

## Fishers' perception and activity shifts in a dolphin bycatch mitigation context

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### ABSTRACT

Fishing exclusion zones aim to reduce cetacean bycatch, but often neglect social and ecological side effects, exacerbating social injustices and reshaping fishing practices. We present a case study of an endangered population of Lahille's bottlenose dolphins (*Tursiops truncatus gephyreus*) in a Brazilian coastal lagoon, known for its unique cooperation with net-casting fishers. However, the local small-scale fisheries (SSF) also employ other fishing gears that contribute to dolphin bycatch, prompting the enforcement of a fishing ban in the area. We investigated fishers' socioeconomic conditions, evidence of social disparities, perceptions on dolphin bycatch, and projected changes on fisheries activities to understand the repercussions of the ban. We categorized 128 surveyed fishers into five groups based on socioeconomic factors and their reliance on dolphin-cooperative and gillnet fisheries. Our findings revealed significant disparities in social capital among fishers and their different attitudes towards dolphin bycatch, highlighting unforeseen consequences. To investigate how fishers would likely shift fishing practices, we considered two management scenarios: 1) should dolphin-fishing cease due to unsuccessful bycatch mitigation, fishing efforts would shift towards shrimp trawling, seine nets, and gillnet effort; 2) if gillnet-fishing is successfully banned as a bycatch mitigation measure, a shift to shrimp trawling and cast net effort. Both scenarios would intensify pressure on shrimp stocks, which are already heavily exploited in this socioecological system. Our research underscores the importance of contemplating alternatives to achieve sustainable outcomes when designing bycatch mitigation measure. Furthermore, our results point to the importance of a participatory governance approach, grounded in the socioeconomic context, to safeguard the livelihoods of small-scale fishers and foster broader conservation efforts beyond species-specific concerns.

### 1. Introduction

Coastal socioecological systems are influenced by a wide range of concurrent human activities (Refulio-Coronado et al., 2021), most notably fishing. Fishing serves as both a cultural and subsistence practice from a human perspective (Díaz et al., 2018), and an extractive activity from an ecosystem standpoint (Pikitch et al., 2004). Small-scale fisheries (SSF), which involves small vessels operated in coastal waters (Allison and Ellis 2001), are particularly relevant in coastal systems, typify the deep connections and relationships between local economics,

ecologies, communities and culture (Pomeroy and Andrew 2011). At developing countries, SSF fishers may struggle with poverty, relying on fisheries for income and food security (Béné et al., 2007; Galligan 2021), and can be marginalized due to inadequate governance (Sumaila, 2012). Simultaneously, as an extractive activity, fishing can cause adverse effects on the coastal system (Pauly et al., 1998).

Given that SSF areas overlaps with the habitat of threatened cetacean populations (Brownell et al., 2019), unintentional capture, or bycatch, is a significant concern, particularly for endangered cetacean populations (Reeves et al., 2005; Jaramillo-Legorreta et al., 2019). Examples of such

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populations include vaquitas (*Phocoena sinus*) in Mexico (Taylor et al., 2017), Franciscana dolphins (*Pontoporia blainvillei*) in South America (Secchi et al., 2022), Atlantic humpback dolphins (*Sousa teuszii*) in Western Africa (Brownell et al., 2019) and Māui dolphins (*Cephalorhynchus hectori mauui*) in New Zealand (Slooten 2013). A number of bycatch mitigation strategies have been implemented to mitigate bycatch and prevent irreversible ecological consequences (Thompson et al., 2000; Jaramillo-Legorreta et al., 2007; FAO 2021; Wade et al., 2021). Commonly used strategies include the use of acoustic deterrent devices, fishing exclusion zones, fishing effort redistribution, or changes in fishing gear or practices (FAO 2021). While these mitigation strategies have been effective in bycatch reduction, they often overlook the social and ecological repercussions that arise from bycatch mitigation (Bennett and Dearden 2014; Wu et al., 2022). Neglected consequences include the exacerbation of social injustices for fishers burdened by area closures (Abbott and Haynie 2012; Cohen et al., 2019) and the potential redirection of their fishing efforts (Powers and Abeare 2009; Lewison et al., 2018). Bycatch mitigation effects may lead to emerging social conflicts and, as a result, addressing socioeconomic contexts has been identified as crucial when defining strategies to mitigate cetacean bycatch (Komoroske et al., 2015; Lewison et al., 2018; Suuronen 2022). Unfortunately, the assessment and discussion of socioeconomic dimensions in practice remain scarce (see Teh et al., 2015, for example).

Here, we present a case study in a coastal lagoon system in southern Brazil (Simões-Lopes et al., 1998), which is home to a small ( $N = 60$ ) and isolated population of Lahille's bottlenose dolphins (*Tursiops truncatus gephyreus*) (Fruet et al., 2014; Bezamat et al., 2019). Despite the apparent population stability with no observed trends in the past 20 years, a Population Viability Analysis (PVA) applied to investigate the long-term viability of this population indicated that only a zero-bycatch approach would be sustainable for its long-term survival (Bezamat et al., 2021). Within this population, a subset of dolphins engages in a unique foraging tactic that involves cooperative interactions with local net-casting fishers: dolphins herd fish schools towards shallow waters, where fishers strategically await behavioral cues provided by dolphins, indicating where and when to cast their nets (Simões-Lopes et al., 2016). This distinctive foraging tactic results in fishers describing two social groups within the dolphin population: "cooperative" dolphins (locally known as "good dolphins") that regularly interact with fishers, and "non-cooperative" dolphins ("bad/lazy dolphins") that primarily forage independently and rarely or never interact with fishers (Daura-Jorge et al., 2012). This dolphin-fisher interaction has led to socio-economic benefits that foster strong emotional connections within the local community (Machado et al., 2019) and enactment of a municipal law (n° 521/1997), recognizing dolphins as part of the cultural heritage of the city of Laguna.

However, in addition to the net-casting fisheries, the local SSF system also involves other fishing gears that contribute to dolphin bycatch, such as gillnets, used overnight to catch catfish (*Genidens* spp.) near the area where fishers and dolphins engage in cooperative foraging activities (Simões-Lopes 1991; Peterson et al., 2008). This gear is likely the main cause associated with six out of 12 stranded dolphin carcasses recovered during 2016–2018 showing signs of entanglement (data from the systematic carcass recovery programme named Santos Basin Beach Monitoring Project, PMP-BS, <https://www.comunicabaciadesantos.com.br/pograma-ambiental/projeto-de-monitoramento-de-praias-pmp.html> (last access: July 1, 2024). To address this bycatch, a permanent closure area for gillnets was established in 2018 within the dolphins' core area (municipal law n° 1998/2018). Unfortunately, the effectiveness of this closure is compromised due to inadequate enforcement, resulting in ongoing illegal gillnet fishing activities. Gillnet fishers argue that they were not involved in the decision-making process. Indeed, the decision to establish the closure area primarily relied on perceptions of net-casting fishers that cooperate with dolphins (Simões-Lopes 1991; Peterson et al., 2008).

