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Bycatch mitigation requires livelihood solutions, not just fishing bans: A case study of the trammel-net fishery in the northern Beibu Gulf, China

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ABSTRACT

Fishery bycatch is an acute threat endangering survival of coastal delphinids. While mitigation measures aim at restricting fishing activities by spatial, temporal and gear management, these measures undoubtedly decrease fishery production and trigger conservation-livelihood conflicts, particularly in artisanal fisheries associating with 'poverty traps'. This study surveyed spatio-temporal activities of trammel-net fisheries and fishers' education-household livelihood background in a rural fishing village in the northern Beibu Gulf, China to investigate dolphin-fishing interactions and the willingness of fishers to exit fishing and their ability to engage in alternative livelihoods with regard to fishers' household livelihood baselines. Within the survey region, overlap between humpback dolphins and trammel-net fishing was high (at least 43.35%). Spatial closures through MPAs would help reduce 46.9% of trammel-net fishing. While labor force aging and low education levels were observed in fishing, farming and casual labor livelihoods, fishers showed an unwillingness to exit fishing and inability to engage in alternative livelihoods. The suspended MPA plan should be enacted immediately to reduce fishing-gear entanglements. Implementation of a permanent trammel-net ban or 'exit-fishing' policy, however, should address the household livelihood consequences to fishers. Though ecotourism is often recommended to fishers as an alternative livelihood, low education level hinders fishers' ability to engage in dolphin-watching tourism in a sustainable manner. Fishing-gear modification, an *ad hoc* training program focusing on sustainable ecotourism, motivating and mobilizing local people in MPA monitoring and management, and integration of traditional ecological knowledge into livelihood diversification programs are critical components to deal with the complexity of this issue.

1. Introduction

For marine megafauna such as cetaceans, sharks and sea turtles, incidental mortality due to entanglement in fishing gear, *i.e.,* bycatch, is one particularly acute threat endangering long-term survival of populations and species [1–6]. Measures mitigating impacts of unsustainable bycatch primarily aim to regulate fishing activities by spatial [7–10], temporal [10] and gear [5,11,12] management. Beside fishing management, other effective measures call for temporarily or permanent closures (bans) of fishing activity through 'exit-fishing' policy [13,14]. These measures, however, concurrently hinder fishery economics and trigger conflicts between ecological and economic needs [5,12,15]. These conservation-livelihood conflicts often result in fishers' non-compliance, due to economic loss and lack of effective law enforcement [15,16], which, in turn, compromises the efficacy of MPA and fishery management.

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This conservation-livelihood conflict will be particularly intense in artisanal fisheries [15,17] in association with 'poverty traps' when fishers find it is difficult to attain alternative incomes other than fishing [18–20]. Unlike commercial fisheries operated by industrialized and financially-invested fleets, artisanal fisheries are small-scale, locally harvested, and support the livelihood of fishers' families [21]. For local fishers, the closure of fishing activity means the loss of household livelihoods until an alternative livelihood solution is adopted. Livelihood diversification that assists fishers in engaging in occupations other than fishing is often recommended to resolve this issue [7,18,20,22]. In practice, however, livelihood diversification sometimes neglects fishers' ability to engage in alternative livelihoods [20,23], imposing further conflicts and compromising mutual trust between fishers and conservationists [7,24]. Fishers' attitudes and capabilities to engage in alternative livelihoods are often associated with their social, economic and education baselines. Relevant information, however, is scarce in the conservation of charismatic marine megafauna, particularly coastal delphinids [25], which hinders actions to reduce fishery activities and hence bycatch impacts.

Conservation-livelihood conflicts can be particularly intense when dealing with conservation of charismatic species facing extinction [7,24,26], as in conservation of the vaquita, *Phocoena sinus* [2,7]. In this situation, unsustainable gillnet bycatch is driving the vaquita to extinction [2]. Conservation measures minimizing gillnet bycatch include fishing-gear conversion [7] and livelihood diversification [2]. These conservation actions, however, have failed to reverse the decline of the vaquita population, while causing collateral damage through intensifying conservation-livelihood conflicts [7]. A similar situation may be happening in the conservation of Indo-Pacific humpback dolphins (*Sousa chinensis*) in Chinese waters, where in some cases unsustainable bycatch impacts are threatening population viability [1,27,28]. Measures aimed at reducing bycatch mortality include establishing MPAs in core distribution areas [29], seasonal closures of coastal fisheries [30] and implementation of 'exit-fishing' policy [13]. These measures, however, seldom address potential problems that the livelihood basis of hundreds of thousands of fishers would be compromised. Socio-economic costs associated with these livelihood-conservation conflicts would be challenging and unacceptable to local governments.

One of the potential solutions is using ecotourism as a surrogate for livelihood-diversification [18,31], such as the fisher-operated dolphin-watching tourism [32,33]. Without external assistance and incentives, however, fisher-operated dolphin-watching tourism may not provide incomes economically equivalent to those of fishing [32]. Further, they would be unlikely to provide on-board lecturing and interpretation services, due to limited space on the vessel, whether fishing boats [34] or customized speed boats [33]. Worse yet, unregulated growth and operation of dolphin-watching tourism can negatively impact humpback dolphin viability and jeopardize the sustainability of both humpback dolphin populations and fishers' livelihoods [32,33]. The fundamental question to ensure dolphin-watching tourism as a sustainable solution for 'exit-fishing' policy is whether the fisher understands the principles of sustainability and has the capability to conduct a sustainable operation. This may be associated with the fisher's educational background.

In Chinese waters, fishing gear entanglement of humpback dolphins has been reported in the waters off western Taiwanese coast [35], Hong Kong [36], Xiamen Bay [37] and northern Beibu Gulf [38]. In the above cases, fishing gear entanglement frequently relates with the use of trammel-nets and other types of gillnets in coastal artisanal fisheries (as in Jutapruet et al. [34]). To resolve present conflicts between trammel-net fishing and humpback dolphin entanglement, this study investigated spatio-temporal activities of trammel-net fishing and explored social-educational conditions of fishers in a rural fishing village to determine the baselines including:

(1) What is the extent of the dolphin-fishing interaction?
(2) What is the proportion of fishing activity reduction under present MPA planning?
(3) What will be the attitude of trammel-net fishers to engage in livelihood diversification? What would be the likelihood to adopt dolphin-watching tourism as a valid alternative-livelihood replacement for fishers?

With these baselines, an action framework was proposed to mitigate trammel-net bycatch on marine coastal megafauna by integrating fishery management and livelihood diversification with community-based MPA management.

