface water salinity ranging from 20.95 to 25.40 was recorded for Site 2. Altamirano et al. (2021) also noted poor growth performance in sandfish reared in protected coves with less water movement than those reared at sites exposed to relatively high-water movements. However, this was more related to the effects of flow velocity on biofilm colonization in hapa nets rather than on water salinity.

Survival of sandfish juveniles in mosquito net hapas during the first 30 d of rearing greatly depended on the design (i.e. SL, DL, TL) which may be due to the juvenile-size and mesh-size relationship. Since sandfish juveniles stocked in the hapas on D0 were only 1-5 mm in length, many juveniles could have easily escaped from the SL (~ 2 mm mesh) set-up. On the other hand, some juveniles in DL and TL were found trapped in between the net layers. In contrast, there is nowhere to go for juveniles in SL but out to the sea if they escape from the relatively big mesh size of the mosquito net. Thus, the significantly higher juvenile survival especially in TL can be attributed to the net design.

The low survival in DL at Site 1 compared to Site 2 may be due to higher exposure to wave action. In addition, the impact of typhoon Surigae may have caused juveniles to be ‘squeezed’ out of the outer net. Conversely, survival of sandfish juveniles in CH at Site 2 was lower compared to the CH (remaining unit) at Site 1. This could be due to the fouling of hapa nets at Site 2 which has minimal water disturbance unlike Site 1. Such condition allows faster biofilm accumulation and subsequent fouling particularly as CH has very fine mesh. Other factors such as handling, predation (Cabacaba and Campo 2019; Altamirano and Noran-Baylon 2020), and salinity fluctuations (Magcanta et al. 2021) during heavy rains also affect growth and survival of sandfish juveniles.

While sandfish juveniles from SL had higher mean weight at both sites, the juvenile survival was incredibly low, and the resulting biomass is also low (251 ± 184 g m^{-2} and 214 ± 455 g m^{-2} for Site 1 and Site 2, respectively). This suggests that SL is not suitable for rearing early-stage sandfish juveniles. On the other hand, TL showed better growth and survival performance in both sites. Additionally, the survival of sandfish juveniles from D31-D60 was high (98.63%) after restocking, which was observed on D60. Unfortunately, it is not possible to compare the growth and survival performance of TL and CH at Site 1, since juveniles were lost when two replicate CH nets got overturned during typhoon Surigae before the D30 monitoring.

Results of this study demonstrated the potential of using mosquito nets in rearing early-stage sandfish juveniles in ocean nursery systems. In particular, the DL and TL designs can substitute the CH. The sandfish biomass at Site 2 on D60 for DL and TL was much higher than that from CH. Likewise, the biomass produced at Site 1 for TL was also much higher than CH. Moreover, the cost of the DL (USD 6.00) and TL (USD 9.00) per unit is significantly much lower than that of the CH (USD 30.00). To validate the results and improve ocean nursery systems of sandfish with the use of mosquito nets, studies on the effect of a) wet and dry seasons, b) cleaning frequency, c) predation, d) stocking density, and e) food availability on the growth and survival of sandfish juveniles using DL and TL are recommended.

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Disclosure statement

All authors have read and approved the final manuscript and declare that they have no conflicts of interest.

Data availability statement

The authors confirm that all relevant data and its supporting information are within the manuscript.

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AUTHOR GUIDELINES

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