While previous studies of Laguna's dolphin population have

provided valuable insights into dolphin-human interactions (Daura-Jorge et al., 2012; Romeu et al., 2017; Simões-Lopes et al., 2016; Cantor et al., 2023), there remains a crucial need for a more comprehensive understanding of the entire fishery community, particularly regarding their perceptions of the system and the dynamics of their fisheries. In this study, we assessed the context of an existing bycatch mitigation strategy for the endangered population of Lahille's bottlenose dolphins (LBD) in an enclosed lagoon in southern Brazil, considering the socioecological conditions, fisher's perceptions, and the dynamics of the local SSF community. We explore three key questions: 1) Are there significant differences in socioeconomic profiles of fishers from different fisheries that have implications for the bycatch management? 2) What are fishers' perceptions, understanding and attitudes towards dolphin bycatch, and how do these vary among different fishers' profiles? and 3) What are the potential consequences of different bycatch mitigation outcomes on local fishing activity? By addressing these questions, our aim is to critically evaluate the adequacy of current bycatch mitigation strategies and identify additional opportunities to improve it and effectively mitigate the bycatch of LBD.

## 2. Methods

### 2.1. Study area

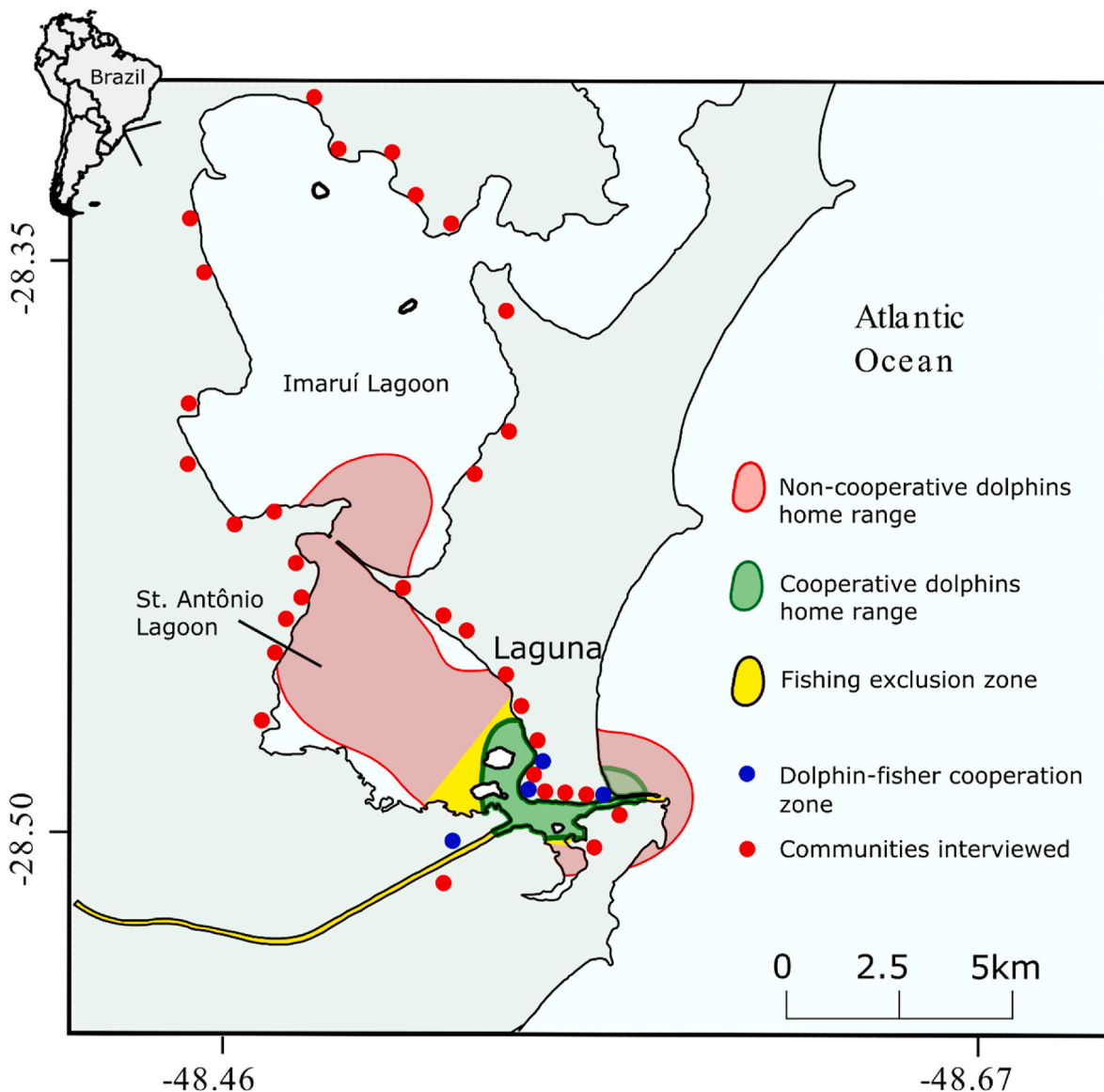
The study area is part of the enclosed estuarine system nearby the city of Laguna, South Brazil. The study area spans the known spatial distributions of the LBD population (Cantor et al., 2018; Daura-Jorge 2013), which covers the Santo Antônio dos Anjos and Imaruí lagoons and the area designated for gillnet fishing prohibition, covering the core area of cooperative dolphins and the Tubarão river (Fig. 1).

Fishing stands as one of the primary economic activities within this socioecological system (Dantas 2018). Historical records trace fishing activity in Laguna back to the Neolithic period, with the *Sambaqui* peoples, succeeded by the *Jê* indigenous peoples, who maintained a strong fishing tradition (Cadorn 2003). When Azorean colonizers settled the region between the 17th and 18th centuries, they incorporated these fishing practices. Nowadays, small-scale fisheries (SSF) in this area are practiced by fishers whose techniques and practices reflect influences from indigenous, African, and Azorean cultures (Santos 2004).

Laguna currently has the largest contingent of registered fishers (>1,300) actively engaged in fishing activity in the state of Santa Catarina (PMAP-SC, 2019). In addition to local artisanal fishers, the lagoon complex attracts numerous tourists and retirees from the region and beyond, motivated by recreational fishing opportunities. The general registration of fishers encompasses all these forms of engagement with fishing, whether as a livelihood or leisure activity. Local SSF primarily targets shrimp (*Farfantepenaeus paulensis* and *F. brasiliensis*), Lebranche mullet (*Mugil liza*), croaker (*Micropogonias furnieri*), crabs (*Callinectes* spp.), catfishes (*Genidens* spp.), flounder (*Paralichthys* sp.), white mullet (*Mugil curema*) and sardines (*Brevoortia* spp.). The gears employed to harvest these stocks in the lagoon complex include fyke nets, cast nets, gillnets, traps, manual trawl nets and lines (Barletta et al., 2017; Dantas 2018). In a previous assessment, Dantas (2018) identified 451 fishers at Santo Antonio dos Anjos Lagoon and the most predominant gears were cast nets (used by 57% of fishers), followed by shrimp trawlers (43% of fishers), seine nets (41% of fishers), fyke nets (32% of fishers), gillnets (25% of fishers), and crab pots (21% of fishers). At Imaruí Lagoon, 693 fishers were interviewed, and their main gears were fyke nets (cited by 81% of fishers), followed by gillnets (24% of fishers), seine nets (22% of fishers), cast nets (19% of fishers), and shrimp trawlers (10% of fishers) (Dantas 2018).