2. Materials and methods

2.1. Study area

Sanniang Bay Village (Fig. 1) is one of the fishing villages along the northern Beibu Gulf, China [39]. Out of *ca.* 5100 registered inhabitants (http://zwgk.gxqn.gov.cn/auto2734/gzdt/202107/t20210705_3558681.html, in Chinese), *ca.* 2500 residents of 400–500 families stay in Sanniang Bay Village all year round while the rest of the registered inhabitants live outside Sanniang Bay Village for education and working. For registered inhabitants, the ratio of female to male is 47.98:52.02; 83.0% of inhabitants received primary (40.9%) or secondary (42.07%) degrees of education attainment and 18.77% of inhabitants are older than 60-years old (http://zwgk.gxqn.gov.cn/auto2734/gzdt/202107/t20210705_3558681.html, in Chinese).

The primary fishing gear adopted in Sanniang Bay Village, as well as many fishing villages along the northern Beibu Gulf [39], is the trammel net that captures shads, mullets, sardines and crustaceans for livelihood consumption and income. The trammel-net fishing generally starts from September to April of the next year, followed by a fishing closure from May to August. Preliminary social-economic investigation revealed, for more than 70% of local fishers, annual incomes from trammel-net fishing were within or lower than 20,000–50,000RMB (equivalent to *ca.* 3096–7758 USD) that is slightly below average Per Capita Disposable Income Nationwide of China in 2020 (https://data.stats.gov.cn/english/easyquery.htm?cn=C01). Since early 2000s, dolphin-watching tourism exclusively targeting humpback dolphins operated by local fishers has been developing [33].

Nearby Sanniang Bay Village, the Dafengjiang River Estuary and adjacent waters (Fig. 1) is one of the key habitats for the humpback dolphin in the northern Beibu Gulf [39–41]. Census surveys indicate a dynamic residency pattern for 389 (CI = 353–430) humpback dolphins that periodically visit, emigrate and re-immigrate the Dafengjiang River Estuary [41]. A humpback dolphin protected area is planning at the Dafengjiang River Estuary (Fig. 1) but temporarily stalled now. Fishing closure was implemented from May to August [30]. During the fishing closure, all fishing activities are literally suspended.

2.2. Spatio-temporal patterns of trammel-net fishing

To measure trammel-net fishing activities, the number of trammel-net boats (Fig. 1) within 1-km radius sampling range, $n_{x,y}$(x, y: the GPS record at the sampling point), was recorded per five kilometers during transect surveys from October 2018 to July 2021. The transect route adopted a zig-zag design used in monthly humpback-dolphin surveys to ensure unified spatial coverage over the study region [42].

The spatial activity of trammel-net fishing was measured by the kernel density estimate (KDE) analysis [8]. A shapefile summarizing $n_{x,y}$ was prepared and projected into UTM49N coordinate system. Then 50% KDE area weighted by the numbers of trammel-net boats was delineated and assigned as the major trammel-net area. The areas where major trammel-net area overlapped the humpback-dolphin's core habitat [42] and planning MPA (Fig. 1) were delineated. The 'percent area overlap (PAO)' [8] was then calculated by:

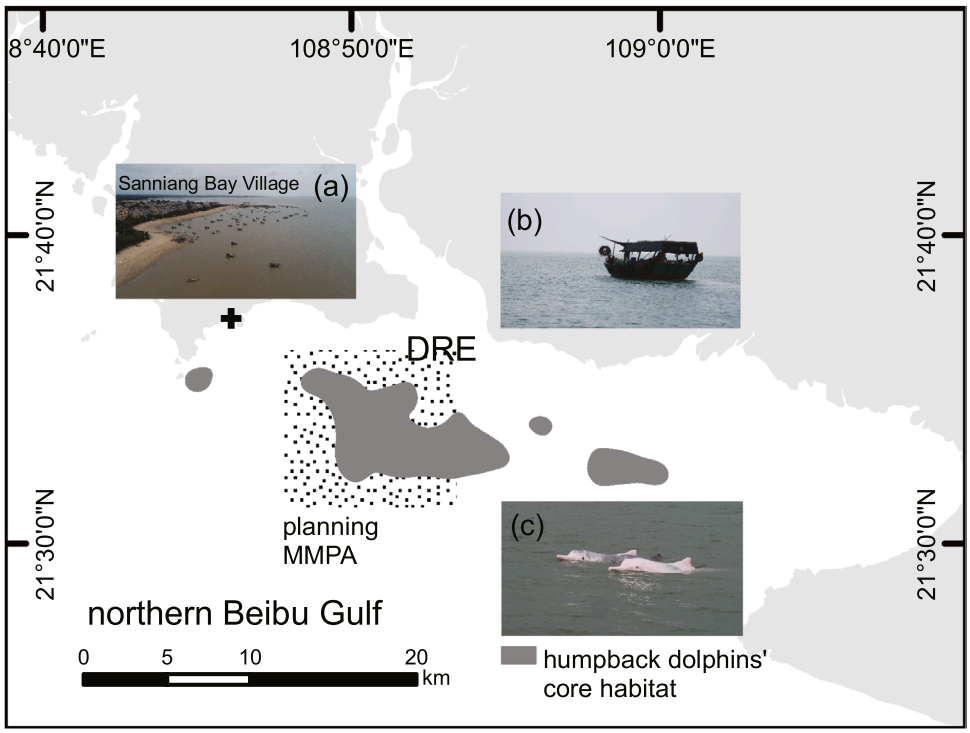

Fig. 1. The study area: Sanniang Bay Village (a) and adjacent Dafengjiang River Estuary (DRE), which is the major area for artisanal trammel-net fishery (b) and humpback dolphins (c). The gray polygon represents the core habitat of humpback dolphins, measured by 50% kernel density estimate of occurrence [42]. The planning MPA is presented by dotted rectangle though the project is presently suspended by the city government.

$$PAO_i = \sqrt{\frac{A_o}{A_i} \times \frac{A_o}{A_f}} \quad (1)$$

where A_i is the area of either humpback dolphins' core habitat (A_d) or MPA (A_m),$A_f$is the major trammel-net area and A_o is the area overlap between major trammel-net area and A_d or A_m. The POA_d was used to indicate dolphin-fishing interaction and POA_m was used to indicate spatial impact of MPA designation on trammel-net fishing.

The temporal activity of trammel-net fishing was measured by the 'number of trammel-net boats per unit transect length (BPUL)':

$$BPUL_s = \frac{\sum n_s}{\sum L_s} \quad (2)$$

where s, n and L are seasons (spring, summer, autumn, winter), seasonally-pooled $n_{x,y}$ and total transect lengths by seasons.