### 2.2. Actors directly involved in the conflict

Considering the focal conflict of dolphin bycatch and the existing



**Fig. 1.** Location of Santo Antônio dos Anjos and Imaruí Lagoons, in Santa Catarina state, Brazil, highlighting the communities interviewed (red dots), the dolphin-fisher cooperation zone (blue dots), the fishing exclusion zone/gillnet ban area (yellow area), and the home ranges of cooperative (green area) and non-cooperative (red area) dolphins.

mitigation strategies (primarily the gillnet ban area), we opted to focus on the fishing gears and respective actors directly involved in this conflict. These actors include those who have the cooperative fishing with dolphins as the most important fishing modality (hereafter dolphin-fishers/dolphin-fishery) and those who have gillnet fishing as the most important fishing modality (hereafter gillnet-fishers/gillnet-fishery). We also anticipate identifying potential bycatch risks associated with others fishing gears that may not have been previously reported. Furthermore, to determine potential shifts in fisheries practices, it is necessary to access information on the use of all fishing gears employed in this area.

### 2.3. Individual interviews

To identify possible interviewees, we applied intentional and snowball sampling methods (Goodman 1961; Robinson 2014). Initially, fishers were chosen based on recommendations from the Fishing Forum of South Lagunar Complex (*Fórum de Pesca do Complexo Lagunar Sul*), with whom the lead researcher has maintained contact since the project was conceived. Intentional sampling consisted in approaching fishers at

piers or when they were engaged in fishing activities within the sampled area (Bernard 2006). Following each interview, respondents were encouraged to suggest additional participants (Goodman 1961; Bernard 2006), and we deemed the sample sufficient either when no new names were suggested, or when theoretical saturation in the information obtained from each locality was achieved (Hagaman and Wutich 2017).

Pilot interviews were conducted with ten fishers across various localities (Fig. 1): Campo Verde (n=2), Magalhães (n = 2), Centro (n = 2), Tesoura (n = 2) and Vila Vitória (n = 2). After adjusting and refining terminologies, we used a semi-structured script (Bernard 2006) comprising 23 questions divided into three sections: (1) socioeconomic assessment (13 questions), (2) fishing activities and dynamics (four questions), and (3) perceptions regarding dolphin bycatch (six questions) (Annex 1). Prior to the interview, participants were informed that participation in the last section was optional, as it touched upon a potentially sensitive topic. Thus, after completing the first two sections, respondents were given the choice to proceed or not with the final section. For analytical purposes, all participants who completed at least the first two sections were considered, along with those who opted to

respond to the last section.

Prior to individual interviews, all participants provided their free and informed consent as per the guidelines of the Ethics Committee for Research with Human Beings at UFSC (CAAE n° 53900721.9.0000.0121). Given the sensitive nature of the interview topics and to ensure participants' comfort, no audio recordings were made. For open-ended questions (related to perceptions about dolphin bycatch), relevant excerpts were summarized during the interview (Flick 2009) and fully transcribed immediately afterward. Data from interviews during which other fishers intervened ( $n = 6$ ) were excluded from the analysis. Additionally, opportunistic participant observations (Patton 2002) were conducted at fishing locations, residences, and during occasional onboard trips with fishers to further enrich our understanding of fishing techniques, gear usage, and the socioeconomic context in which fishers operate (Musante and DeWalt 2010).

### 3. Data analysis

#### 3.1. Socioeconomic attributes

To evaluate the socioeconomic attributes of fishers, we analyzed gender distribution (men and women), age, educational level, months dedicated to fishing per year, reliance on fishing for income, variety of fishing gears used, number of target species captured, and significance of dolphin and gillnet fisheries (Annex 1, questions 1 to 17). These attributes were visually represented using graphs.

In determining fishers' profiles, we considered several socioeconomic attributes alongside the importance of dolphin and gillnet fisheries (Annex 1, questions 14 to 17). We standardized educational level, fishing dependence, and the importance of dolphin and gillnet fishing as ordinal categorical variables on a scale from 0 to 10 (SM1, Table S1). Next, we applied a clustering analysis using the k-means algorithm (Kaufman and Rousseau 2009) to all attributes converted into numeric values. To ensure that variable units did not influence the clustering algorithm, we standardized the data using the *preProcess* function of 'caret' package (Kuhn 2008). The transformation type was set as "range" in the 'method' argument to rescale the data within a specific range (0–1 in this case). To determine the optimal number of clusters, we used the NbClust function, which compares 30 different methods for cluster determination (Charrad et al., 2014).

To operationalize the concept of social disparity among groups of fishers, the factors included in the cluster analysis as proxies for this concept were age, educational level, and reliance on fishing for income. These socioeconomic indicators influence access to social resources and services (Parlee et al., 2021), impact resilience and adaptability of socio-ecological systems (Barnes et al., 2020; D'agata et al., 2020), affect the risk of food insecurity (McClanahan et al., 2015), and determine the flexibility to engage in alternative livelihoods and income activities (Barnes et al., 2020; Amadu et al., 2021).

#### 3.2. Perception of dolphin bycatch

In this study, perceptions refer to individual observations, understandings, interpretations, and evaluations concerning a specific theme (Bennett 2016). These perceptions of reality are subjective and socially shaped, arising from the history and environmental contexts in which individuals are situated (Munhall 2008). Incorporating perceptions into fisheries research and management, though challenging, offers valuable insights into factors influencing fishers' understanding and engagement (Mesquita and Medeiros 2023).

Concerning the central conflict of dolphin bycatch, we posed objective questions to delineate that issue (Annex 1, questions 20 to 22) and open-ended questions to gather insights on perceived harms resulting from bycatch (Annex 1, questions 23 and 24) and suggestions for solutions (Annex 1, question 25). We categorized the suggested solutions according to FAO bycatch mitigation strategies (FAO, 2021).

This guideline provides a comprehensive set of strategies for bycatch reduction through technical measures, categorized into spatial closures, acoustic alerting or deterrent devices, fishing gear modifications, changes in fishing operations, and other strategies.

#### 3.3. Shifts in fishing effort

To assess potential changes in fishing effort related to bycatch, we queried fishers about their primary fishing methods and whether they would consider switching to alternative methods if their primary method were restricted. Our emphasis was on fishers directly involved in the conflict, specifically those engaged in dolphin-fishing and gillnet-fishing. We formulated two hypothetical scenarios, each representing distinct bycatch management strategies and their potential outcomes (Table 1). The first scenario relates to the currently proposed and implemented (but insufficiently enforced) gillnet ban area, considering that adequate compliance and enforcement would eliminate dolphin bycatch in gillnets. The second scenario is based on a Population Viability Analysis of the LBD population (Bezamat et al., 2021), indicating that if current bycatch rates persist without effective reduction measures, the dolphin population faces a high probability of extinction within about 50 years. Then, we analyzed these scenarios to depict potential shifts in fishing activity, drawing from response provided by fishers (Annex 1, questions 15 to 17).

## 4. Results

#### 4.1. Socioeconomic attributes and fishery dynamics

We conducted interviews between July 2021 and November 2022, involving a total of 128 fishers, mostly men ( $n = 121$ ). The mean age was  $51.75 \pm 12.74$  years (min = 22, max = 78) (Fig. 2-A), with the most prevalent educational levels being incomplete primary education (39%,  $n = 50$ ) and complete primary education (32.8%,  $n = 42$ ) (Fig. 2-C). Most fishers (70.3%,  $n = 90$ ) rely solely on fishing for income (Fig. 2-B). On average, fishers engage in fishing for  $11.24 \pm 2.08$  months annually, use  $3.19 \pm 1.12$  fishing gears, and capture  $3.62 \pm 1.45$  different target species (Fig. 2D–F). Fishers who depend on fishing as a primary or significant source of income tend to fish for more months each year and use more gears, compared to those for whom fishing plays a lesser or no role as an income source (Fig. 2D–F). The cited fishing gears include fyke nets, gillnets, seine nets, cast nets, shrimp trawler, pole-and-lines, crab pots, throw scoop nets, longlines and hand scoop net.

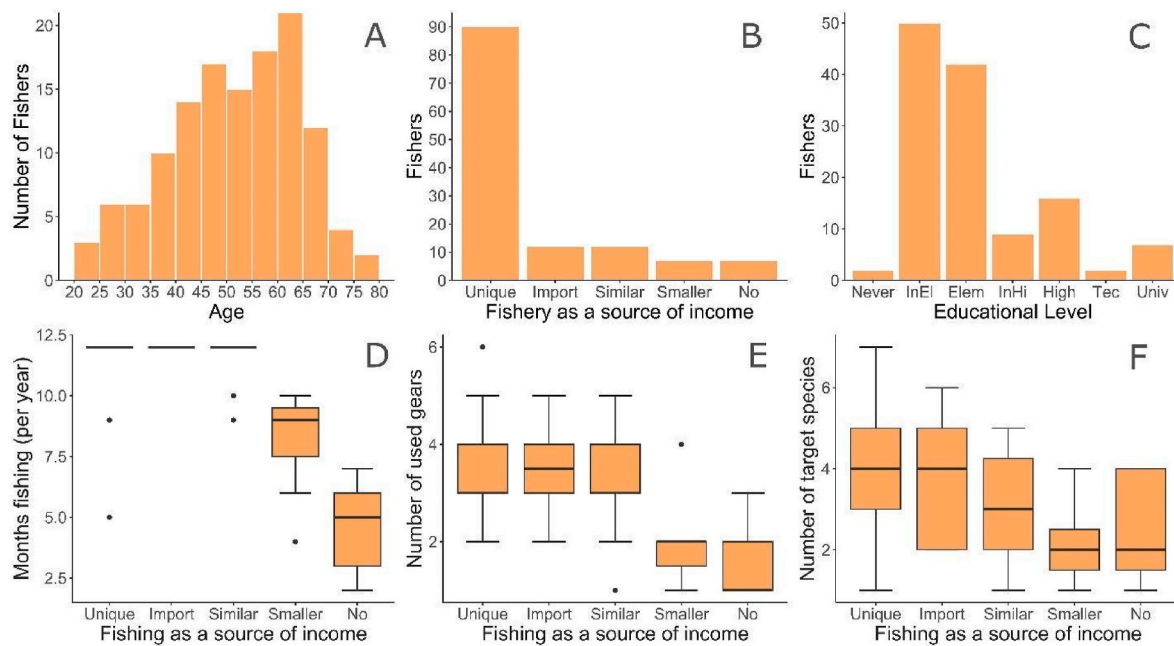
Using socioeconomic attributes (age, education, reliance on fishing income, number of fishing months per year, number of gears used, number of target species captured, and the level of importance of dolphin and gillnet fisheries), fishers were grouped into five groups (Fig. 3 and SM2, Table S2) as follows:

Group 1 (Gillnet group) concentrates most fishers (40.63%,  $n = 52$ ) and consists of older fishers with lower levels of education. They exhibit high economic dependence on fishing, engage in year-round fishing, and utilize an intermediate number of fishing gears and target species captured. Only a few fishers in this group participate in dolphin-fishing ( $n = 3$ ), while all are involved in gillnet-fishing (Fig. 3 and SM2, Table S2). The mean level of importance (scale 0 to 1) of gillnet-fishing in this

**Table 1**

Hypothetical scenarios considering two different bycatch management strategies and their respective outcomes.

	Management strategy	Outcomes
Scenario 1	Exclusion of gillnet-fishing from the system	Bycatch mitigation with the maintenance of the dolphin population and dolphin-fishing
Scenario 2	Unrestricted gillnet-fishing	Unsustainable bycatch levels for the dolphin population and consequent exclusion of dolphin-fishing



**Fig. 2.** General overview of socioeconomic attributes and fishing activity characteristics of interviewed fishers in Laguna (Brazil). (A) Age distributions of fishers. (B) Distributions of fishers by their levels of reliance on fishing for income: **Unique** (fishing as unique source of income), **Import** (most important), **Similar** (comparable to other sources), **Smaller** (less significant than other sources), **No** (fishing not an income source). (C) Education levels of fishers: **Never** (no school attendance), **InEl** (unfinished elementary school), **Elem** (complete elementary school), **InHi** (unfinished high school), **High** (complete high school), **Tec** (technical level), **Univ** (university level). (D) Months engaged in fishing per year for fishers, categorized by the level at which fishing is a source of income. (E) Number of fishing gears used by fishers, categorized by the level at which fishing is a source of income. (F) Number of target species for fishers, categorized by the level at which fishing is a source of income.

group is 0.65, while dolphin-fishing is 0.02.

Group 4 (Shrimp-crab group) is the second-largest group (35.16%,  $n = 45$ ) and shares similarities with group 1, including limited schooling, high dependence on fishing, year-round fishing activity, and a moderate number of gears. However, Group 4 has a slightly younger age profile, fewer target species, no use of gillnets, and no involvement in dolphin-fishing (Fig. 3 and SM2, Table S2). Here, the mean level of importance (scale 0 to 1) of both gillnet-fishing and dolphin-fishing is zero. They primarily alternate between shrimp and crab fishing, using fyke nets, shrimp trawlers, crab pots, and longlines.

Groups 3 and 5 primarily engage in dolphin-fishing but differ significantly in terms of age, education and fishing dependence (Fig. 3 and SM2, Table S2) – exposing a marked social disparity within fishers engaged in dolphin-fishing. Group 5 (Dolphin-dependent group), the third largest group (14.06%,  $n = 18$ ), consists of young fishers with minimal education and a high economic dependence on fishing. The mean level of importance (scale 0 to 1) of dolphin-fishing in this group is 0.98, while gillnet-fishing is 0.19. In contrast, group 3 (Dolphin-leisure group), the smallest group (3.91%,  $n = 5$ ), comprises highly educated, elderly fishers with no economic reliance on fishing (Fig. 3 and SM2, Table S2). The mean level of importance (scale 0 to 1) of dolphin-fishing in this group is 1, while gillnet-fishing is 0.14.

Finally, Group 2 (Occasional group) represents a small proportion (6.25%,  $n = 8$ ) and consists of a few young fishers with intermediate education levels. They fish half of the year, have minimal income from fishing, use limited equipment, capture a few target species, and have minimal involvement in dolphin and gillnet-fishing (Fig. 3 and SM2, Table S2). The mean level of importance (scale 0 to 1) of gillnet-fishing in this group is 0.08, while dolphin-fishing is zero.

Their main gear are pole-and-lines and fyke nets.