2.3. Questionnaire interviews

Questionnaire interviews targeting household breadwinners were targeted on regular residents of Sanniang Bay Village in 2019 and 2020 using the random sampling method. In the present study, the 'regular residents' indicated those registered inhabitants that stay and live in Sanniang Bay Village all year round. Registered inhabitants living outside Sanniang Bay Village for education and working, long-stay visitors and tourists inside the village were not included in the questionnaire investigation. The 'household breadwinner' indicated the person who earns household income in the family. Questionnaire forms were deployed by families with assistance of local residents and responded by the breadwinner of the family. Information on demographic-social conditions, including gender, age, household size, education attainment and principal household livelihood, was investigated for all respondents. Seven livelihood patterns were categorized in this study, including fishing (trammel-nets), dolphin-watching tours, contract employment of enterprises or government, guest house, restaurant, souvenir shop and other tourism-related business, farming and casual labor (Table 1). For trammel-net fishers, questions including willingness to exit fishing, options seeking alternative livelihoods, experience in seeing illegal and unsustainable fisheries (electric, shellfish dredging, benthic trawling and other harmful fishing gears) at sea and willingness to report illegal and unsustainable fishing activities were further investigated (Table 1).

The ratio of female to male and composition of respondents' ages and education attainments were compared to those of registered inhabitants (http://zwgk.gxqn.gov.cn/auto2734/gzdt/202107/t20210705_3558681.html) by χ^2 and Kolmogorov-Smirnov tests. An ANOVA test was used to examine the difference of respondents' ages in household livelihoods. By scoring education attainments from 1 (uneducated) to 5 (college and higher), a general linear model (GLM) was used to examine associations of education attainment of respondents with gender and household livelihood. Differences of education attainment between household livelihoods were further explored by t-test (for average education degree) and χ^2 test (for counts).

3. Results

3.1. Trammel-net fishing activity

In the study region, trammel-net fishing was mainly concentrated in eastern Qinzhou Bay, the waters off Sanninang Bay Village and the Dafengjiang River Estuary (Fig. 2). The major fishing area was 74.2 km^2, where POA_d was 43.3% and POA_m was 46.9% (Fig. 2). BPUL of artisanal fishing was 0.093 boat/km during the fishing-closure season and 0.61 boat/km, 0.43 boat/km and 0.42 boat/km during spring, autumn and winter, respectively (Fig. 2).

3.2. Education-household livelihood conditions

A total of 232 questionnaire forms were completed and collected. Average household number of respondents was 5.22 (SD = 1.89), which

Table 1
Details of respondents' education and household livelihood backgrounds, willingness to exit fishing, options of livelihood conversion, and potential to report illegal and unsustainable fisheries.

respondents' education-household livelihood background	education attainment	none	primary	secondary	senior	college and higher			
	female/ respondents	5.6%	22.0%	14.2%	4.3%	2.6%			
	male/ respondents	0.4%	16.4%	21.6%	8.6%	4.3%			
	major livelihoods[a]	fishers	dolphin-watching	contracted employment	restaurant	souvenir shop, other tourism	guest house	casual labor	farming
	female/ respondents	9.1%	0.4%	3.9%	1.7%	3.4%	6.9%	18.5%	7.3%
	male/ respondents	22.0%	0.9%	6.5%	2.6%	1.3%	2.6%	12.9%	4.3%
willingness and options of exit fishing[b]	willingness of exit fishing		unwilling	fishing-gear surrender	tourism	refuse to answer			
	male/fishers		52.8%	11.1%	6.9%	6.9%			
	female/fishers		13.9%	4.2%	2.8%	1.4%			
	options of alternative livelihoods		no	casual labor	dolphin-watching		restaurant	guest house	unknown
	male/fishers		43.1%	18.1%	1.4%		1.4%	1.4%	13.9%
	female/fishers		15.3%	1.4%	1.4%		0.0%	0.0%	2.8%
experience in observing and willingness to report illegal and unsustainable fisheries[b]	observing before and present		electric	shellfish dredging	benthic trawling		others	none	
	female/fishers		25.3%	29.1%	31.6%		11.4%	2.5%	
	male/fishers		38.0%	38.0%	45.6%		10.1%	6.3%	
	willingness to report illegal and unsustainable fisheries			willing	not willing	willing but no reporting channel			
	female/fishers			10.1%	1.3%	31.6%			
	male/fishers			26.6%	3.8%	26.6%			

[a] Nine out of 232 respondents conducting two or more livelihoods (e.g., fishing + tourism-related livelihoods).
[b] questions specific to fishers.

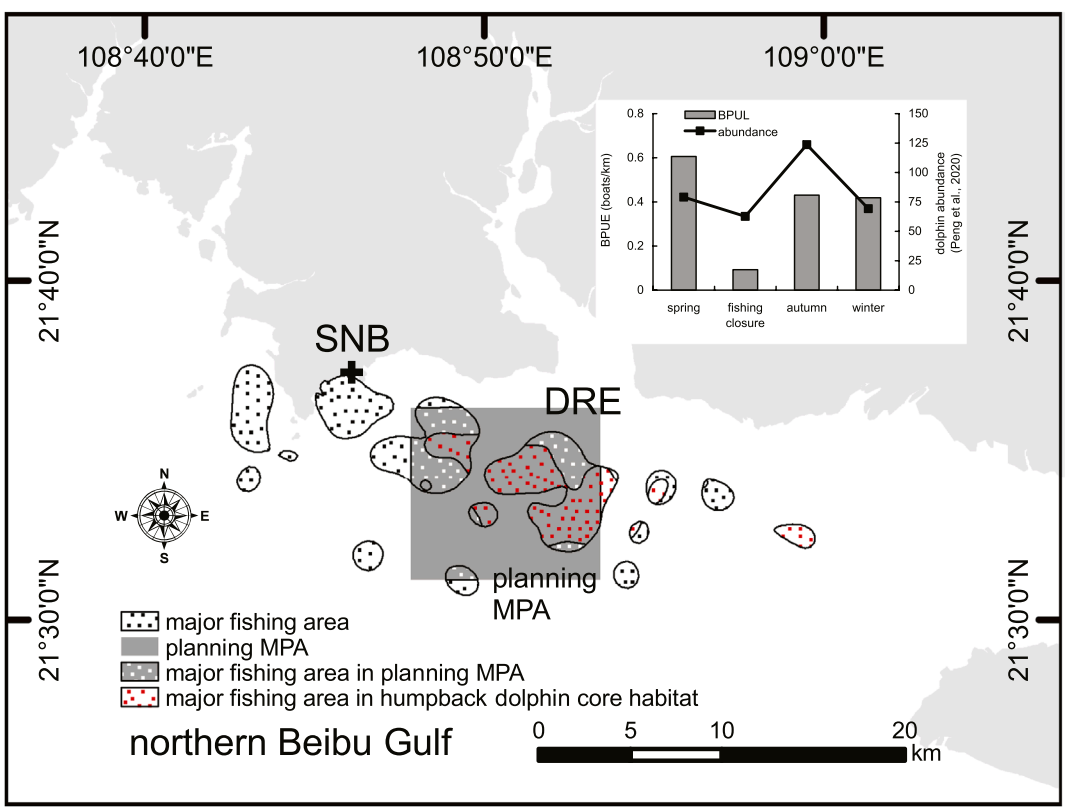

Fig. 2. The major fishing area (dotted polygons) and seasonal activities (in the upper-right panel) of trammel-net fisheries in the study region.

resulted in a total of 1212 regular residents covered by the 232 respondents. The ratio of female to male respondents was 113:119, which was not statistically biased from an assumed 1:1 ratio ($\chi^2 = 0.155$, $P = 0.69$) nor the female:male ratio of the registered inhabitants ($\chi^2 = 0.049$, $P = 0.82$). The average ages of female and male respondents were 46.3 (SD = 11.4) and 48.2 (SD 12.9) years old. The differences of average ages (t-test = 1.19, F = 1.44, $P = 0.23$) and age compositions (Kolmogorov-Smirnov test = 0.134, $P = 0.24$) between female and male

respondents were not statistically significant. For respondents' education attainment, 14 (6.0%) out of 232 respondents were uneducated, which was significantly higher than the ratio of crude illiteracy of Guangxi ($\chi^2 = 21.54$, $P < 0.01$). For the educated respondents, difference of education attainment composition between respondents and registered inhabitants was not statistical significant ($\chi^2 = 5.42$, df = 3, $P = 0.14$).

Trammel-net fishers (72/232 = 31.03%) and casual laborers (73/232 = 31.5%) accounted for the highest proportions of household livelihoods (Table 1), followed by tourism-related livelihoods (46/232 = 19.8%), farming (27/232 = 11.6%) and contracted employment (24/232 = 10.35%). Among trammel-net fishers, the female:male ratio was 21:51, which was significantly different from the ratio of respondents' genders ($\chi^2 = 12.5$, $P < 0.01$, Fig. 3a). Among respondents presently running guesthouses, the number of female guesthouse owners (16 respondents) was significantly higher than the number of males (6 respondents) ($\chi^2 = 4.55$, $P < 0.05$, Fig. 3a). The number of female casual laborers (43) was numerically higher than that of male casual laborers (30), though the difference between this ratio (43:30) and respondents' genders (113:119) was not statistically significant ($\chi^2 = 2.315$, $P = 0.128$). For the rest of the livelihoods, the female:male ratios were not statistically different from the ratio of respondents' genders ($\chi^2 = 9.57$, $P = 0.14$, df = 6).

ANOVA showed a significant difference of respondents' ages between household livelihoods ($F = 21.38$, $P < 0.001$). Pairwise t-test (Table 2) further showed respondents with contracted employments had the lowest average age while the casual laborers had the highest average age (Fig. 3b). The difference of average ages between fishers, farmers and tourism operators was not statistically significant (Table 2).

Table 2
Pairwise t-tests of respondents' age among household livelihoods. Dolphin watching, guest house, restaurant, souvenir shop and other business livelihoods were grouped together as "tourism-related". *: $P < 0.05$, **: $P < 0.01$.

	Fishing	Farming	Casual labor	Tourism-related
farming	0.93			
casual labor	1.58	2.10*		
tourism-related	0.70	0.33	2.11*	
contracted employment	7.95**	5.93**	9.08**	6.98**

GLM analysis showed education attainments of respondents are significantly associated with genders (F = 9.82, $P < 0.01$, Fig. 3c) and household livelihoods (F = 26.29, $P < 0.01$, Fig. 3d) without significant synergistic influence ($F = 1.157$, $P = 0.332$). By gender, female respondents received significantly lower education attainments than male respondents ($t = -3.897$, $P < 0.001$) by a significantly higher proportion of uneducated attainment ($\chi^2 = 10.3$, $P < 0.01$), but a lower proportion of secondary and senior high-school degree completion ($\chi^2 = 6.82$, $P < 0.05$, Fig. 3c). By household livelihood, respondents with contracted employment (24 respondents) had the highest education attainment (Fig. 3d, $t = 7.26$, 4.79, 6.17 and 6.25 compared to those of fishing, tourism, farming and casual labor, respectively, $P < 0.001$) with insignificant difference between genders (t-test = 0.784, $P = 0.44$). Respondents engaged in tourism-associated livelihoods had intermediate education level that were significantly higher than those of trammel-