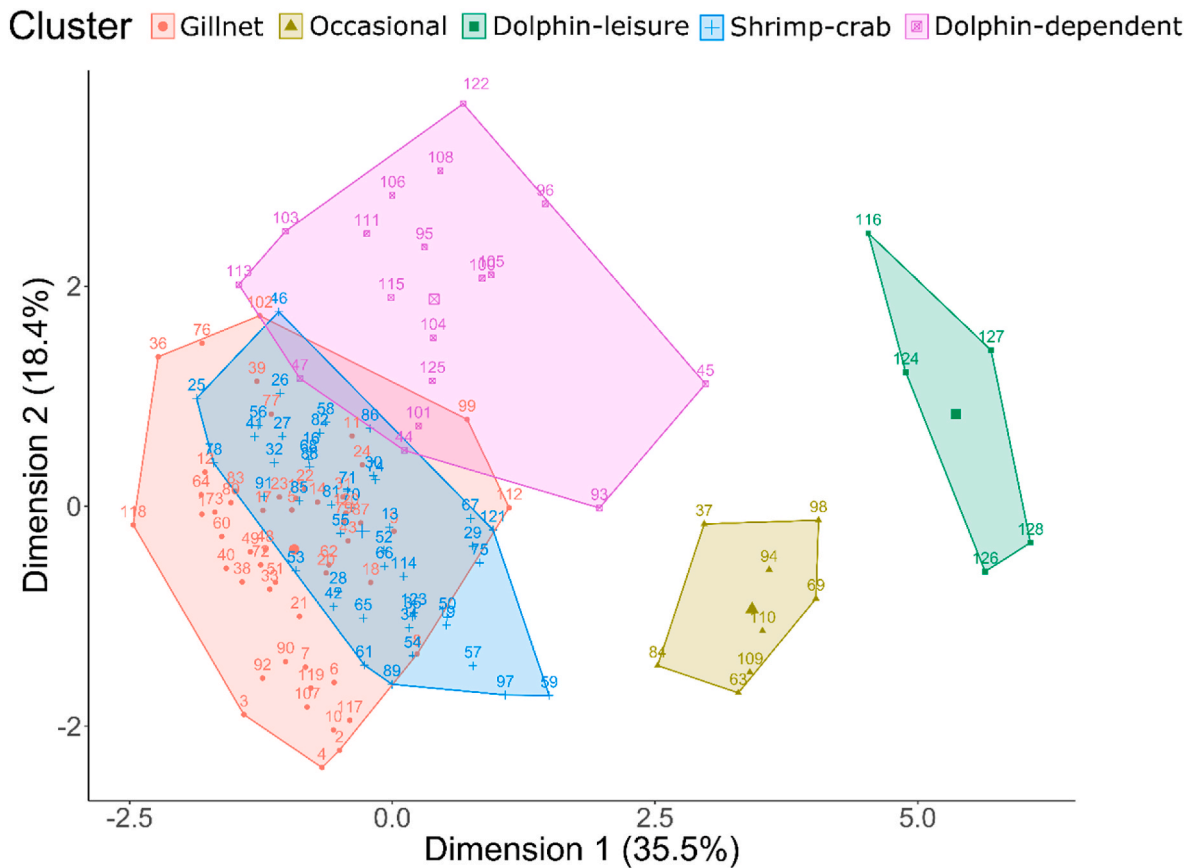
Despite differences in age and fishing methods, Groups 1 (gillnet-fishers), 4 (crab-shrimp fishers) and 5 (dolphin-fishers) overlap due to their low education level, high dependence on fishing income, and year-round fishing activity (Fig. 3 and SM2, Table S2). Together, these three

groups represent 89.85% ( $n = 115$ ) of fishers.

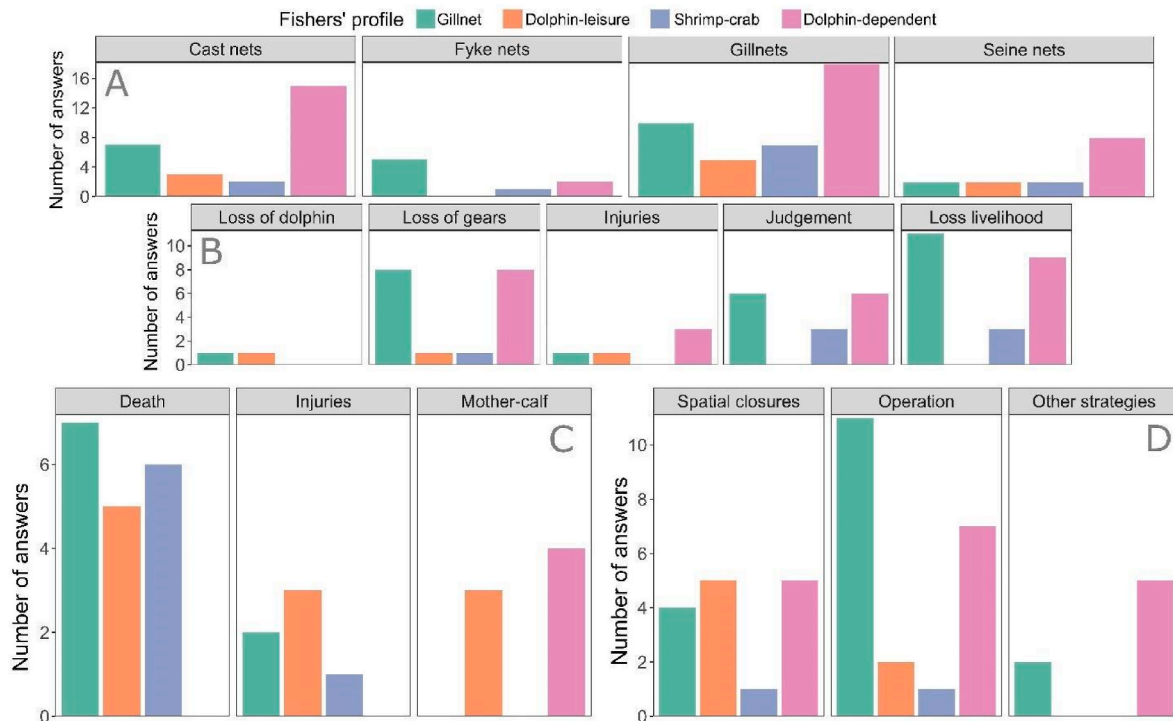
#### 4.2. Fishers' perceptions on dolphin bycatch

Out of the total respondents ( $n = 128$ ), 32.8% ( $n = 42$ ) agreed to answer questions about dolphin bycatch. All fishers from dolphin-dependent group ( $n = 18$ ) and dolphin-leisure group ( $n = 5$ ) participated in this section, while only 23% ( $n = 12$ ) of the gillnet group and 15.5% ( $n = 7$ ) of the shrimp-crab group participated. None of the occasional group fishers participated. Considering all respondents in this section, the most represented groups were those directly engaged in the conflict: dolphin-dependent fishers (43%,  $n = 18$ ) and gillnet fishers (29%,  $n = 12$ ). Although they recognize the existence of local dolphin bycatch, all fishers responded negatively when asked if they had personally experienced any dolphin bycatch incidents. Four types of gears were cited as potentially involved in these events: gillnets ( $n = 40$ ), cast nets ( $n = 27$ ), seine nets ( $n = 14$ ) and fyke nets ( $n = 8$ ) (Fig. 4-A).