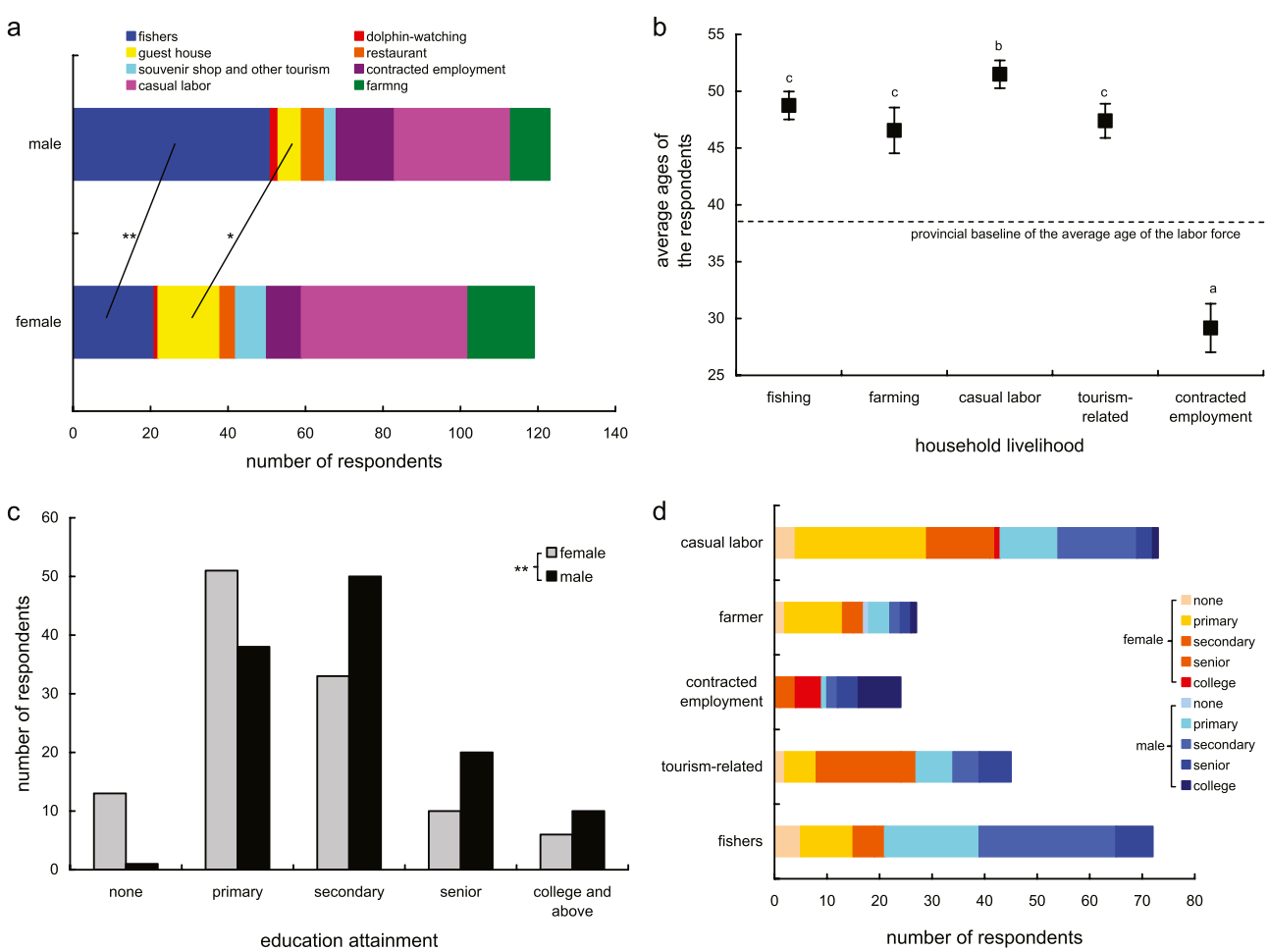

Fig. 3. Education-household livelihood conditions for 232 respondents, including the composition of household livelihoods (a), respondents' ages (mean±SE) of major household livelihood patterns (b), differences of respondents' education levels between gender (c) and household livelihood (c).

net fishers ($t = 2.78$, $P < 0.01$), farmers ($t = 2.15$, $P < 0.05$) and casual laborers ($t = 2.63$, $P < 0.05$) with insignificant difference between genders ($t = 1.54$, $P = 0.13$). Differences of education attainment between fishing, farming and casual labor were not statistically significant ($t = 0.04$, $P = 0.97$ between fishing and farming, $t = 1.46$, $P = 0.15$ between fishing and casual labor, $t = 1.05$, $P = 0.30$ between farming and casual labor).

Regarding 'exit-fishing' policy, 66.7% of fishers expressed reluctance to exit fishing by an unwillingness to permanently leave fisheries (Table 1). For the ability of exit-fishing, a total of 75.0% of fishers had no (58.3%) or did not know (16.7%) an alternative livelihood other than fishing, 19.50% of fishers selected casual labor when leaving villages (most of them were at ages lower than 50 yeas old), and 5.6% of respondents would convert to tourism-associated livelihoods (Table 1). Unsustainable fisheries (electric, benthic trawling and shellfish dredging) were reported in major fishing areas by 96.3% of fishers (Table 1), while 94.9% of fishers were willing to report unsustainable fisheries, though 58.2% of fishers indicated the lack of adequate reporting channels (Table 1).

Supplementary to above social-economic conditions, 45.7% of respondents reported a positive influence on lifestyle since the development of dolphin-watching tourism in Sanniang Bay Village, while 4.74% of respondents reported the negative influence. Differences of responses between genders ($\chi^2 = 12.47$, $P < 0.01$) and livelihoods ($\chi^2 = 17.9$, $P < 0.01$) were statistically significant. The positive influence of dolphin-watching tourism primarily came from increasing benefits while the negative influence came from increasing prices in association with tourism growth in Sanniang Bay Village.

4. Discussion

4.1. Education-household livelihood baselines of residents in Sanniang Bay village

In the present study, the average age of respondents was 46.3 years old for females and 48.2 years old for males. This average can not be regarded as the average age of residents or that of registered inhabitants but, instead, indicated the average age of the principal labor force that support household livelihoods in Sanniang Bay Village. Compared to provincial and national averages of the labor force, the average age of respondents was much higher than that of provincial (37.95) and national (38.42) baselines [43]. Excluding respondents older than 60 years old [43], the average age of the labor force in the present study (43.93) was still higher than the provincial and national averages, which implies an aging labor force structure among regular residents of Sanniang Bay Village. Demographic aging in fishing villages [44–46] is one of the important driving forces contributing to labor force aging. The latest census in China (http://zwgk.gxqn.gov.cn/auto2734/gzdt/202107/t20210705_3558681.html) reported high proportions of elderly inhabitants in Sanniang Bay Village and other rural fishing villages, which indicates an aging demographic structure in Guangxi.

Differences of age and education attainment in respondents' household livelihoods imply other mechanism driving household labor force aging in Sanniang Bay Village. In many rural villages, the local education system is composed of primary schools only, as that in Sanniang Bay Village, unlike the education system in urban district. After finishing primary school education, local residents leave villages for higher education degrees, either to neighboring townships or urban districts. Those inhabitants finishing senior-high school, college or higher education degrees usually stay in cities and seek long-term contracted employment for more favorable incomes and a stable life. In the meantime, the economic activity in rural villages seldom provides sufficient capacity and capital offering contracted employment to attract young inhabitants to return, particularly for those that have high education attainment, which forming a 'poverty trap' continuously 'catching' those who hardly find skillful and better-paid livelihoods [18–20]. In this scenario, the proportion of the elderly and low-educated labor force would gradually increase, particularly those in fishing and farming, as revealed by the ages and education levels in respondents' household livelihoods.