Most respondents indicated that these interactions have negative effects on both fishers (79%,  $n = 33$ ) and dolphins (90%,  $n = 38$ ). Among dolphin-leisure fishers, all recognized that bycatch harms dolphins, with only one mentioning harm to fishers. Respondents who did not recognize the harms of dolphin bycatch to fishers were those engaged in dolphin-fishing, with the highest age, highest educational level, and low reliance on fishing for income, reflecting the effects of social disparities on these perceptions. All fishers identified harms to dolphins, except for two fishers from the gillnet group (Fig. 4-C). The reported damages ( $n = 78$ ) caused by dolphin bycatch to fishers included livelihood loss due to restrictive measures ( $n = 23$ ), which was mainly cited by gillnet fishers (100%,  $n = 9$ ) and dolphin-dependent fishers (60%,  $n = 9$ ). Other cited damages were gear loss ( $n = 18$ ), public judgment, and treating fishing as a crime ( $n = 14$ ), loss of dolphin-fishing ( $n = 14$ ), mainly mentioned by dolphin-dependent fishers ( $n = 12$ ), and the risk of injury to the fishers involved ( $n = 5$ , Fig. 4B). Citations of damages to dolphins ( $n =$



**Fig. 3.** Fishers clustering analysis based on socioeconomic attributes of interviewed fishers in Laguna. Fishers were grouped into five distinct clusters, defined by their age, educational level, fishing frequency per year, reliance on fishing for income, number of gears used, target species diversity, and the importance of dolphin and gillnet fisheries.



**Fig. 4.** Perceptions of fishers from different profiles, who participated in the second round of interviews regarding dolphin bycatch. None of the fishers claimed to have personally experienced dolphin bycatch. Perceptions on A) gears involved in dolphin bycatch, B) harms of dolphin bycatch to fishers, C) harms of dolphin bycatch to dolphins and D) suggested solutions to dolphin bycatch, categorized according to the FAO's bycatch mitigation strategies (FAO, 2021).

62) included the risk of drowning ( $n = 36$ ), injuries from gear interactions ( $n = 19$ ), and the potential separation of mother and calf during these encounters ( $n = 7$ , Fig. 4C).

#### 4.3. Fishers' perceptions on potential solutions

The potential solutions proposed ( $n = 44$ ) for these bycatch interactions primarily focused on gillnets and cast nets, with no suggestion directed towards seine nets or fyke nets. Based on FAO measures descriptions, most of these suggestions fell into the categories of changes to fishing operations (48%,  $n = 21$ ) or spatial closures (34%,  $n = 15$ ) (Fig. 4-D). Suggestions classified as changes in fishing operations ( $n = 21$ ) came from fishers across all groups, but were mainly offered by gillnet fishers (52%,  $n = 11$ ) (Fig. 4-D). One proposal involves establishing fishing hours for setting gillnets in the river, considering the observed pattern of dolphin entry and exit. By placing gillnets only after the dolphins have left the river (at nightfall) and removing them before dawn (when dolphins return), the risk of bycatch could be reduced. Another proposal pertains to the size of gillnets. It was suggested that accidental dolphin bycatch increased due to a reduction in the allowed gillnet size. A smaller size makes it challenging to set the net in a stretched position ('*estaiada*'). With the net tightly stretched, dolphins would 'hit' the net but not become entangled. Conversely, with a loose net, dolphins are more likely to get entangled (SM3).

One suggestion of change in fishing operation relates to catfish catches, which are the main gillnet activity associated with dolphin bycatch (Fig. 4-D). This suggestion originates from gillnet fishers and involves permitting a specific technique within the existing no-fishing area. The fishing modality is known as "*pescada maré*" (tidal fishing), and consists of an assisted method of catfish capture that traditionally occurred in the channel. In this method, the gillnet is soaked for about 30 min during the transition from low to high tides. Since this modality holds significant cultural value, the suggestion is to restrict it to local fishers and those that rely on fishing income (SM4).

Suggestions for spatial closures ( $n = 15$ ) were also proposed by all groups, with dolphin-leisure fishers being the most predominant advocates (100%,  $n = 5$ ) (Fig. 4-D). The suggestions varied in their restriction levels. The most restrictive proposals entail a complete ban of gillnets in the lagoons and were suggested exclusively by fishers from the dolphin-leisure group ( $n = 5$ , SM5). Other spatial restrictions were partially aligned with the restrictions mentioned above, including restrictions of any gillnet fishing activities in the channel and Tubarão river mouth, along the entire river extension, or a partial restriction on the river bed (SM3).

Other areas, specifically the northern portion of the Imarú lagoon, were recognized as locations where gillnets overlapped with dolphins that do not interact with fishers. However, fishers did not view this as a significant bycatch risk, because these dolphins are not the ones involved cooperative fishing (SM3). Additional strategies (18%,  $n = 8$ ) were mentioned by gillnet fishers ( $n = 3$ ) and dolphin-dependent fishers ( $n = 5$ , Fig. 4-D) and consisted of limiting gillnet and cooperative fishing activities to local fishers and banning outsider fishers who come from other cities or are not economically dependent on fishing. Interviewed fishers associated dolphin bycatch with practices of these outsider fishers, who are often inexperienced, or disrespect local agreements and practices considered adequate for organizing local fishing. Concerning gillnets, the risk of dolphin bycatch would increase because outsider fishers would not respect local agreements regarding when and how to set up the nets. They might deploy the nets during periods when dolphins are present in the river and not properly stretch the nets, thereby increasing the risk of entanglement (SM3). With cast nets, outsider fishers might ignore agreements regarding the optimal moment for casting the nets, raising the risk of hitting dolphins, especially young individuals and calves. The proposal involves restricting cooperative fishing to local and experienced fishers who rely on fishing income, aiming to avoid unwanted interactions between cast nets and dolphins

(SM6). These unintentional interactions were attributed to those who are not the genuine fishers, including people who visit the area for leisure or solely to participate in dolphin-fishing.

#### 4.4. Additional insights from open questions

The use of open-ended questions provided valuable insights into understanding the conflict. One notable perception was the need for fishers to actively participate in discussions and decision-making processes ( $n = 18$ ), particularly evident among gillnet fishers (42%,  $n = 5$ ) and dolphin-dependent fishers (44%,  $n = 8$ ). Statements from gillnet fishers targeting catfish underscored their sense of exclusion from the decision-making process (SM7). Gillnet fishers, especially those focused on catfish, conveyed feelings of injustice and complex emotions, exhibiting both detachment and affection towards the dolphins (SM8, Table S3). Additionally, fishers employing this modality indicated their persistence in fishing within the closure area (SM9, Figure S1 and SM10).