In Sanniang Bay Village, the present study revealed fishing, casual labor and tourism-related livelihoods accounted for 82.3% of household livelihood composition. In tourism-related livelihoods, dolphin watching and guest house accounted for 19.8% of household livelihood composition. Though the proportion of respondents operating dolphin watching seems few (3 out of 232 respondents), it is indeed the number of respondents basing household livelihoods exclusively on dolphin-watching tourism, but not the number of residents operating dolphin watching. For most fishers, incomes from dolphin-watching tourism are generally regarded as avocation subsidies, particularly during long vacations [33], as daily tour capacity can not provide sufficient capital for household livelihoods or 'pure' dolphin-watching operators [33]. Fishing is still the major household livelihood of fishers in Sanniang Bay Village. In the past few years, some fishers surrendered their fishing boats since the implementation of the fishing vessel buyback program [Shihe Sun, personal communication] and many fishers now live on guest house and restaurant livelihoods, as presented in the livelihood composition of respondents. The proportion of fishing livelihood and concurrently artisanal fishing activities in Sanniang Bay Village would be expected to decrease in the future based upon the synergistic influence of population aging, out-migration of skillful and well educated young labor force for seeking favorable incomes and a stable household life, and implementation of exit-fishing policy.

4.2. Trammel-net fishery: Activities, conservation conflicts and problems in sustainable management

Information on the spatio-temporal activities of the trammel-net fishing is essential for evaluating dolphin-fishing interactions and planning for mitigating bycatch impacts [8]. Relevant information, however, is rarely reported throughout the species' range of the Indo-Pacific humpback dolphin. This information gap may relate to data scarcity from the lack of a registering system for collecting data on time, location and level of catch in artisanal fisheries. Fisheries observer programs have been proven effectively in collecting bycatch statistics [47]. This approach, however, may be not suitable for artisanal fisheries in coastal waters due to small size of the boat in artisanal fisheries (Fig. 4). This gap can be partially addressed by instituting transect surveys that concurrently collect data on dolphin and fishing activities (as in Di Tullio et al. [8] and this study). As conservation of the Indo-Pacific humpback dolphin has attracted substantial research attention in China and South-east Asian countries [25,28,48], this action can provide a quantitative baseline data to inform spatial closures in the management of the trammel-net fishery [8], which is strongly recommended for incorporation into the current conservation planning for the Indo-Pacific humpback dolphin in China.

In the Dafengjiang River Estuary and adjacent waters, this study showed a 43.35% overlap between humpback dolphin and trammel-net fishing. Actual dolphin-fishing interactions could be higher than this value, as this study surveyed trammel-net fishing during daytime only, but left activities during nighttime and fisheries other than trammel-net, such as crab trap, shellfish dredging, benthic trawling, fyke net and illegal electric fishing (Fig. 4) from neighboring counties and provinces uninvestigated. Entanglement of humpback dolphins [38] in fishing gears is frequently observed during field surveys (Fig. 4e, f), which implies an alarming level of bycatch mortality. Reducing the use of trammel nets in local fisheries will be crucial for mitigating bycatch impacts on the 353–430 humpback dolphins that occur in the northern Beibu Gulf, China [41].

The reduction of trammel-net use includes the permanent trammel-net ban [13], fishing-gear conversion [5,11,12] and spatial closures through MPAs or no-take zones [6,8,9]. A permanent trammel-net ban enforced by law could be an ultimate solution to eliminating bycatch

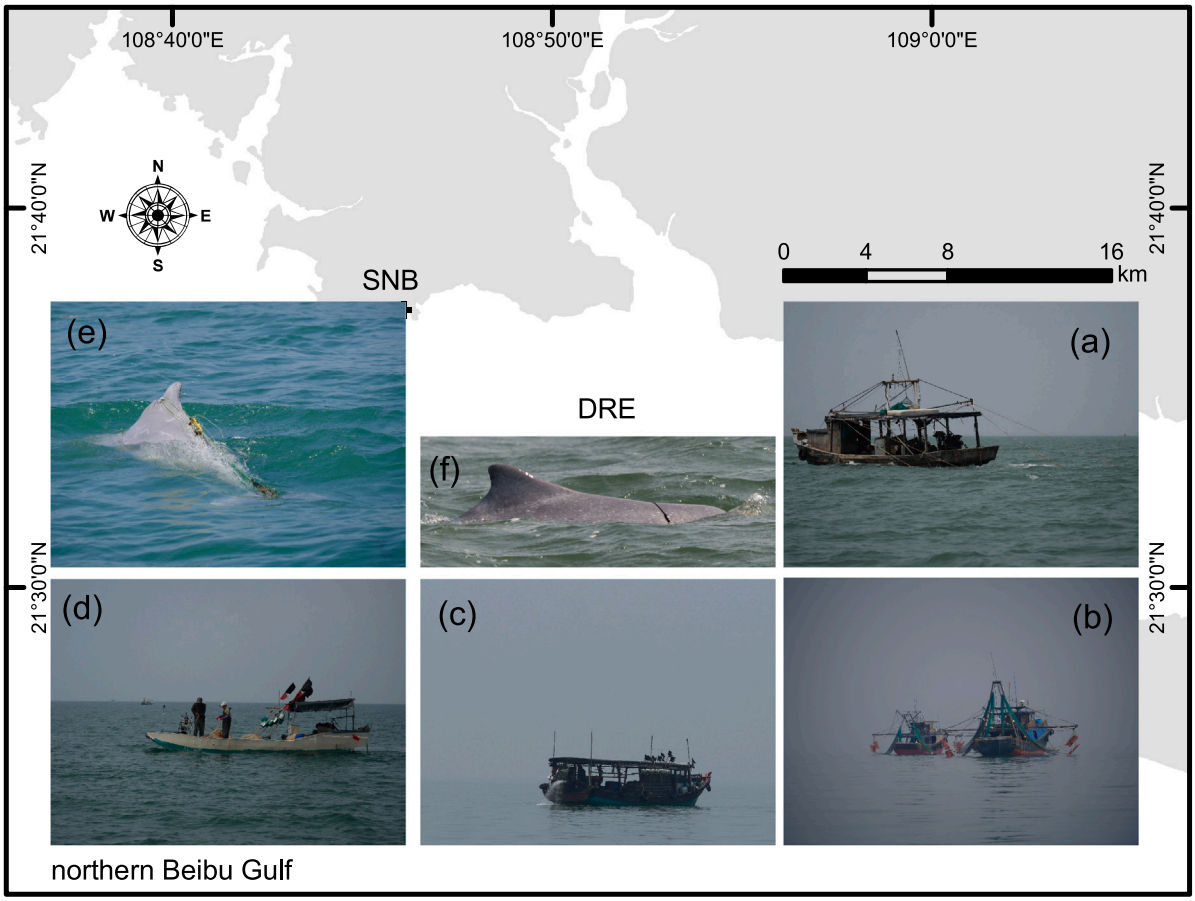

Fig. 4. Electric trawling (a), benthic trawling (b), crab trap fishing (c) and customized trammel-net fishing boats from adjacent counties (d) in the Dafengjiang River Estuary and adjacent waters. Fishing gear entanglements (e, f) were observed during humpback dolphin surveys.

impacts [13]. In practice, however, this action will immediately trigger intense conflicts between dolphin conservation and local livelihoods [5] as trammel-net income is the principal source of household livelihood of fishers but below average Per Capita Disposable Income Nationwide of China (https://data.stats.gov.cn/english/easyquery.htm?cn=C01). A similar situation was also observed in other fishing villages along the coast of Guangxi (Q. Li, personal data) and western Taiwan (https://www.fa.gov.tw/cht/PublicationsFishEco/) in China. A permanent trammel-net ban without subsidies compensating the economic loss will hamper the livelihoods and wellbeing of thousands of fishing families and be unacceptable for fishers and local governments. An alternative measure may consider a 'local' ban in Sanniang Bay Village. This measure, indeed, does not reduce but may further introduce more conflicts not only between conservation and livelihood needs, but also between management and fisher sectors. In the northern Beibu Gulf, the Dafengjiang River Estuary is utilized by fishers from several villages [39] that adopt a variety of fishing gears (Fig. 4). The trammel-net ban specific to Sanniang Bay Village but not to other villages and fishing gears will inevitably induce intense reluctance in fishers by questions like "why trammel-net fishers from other villages can still fish in my fishing areas but I can not" and "why can fishing gears more harmful than trammel nets still be used in my fishing areas without any restriction". A comprehensive trammel-net ban could be the ultimate solution to save dolphins from bycatch impacts. Implementation of trammel-net ban actions should be carefully planned through a long-term and adaptive process nonetheless and should consider compensatory measures.

Programs assisting fishers in using modified fishing nets or adopting gear other than trammel nets, such as the fishing-gear conversion program, can be the solution to bycatch impacts without jeopardizing fishers' livelihoods [5,11,12]. This program depends on '*the development of efficient, inexpensive, alternative fishing gear* [5]' that is not yet available in the context of humpback dolphin conservation. Hasty implementation of the fishing-gear conversion policy could lead to increase the use of crab traps, fyke nets, purse seines, trawling and even electric gears in local fisheries, which still catch dolphins [38] and cause collateral damage to local ecosystem functionality [7]. Conventional trammel nets can be modified by adding physical [12] and acoustic [11] devices to reduce bycatch. Difficulties in introducing those modifications to fishing communities come from the significantly higher cost of nets, but reduced fish harvesting [12] and the complexity of operating and maintaining acoustic devices [11] not appropriate to the vessel size (< 10 m long) in coastal artisanal fisheries. This may hinder the willingness of fishers to engage in fishing-gear conversion. Before the above difficulties in fishing-gear conversion is solved, spatial closure of trammel-net fisheries by MPA or no-take zone enforcement seems the most promising approach [6,8,9].

Precautionary spatial closures through MPAs can reduce trammel-net fishing by 46.9%. Efficacy of MPAs in reducing fishery bycatch depends whether fishing activities are truly suspended in the protected area, which is determined by the level of enforcement, and fishers' willingness to leave their traditional fishing area. Fishing activities were reduced low during fishing-ban season, as shown in the present study. Indeed, crab trap, shellfish dredging, benthic trawling and electric fishing were completely suspended during the fishing ban, not just trammel-net fishing, indicating the effectiveness of fisheries enforcement. Ensuring fishers' willingness to leave their major fishing area, however, could be the primary challenge. The fact that artisanal fishers often pursue the same species consumed by dolphins leads to both dolphins and fishers utilizing the same area [8]. Fishers leaving the core

fishing area of an MPA may re-aggregate in other core habitats of humpback dolphins outside the MPA, which could intensify the interaction frequency between fishing and humpback dolphins. Enhanced law enforcement can temporarily suspend fishing activities from MPAs. Fishers' sneaking entry during patrolling gaps, or nighttime, can compromise MPA efficacy and meanwhile increase local conflicts [15,26].

Conflicts of fisher's attitudes to MPA management are not inevitable, however. Fisher's knowledge of marine biodiversity resources and marine environmental dynamics, through traditional ecological knowledge (TEK), is one of the most valuable pieces of information identifying key biodiversity areas [49], assisting field surveys [50] and planning ecological monitoring [6,51]. Hiring local resource users, such as hunters, in terrestrial wildlife conservation has been practiced in many countries, including China. A similar strategy, however, is seldom implemented in marine biodiversity conservation for humpback dolphin habitats throughout the species' range. The overlap between dolphins and fishing activities, on the one hand, implies potentially high risk of bycatch mortalities, but on the other hand, provides a low-cost solution for long-term monitoring of humpback dolphin activities by local fishers. Such is seen in this study in which most of the fishers watched and were willing to report illegal and unsustainable fisheries, particularly electric fishing. The major gap comes from questions of how to find fishers who are willing to participate in MPA and humpback dolphin monitoring, where the mechanism that consolidates fishers with MPA management is, and how to develop a training program changing consumptive resource-harvesting behavior into non-consumptive resource-monitoring behavior.

4.3. Ecologically-friendly tourism as an alternative to trammel-net fishing: Opportunities, challenges and solutions

One of the tactics in livelihood-diversification programs is changing consumptive utilization to non-consumptive use of marine resources through ecotourism [18,52], particularly dolphin-watching tours, by taking tourists to their traditional fishing areas to watch dolphins [33,53]. Potential options of livelihood diversification in the context of ecotourism are not restricted to dolphin-watching ventures, but also encompass services associated with dolphin-watching tours, including meals, accommodation and gifts that are presently adopted by villagers of Sanniang Bay Village. In Indonesia, boat fees comprise a minor percentage of total expenses on dolphin-watching tours [53]. In Sanniang Bay Village, tourists spend higher amounts on accommodations and food (Haiping Wu, unpublished results) than boat tickets [33]. In the past five years, more and more fishers in Sanniang Bay Village have surrendered their fishing boats and refitted their houses to provide accommodation and catering services for tourists, even without external incentives.