#### 4.5. Shifts in fishing effort

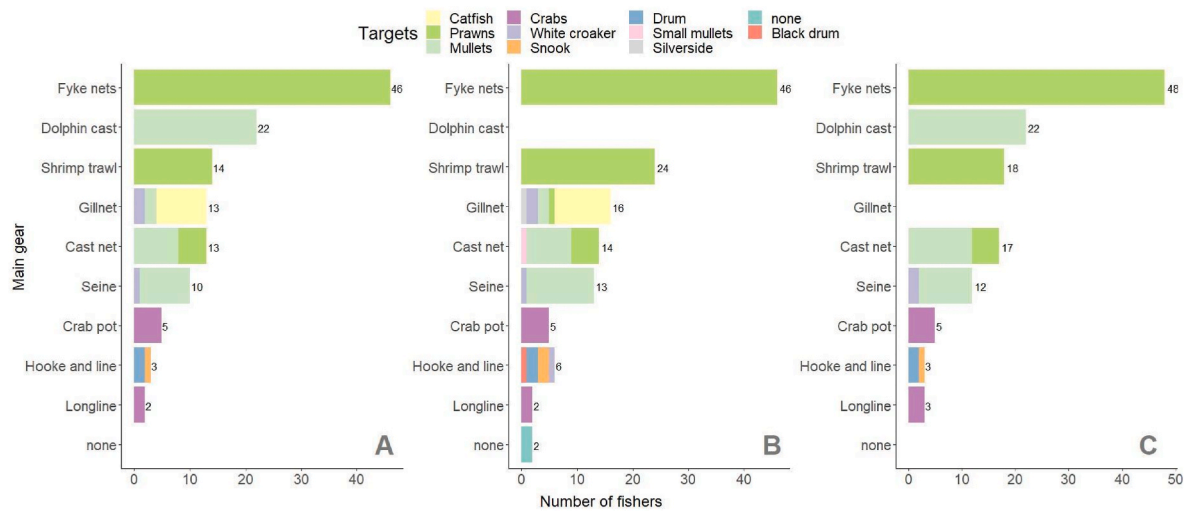
For fishers primarily employing cast nets with dolphins ( $n = 27$ ), in a hypothetical scenario where dolphin-fishing ceased, their focus would predominantly shift towards shrimp trawler (37.1%,  $n = 10$ ), followed by seine nets (11.1%,  $n = 3$ ) and gillnets (11.1%,  $n = 3$ ) (Fig. 5-B). Similarly, in a situation where gillnet-fishing was eliminated, considering those who primarily use this gear ( $n = 13$ ), the main shift in activities would be towards shrimp trawler (30.8%,  $n = 4$ ) and cast nets (30.8%,  $n = 4$ ) (Fig. 5-C). In both scenarios (extinction of dolphin-fishing or exclusion of gillnet-fishing), the predominant outcome would be an increased fishing effort directed at shrimp, notably through shrimp trawlers (Fig. 5A-C).

## 5. Discussion

We investigated the social-ecological repercussion of a fishing ban, aimed to mitigate dolphin bycatch, by analyzing fishers' socioeconomic conditions, evidence of social disparities, perceptions on dolphin bycatch, and projected changes on fisheries activities. Our findings on fishers socioeconomic factors and perceptions bring three main contributions to discuss the planning and implementation of bycatch management measures in Small-Scale Fisheries (SSF) systems: the existence of notable heterogeneity among fishers within a single fishing community; the variation of fishers' perceptions regarding dolphin bycatch based on their social profiles; and the potential for bycatch mitigation strategies involving fishing bans to exacerbate other ecosystem impacts. Our findings highlight the importance of incorporating socioeconomic factors and an integrated SES framework when addressing SSF bycatch.

### 5.1. Fishers' profiles

As expected for an SSF community (Wu et al., 2022; Béné et al., 2011), most interviewed fishers in Laguna rely primarily or exclusively on fishing as their income. They typically have low levels of formal education, are older in age, and engage in various fishing modalities. The most important gears included fyke nets, cast nets, shrimp trawls, and gillnets, consistent with previous local assessments and reports (see Barletta et al., 2017; Dantas 2018; PMAP-SC, 2019). Our findings highlight, however, distinct subgroups, especially among fishers involved in dolphin-fishery. Some do not depend (at all or solely) on fishing for income and possess higher levels of education. Known as "outside fishers", these fishers only fish in dolphin-fishery and have other professions or are retired (Peterson et al., 2008). Conversely, another segment of dolphin-fishers comprises younger individuals (<35 years old) who rely heavily on fishing for income and have limited educational attainment. This presence of younger fishers contrasts with



**Fig. 5.** (A) Fishing activity distribution reported by fishers for the current fisheries scenario. (B) Scenario depicting shifts in fishing activity due the exclusion of dolphin-fishing. (C) Scenario illustrating shifts in fishing activity due to the exclusion of gillnet-fishing.

the typical aging trend observed in most SSF communities and among fishers involved in other fishing modalities in Laguna. The local economic importance and cultural significance associated with dolphin-fishery (Machado et al., 2019) appear to attract and engage younger fishers, thereby sustaining the intergenerational livelihood of this activity.

The relatively privileged socioeconomic status of some dolphin-fishers, compared to the other fishers in Laguna, draws attention to the disparities in social capital among these stakeholders. Combined with the widespread public appeal of dolphin-fisheries, these disparities enhance the prominence of dolphin-fishery within this SSF. Consequently, these fishers are more adept at organizing themselves effectively and having their demands addressed by decision makers (Santos-Silva et al., 2022). Conversely, fishers with lower social capital may face more obstacles in being included in research initiatives and decision-making processes regarding fishing governance. In fact, gillnet-fishers expressed being marginalized during the development bycatch mitigation strategies, despite being the most affected by fishing closures.

Gillnet fishers, the primary targets of restrictive measures, are among those most dependent on fishing for income, are older in age, and have lower levels of education, actors known to hinder access to alternative income sources. Thus, it is unsurprising that, in the absence of enforcement (Azevedo et al., 2020), they persist in fishing within the closure areas. Even after five years of implementation fishing bans, gillnets are still being seized within the restricted zones. Neglecting these socioeconomic conditions, imposing restrictions without viable livelihood alternatives and facing a lack of means of control are among the key reasons why bycatch mitigation strategies often fail, especially in the medium to long terms (Wu et al., 2022). Additionally, non-participatory processes can erode trust between fishers, researchers and managers, exacerbating socioecological injustices, and fostering illegal, unreported and unregulated fisheries, major challenges in fishery governance (Le Gallic and Cox 2006; Song et al., 2020).

Our results highlight significant disparities among fishers sharing resources within the same lagoon system where fishing bans were enacted to mitigate dolphin bycatch. This socioeconomic heterogeneity within the fishing community can lead to disproportionate consequences when managing the burden of fishing bans or closures. Recognizing the unique characteristics and circumstances of individual fishers allows management approaches to be tailored to address specific challenges and needs within the community, ensuring conservation measures are ecologically sound and socially just, thereby fostering cooperation and support from the fishing community. We advocate for recognizing and

leveraging social diversity to establish fair and effective management strategies for bycatch mitigation. Instead of assuming homogeneity within fishing communities, empirical validation is necessary (Ross et al., 2005) to avoid social and epistemic injustices when planning and implementing conservation strategies (Renck et al., 2023).

## 5.2. Bycatch perception

Fishers who do not rely on fishing for income exhibit different perceptions of the conflict when compared to those reliant on fishing income. Dolphin-leisure fishers often perceive dolphin bycatch solely as harmful to dolphins, while fishers highly dependent on fishing income (such as gillnet-fishers and dolphin-dependent fishers) recognize it as harmful to both dolphins and themselves. The diversity in these perceptions underscore the importance of understanding and considering the various socioeconomic profiles of fishers. Recognizing these distinctions in perception is vital for developing targeted outreach and education initiatives. Tailoring communication strategies to address the specific concerns and priorities of different fishing groups can enhance the effectiveness of conservation efforts and promote a shared understanding of the challenges at hand.