Challenges inhibiting the development of ecotourism as a livelihood alternative include whether the ecotourism is operated in a sustainable manner and whether the fishers are capable of running sustainable tourism. Adverse effects of uncontrolled dolphin-watching tourism [32,33] indicate the risks of spontaneous conversion of livelihoods. In Sanniang Bay Village, the maximal number of allowable tours per day was estimated to be 30 tours for 10 h [33]. This threshold value, however, is much lower than the number of fishers, 72 out of 232 respondents in this study or more than 100 fishers in Sanniang Bay Village. In this case, tour activities would easily become unsustainable if most fishers are conducting dolphin-watching tours, or when fishers focus on short-term profits. Unsustainable dolphin-watching activities, including uncontrolled tours during long vacations, aggregation of dolphin-watching boats around one dolphin group and aggressive maneuvers during accessing and watching dolphins, have been reported [33] and have been escalating recently. Similar development of uncontrolled dolphin-watching tours was also observed in Khanom, Thailand (Suwat Jutapruet, personal communication); those are operated by fishers as well [32,34,53]. In Sanniang Bay Village, negative consequences have been jeopardizing tourism sustainability by causing significantly longer travel distances and durations, which increase costs [33] and decrease prices of boat tickets (from 100RMB in the past [33] to 30–60 RMB per tourist now). In this situation, dolphin-watching tourism in Sannaing Bay Village would be likely unsustainable, both ecologically and economically.

The second challenge that likely restricts the development of sustainable ecotourism comes from low education level of fishers. In Sanniang Bay Village, this study showed fishers, as well as farmers and casual laborers, had the lowest education level that encompasses primary and secondary school degrees. For cetacean-watching tourism, conducting lecturing and interpretation before and during dolphin-watching tours are important components to facilitate tourists' awareness of sustainable guidelines for conservation and protection of cetacean resources [54]. Present dolphin-watching tourism in Sanniang Bay Village, however, has no pre-tour lecturing or on-tour interpretation exercises. One of the apparent reasons comes from the speed/fishing boats that carry a handful of tourists [33]. The major explanation comes from fishers' low education level does not support the ability to conduct quality lecturing and interpretation services; even the education level of tourism operators (high school primarily) is higher than that of fishers in this study. Low education attainment of fishers is comprehensively reported in fishing villages [7,55,56], this study and is one of the decisive factors forming exit-fishing reluctance [7,14,20]. The association of education level with household livelihoods in the present study indicates a 'poverty trap' that hinders their ability to approach 'better--income' livelihoods. In this context, even if a fisher 'diversifies' his or her livelihood from fishing to dolphin-watching, the dolphin watching venture may still be treated as an alternative form of 'fishing', *i.e.*, '*catching*' as many tours/tourists as possible, which is precisely how dolphin-watching tourism is operated in Sanniang Bay Village [33]. Without external assistance for education and training, sustainable dolphin-watching tourism is unlikely to be developed, while negative impacts of unsustainable dolphin-watching tours will eventually jeopardize both humpback dolphin survival and fishers' livelihoods [33].

An implicit concern associated with the exit-fishing policy comes from fading traditional ecological knowledge in fishers [57]. In China, fishers play a central role in searching for, locating and following humpback dolphins during field surveys. Fishers' own experience in wildlife and nature resources, *i.e.*, their own traditional ecological knowledge, is one key element ensuring ecotourism and artisanal fishery is ecologically sustainable [57]. As previously discussed, the proportion of artisanal fishing livelihoods would decrease due to aging demographic structure and out-migration of young and well-educated residents and voluntary conversion of fishing to other livelihoods. Spontaneously reduction in fishers' traditional ecological knowledge is expected, but comprehensively enacting an 'exit-fishing' policy without culture-transmission reinforcement further hampers local traditional ecological knowledge and accelerates cultural deterioration and disintegration [57].

To cope with the above difficulties, basing an exit-fishing policy on development of ecotourism to reduce fishing activities, and hence bycatch impacts, should consider the following components: eco-friendly and sustainable principles [18,58], integration of environmental education, nature-based experience and human-nature associations to raise conservation awareness [52,58] and diversifying ecotourism development to a variety of livelihoods, including guest house, restaurants and souvenir shops, in addition to actual running of dolphin-watching tours. An integrative *ad hoc* public education program, such as the Dolphin SMART program (https://sanctuaries.noaa.gov/dolphinsmart/), assisted by NGOs, academic teams and government sectors (including the MPA administrative or maritime authorities), is recommended to ensuring ecotourism-based livelihood diversification is ecologically sustainable [18]. A plan to share, deliver and transmit traditional ecological knowledge between generations of residents and between residents and stakeholders is essential in planning

and implementation of these actions. Community-based management is a valid strategy to cope with biodiversity conservation and ensure traditional ecological knowledge preservation [18]. In China, the "Eco-Civilization Construction" policy provides policy baselines to incorporate the above recommendations and integrate assistance from multiple management sectors [30].

5. Conclusion

Livelihood-based trammel-net and gillnet fishing often overlaps the core distribution areas of coastal delphinids, which potentially imposes a high risk of bycatch mortality on threatened populations. Mitigation actions against unsustainable bycatch mortality often aim at restricting and reducing trammel-net fishing in core habitats of dolphins through spatial closures (bans) and 'exit-fishing' policies. Actions including fishing-gear modification, MPA designation, motivating and mobilizing local community participation, and livelihood diversification should be planned in an integrative manner and should refer to local household livelihood baselines. The fundamental question in the context of sound 'exit-fishing' policy to cope with bycatch mitigation is whether the fishers are capable of engaging in alternative livelihoods other than fishing. This paper demonstrated that, in a fishing village, contracted employment and ecotourism-related livelihoods require higher education levels than fishing, farming and casual labor, and fishers are reluctant to embrace 'exit-fishing' policy and livelihood diversification, due to a 'poverty trap' from low education attainment. Furthermore, neither 'exit-fishing' policy nor livelihood-diversification programs consider intergenerational transmission of traditional ecological knowledge, which is crucial for monitoring humpback dolphin and maritime activities and supporting baseline surveys of threatened dolphin populations, as well as operating sustainable ecotourism and maintaining sustainable fisheries. Though conflicts between conservation action planning and livelihood-based resource utilization seem inevitable, engagement of local participation, *ad hoc* training programs assisting livelihood diversification and preservation of traditional ecological knowledge in local marine education would minimize those potential conflicts. A stakeholder network bringing together MPA managers, scientific researchers and local communities is essential to address the gaps between conservation action planning and livelihood-based resource utilization. Such programs can be organized and operated by local governments and conservation NGOs.

CRediT authorship contribution statement

Haiping Wu: Conceptualization, Methodology, Investigation, Writing – original draft preparation; **Qiuhui Li**: Conceptualization, Investigation, Writing – original draft preparation; **Chunyan Wang**: Investigation, Data curation; **Qianwen Wu**: Investigation, Data curation; **Chongwei Peng**: Investigation; **Thomas A. Jefferson**: Conceptualization, Writing-Proofreading; **Zhizhen Long**: Investigation; **Fangqiang Luo**: Investigation; **Youhou Xu**: Investigation; **Shiang-Lin Huang**: Methodology, Data analyzing, Visualization, Writing – reviewing and editing.

Declarations of interest

none.

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