While current strategies face challenges with non-compliance, most fishers agree that fisheries regulation is necessary to address dolphin bycatch. However, there are distinct preferences among fishers regarding the level of restriction in proposed solutions. The most stringent proposals, such as a gillnet ban, are predominantly advocated by fishers who do not rely on fishing for income, such as dolphin-leisure fishers. Although some dolphin-fishers support fully restrictive solutions, most of other fishers favor partial restrictions instead. Some proposed actions align with the existing strategies and provide suggestions for refinement. For instance, gillnet-fishers proposed allowing fishing using the 'pesca da maré' (tidal fishing) technique within the closure area. The 'pesca da maré' involves an assisted fishing technique where a gillnet is soaked for approximately 30 min precisely during the tide transition, primarily targeting catfish. This approach warrants further investigation as an option to accommodate their needs in management actions, minimizing the negative consequences of restrictions on their subsistence and livelihood through a technique with minimal or no risk of bycatch.

The combination of differences in bycatch perception and support for restrictive measures can exacerbate local conflicts, as many gillnet-fishers now associate dolphins with the prohibition of their fishing activities. Fishers burdened by fishing bans tend to develop a sense of estrangement towards dolphins, potentially intensifying local tensions.



### 5.3. Shifts in fishing effort

A pivotal yet often disregarded systemic ramification of bycatch and its associated mitigation strategies is the shift in local fishing activity. Well-intentioned, and even effective, initiatives to reduce species-specific bycatch can inadvertently result in the displacement of fishing activities, potentially causing, or exacerbating ecological consequences elsewhere. By accessing fisheries activity dynamics, we have demonstrated that if dolphin-fishing were to cease due to failure in bycatch mitigation, fishing efforts would migrate towards shrimp trawling (a prohibited gear), seine nets, and gillnets. Similarly, if gillnet-fishing were to be discontinued as a bycatch mitigation strategy, gillnet-fishers would redirect their efforts to shrimp trawling and cast nets. Both scenarios would escalate pressure on shrimp stocks, which are already heavily exploited in this socioecological system, demanding alternative solutions that have not yet been adequately discussed. Fishers, community leaders, and researchers have been exploring sustainable management options for the shrimp fishery (Dantas 2018). Ongoing discussions include regulating the number of fyke nets per fisher, registering shrimp fishers under environmental policies, and evaluating the adequacy of the implemented shrimp closed season, which includes a monetary compensation for fishers (known as 'defeso'). An increase in the number of fishers targeting shrimp could challenge maintaining the 'defeso' and other initiatives aimed at preventing shrimp stocks depletion. Anticipating and deliberating on alternatives to these shifts when designing bycatch mitigation strategies is an essential step toward achieving more sustainable outcomes.

Despite relying on the necessity of consistent enforcement and the consideration of fishers' socio-economic circumstances in the design of management strategies, the implementation of the current mitigation strategy and the subsequent reinforcement of its enforcement have indeed led to a reduction in dolphin mortality compared to previous years. Similar positive outcomes have been observed in other strategies implemented to mitigate bycatch in SSF (O'Keefe et al., 2014). However, it is important to note that these positive results tend to diminish over time, largely contingent on sustained efforts in enforcement (Cox et al., 2007).

The implications of fishers' heterogeneity, the disparities in their perceptions, and the challenges associated with redistributing effort reinforces the fact that dolphin bycatch in SSF is often a wicked problem: difficult to define, distinguish from larger issues, prone to resurface rather than being permanently solved, devoid of a universally correct solution, and requiring governance to address the collective judgment of stakeholders engaged in an experiential, interactive, and deliberative process (Jentoft and Chuenpagdee 2009). To surpass immediate effects and ensure long-term success by stabilizing or restoring populations, bycatch mitigation strategies should foster collaboration, compliance and garner support from the fishing community (Cox et al., 2007; Di Franco et al., 2016). When managing bycatch, it is imperative to refrain from exacerbating social injustices by burdening actors who already face socioeconomic vulnerability without engaging in discussions and proposing alternatives collaboratively. Given their heavy reliance on natural resources, maintaining SSF fishers in their territories and moving towards a participatory governance is vital to prevent other impacts that could have ecosystemic consequences (Espinosa-Romero et al., 2014; Truchet et al., 2022), such as escalating chemical pollution and urban development. Embracing a participatory governance approach grounded in a socioeconomic baseline can not only facilitate specific bycatch reduction outcomes but also safeguard the livelihood of small-scale fishers in their territories, transcending a species-specific conservation perspective to embrace a broader conservation framework encompassing socioecological systems.

### 5.4. Gaps, recommendations, and future directions

Here, we discussed the consequences of the bycatch mitigation

measure from two perspectives: highlighting the heterogeneity of fishers within the community and exploring the potential redistribution of fishing effort within the lagoon. Additional critical perspectives that we have not covered include quantifying temporal changes in economic conditions before and after the bycatch mitigation measure implementation. This assessment is crucial for calculating the economic impacts that fishers might already be facing and guiding discussions on monetary compensation for affected gillnet-fishers.

The two scenarios we built (exclusion of gillnet-fishing and unrestricted gillnet-fishing) were based on the current management strategy. These scenarios do not cover all possibilities: alternative proposals, such as compensating gillnet-fishers to leave fishing, are also possible. This approach involves two key steps: estimating the costs (i.e., how much fishers would earn by stopping fishing with gillnets) and assessing fishers' willingness to stop fishing with gillnets in exchange for compensation.

Understanding fishers' willingness and conditions to exit fishing is extremely sensitive but crucial to be addressed before making this recommendation. This allows for considering their attitudes, perceptions, compliance, and adaptation to such policies, as well as the socio-cultural, economic, and institutional factors influencing these aspects (Ma et al., 2022; Owusu et al., 2023; Sun et al., 2024). Addressing these factors helps ensure compliance and prevents the erasure and silencing of fishers' identities and the delegitimization of their knowledge and experiences in the decision-making process.

Additionally, this proposal should be conducted carefully, given that most fishers have low levels of formal education and are older, factors known to complexify livelihood transitions (Engie 2015; Nayak 2017; Avila-Forcada et al., 2020). Their food security is typically closely tied to their livelihoods (Hanazaki et al., 2013). Moreover, artisanal fishers often defend their territories to preserve social-ecological system functions (Almudi and Kalikoski 2010) and their own cultural identity. Displacing these social actors could expose the system to other threats, such as real estate speculation and disorderly occupation of fishery territories by activities that may exacerbate impacts (Kramer et al., 2017). Indeed, Laguna is already facing many of these pressures (Dantas 2018; Gallardo et al., 2021). Thus, transitioning fishers away from fishing to achieve more sustainable scenarios must be approached very cautiously.

As overall recommendations for providing win-win solutions for both fishers and dolphin population, we highlight.

- Investigate the tidal fishing ('pesca da maré') technique in terms of gillnet-fishers' adherence and dolphin catchability;
- Regulate external and recreational fishers to facilitate local management and ensure compliance of local agreements and regulations, especially along the Tubarão River regarding gillnets and dolphin-fishing;
- Investigate potential financial losses faced by gillnet-fishers due to the fishing ban area;
- Assess the willingness and perceptions of gillnet-fishers regarding financial compensation to stop fishing with this gear, focusing on the implications for their territories, identities, and the possibilities of livelihood replacement.
- Investigate how dolphins use the Tubarão River, including circadian variations and the extent of its use;
- Increase awareness of the broader fishing community about the ecosystemic consequences of dolphin bycatch.

### CRedit authorship contribution statement

**Larissa Dalpaz:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Fabio G. Daura-Jorge:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Rebecca Lewison:**

Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Sofia Zank:** Writing – review & editing, Methodology. **Natalia Hanazaki:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

Data will be made available on request.

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### Appendix A Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ocecoaman.2024.107375>.

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