Future of Asian horseshoe crab conservation under explicit baseline gaps

A global perspective

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Horseshoe crabs are currently threatened by escalating human stresses along the Indo-Pacific coastline. Conservation of their remaining populations, however, is hindered by limited baselines throughout their ranges. We performed a questionnaire survey of conservation experts from diverse geographic regions to identify baselines, prominent threats, impediments and alternative strategies that prioritize Asian horseshoe crab conservation. Despite long-term monitoring across habitat types is lacking, local population declines were widely perceived. Ongoing residential/commercial development along the coast was regarded as the most serious threat. A combination of top-down institutional management and bottom-up stakeholder participation was cited as the most promising strategy. Population and habitat baseline collections should be prioritized in future research to inform conservation planning. In this paper, we summarize the survey findings into the BTPAE (Baseline, Threat, Purpose, Action and Evaluation) framework, which constitutes to our best hope for the future of Asian horseshoe crab conservation.

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1. Introduction

Horseshoe crabs, the well-known example of “living fossil” (Rudkin and Young, 2009), span their whole life history across diverse habitat types from beaches near the high-tide line, through intertidal mudflats, to coastal waters within 30 m in bathymetry as their nesting, nursery and feeding grounds, respectively (Shuster and Sekiguchi, 2009; Chen et al., 2015; Mohamad et al., 2019). The Atlantic horseshoe crab, Limulus polyphemus and the tri-spine horseshoe crab, Tachypleus tridentatus have been harvested since the 1980s to commercially manufacture Limulus/Tachypleus amebocyte lysate (LAL/TAL; Novisky, 2015), a standard assay for protecting vaccines, injectable drugs and other pharmaceutical devices from the contamination of bacterial endotoxins. Large quantities of LAL/TAL would be immediately needed, for example during the prevailing coronavirus pandemic, for vaccine testing and general public health (Arnold, 2020; Waycott, 2020). Among the four extant horseshoe crab species, L. polyphemus and T. tridentatus are listed as “Vulnerable (VU)” (Smith et al., 2017) and “Endangered (EN)” (Laurie et al., 2019), respectively on the International Union for Conservation of Nature (IUCN) Red List, while the other two, the coastal horseshoe crab, T. gigas and the mangrove horseshoe crab, Carcinoscorpius rotundicauda are currently listed as “Data Deficient (DD)”. However, there are reports indicating the populations of T. gigas are also in decline (Nelson et al., 2015, 2016) and the extensive loss of mangrove habitats in Asia may have affected the existence of C. rotundicauda (Friess et al., 2012; Mishra et al., 2015). All in all, this may imply that horseshoe crab populations worldwide are under potentially high extinction risks.

The three Asian species, namely T. tridentatus, T. gigas and C. rotundicauda (see Supplemental Fig. 1 for species photographs), are distributed in the wide geographic range of the Indo-Pacific across several countries/regions from East Asia through Southeast Asia to South Asia (John et al., 2018; Vestbo et al., 2018). Population size, population dynamics and distribution range are the key baselines for species/population status assessment following IUCN Red List criteria (IUCN 2001; 2012). However, the continuous collection of these baselines is demanding, especially for widely ranged marine organisms, leading to the fact that reliable baseline data for evaluating Asian horseshoe crab populations are largely lacking. Facing increasingly accumulated anthropogenic stresses along the coast (Halpern et al., 2008), the future of Asian horseshoe crab conservation should not be optimistic. Effective conservation measures are immediately needed, despite the currently significant baseline gaps. To close up the knowledge gaps, we applied questionnaire surveys to gather the “academic ecological knowledge” (Duncan et al., 2017; Lewis et al., 2020) from a group of conservation experts throughout the ranges. Our goals were to: (1) determine population trends and major threats; (2) identify impediments to conservation; and (3) prioritize conservation strategies to address the perceived gaps, threats and hindrance, with a hope for a bright future of Asian horseshoe crab conservation.

2. Methods

An online survey (Box 1) that contains questions about population trends, threats, availability of relevant marine protected areas and legislation, impediments to conservation, conservation strategies and research priorities, was administered to the members of IUCN Species Survival Commission Horseshoe Crab Specialist Group and other conservation experts working on Asian horseshoe crab research, education/awareness or resource/habitat management, in May–June 2019 around the Fourth International Workshop on the Science and Conservation of Horseshoe Crabs (http://www.gxbrc.org.cn/horseshoecrab2019/). Types of threats in the survey followed the classifications and definitions of the IUCN Threats Classification Scheme, Version 3.2 (https://www.iucnredlist.org/resources/threat-classification-scheme) with an exclusion of “geological events” threat. Suggestions on perceived impediments and research priorities were open-ended, and a maximum of three replies was allowed. For conservation strategies, the respondents would choose and rank three from a list of twelve possible options. To improve the validity of the data, the respondents were allowed to ignore any questions irrelevant to their expertise. A blank option was also provided for all multiple-choice questions in the survey to allow other different responses.

3. Results and discussion

3.1. A global survey of horseshoe crab experts

In total, 46 participants from 11 countries/regions, which cover the entire distribution range of Asian horseshoe crabs except for Bangladesh, Cambodia, Brunei and the Philippines, returned questionnaire surveys (Supplemental Table 1). Nearly all respondents (96% participants) responded to the questions concerning threats, impediments to conservation, conservation strategies and research priorities, while only 39% of the respondents provided their information on population baselines and surveys.

3.2. Baseline information

Baseline data set the historical benchmark for current status and future projection of focal species/population (e.g., Baum and Myers, 2004; Cardinale et al., 2011; McClanahan et al., 2012; Collins et al., 2020). For Asian horseshoe crabs, most respondents perceived an overall decline in local populations across the three kinds of habitats, i.e., nesting, nursery and feeding grounds (Table 1). A high level of habitat destruction was commonly indicated across the habitat types (Table 1). The
A proportion of available baseline information on each habitat type showed different patterns throughout the countries/regions (Fig. 1a). Seven of the nine countries/regions had collected population information from the intertidal nursery habitat, which was mostly concentrated in the Chinese regions (including Hong Kong and Taiwan, Fig. 1a). Conversely, the amount of baseline information on adult feeding habitats in the subtidal areas was the least and virtually unavailable in the East Asia countries/regions, i.e., Japan, Mainland China, Hong Kong and Taiwan. Only Singapore had a relatively complete baseline across the three habitat types (Fig. 1a).

Reliability and robustness of survey conclusions depend heavily on its sampling method (e.g., Thomas et al., 2010; Boersch-Supan et al., 2019; Wang et al., 2019). To date, most Asian horseshoe crab baselines were acquired from personal field observation (37%) or fishers’ perception (24%). Only about one-third of the reported population information was sampled

Table 1
Response frequencies on trend of population dynamics and level of habitat destruction. Most respondents perceived a declining Asian horseshoe crab local population and a high level of habitat destruction across habitat types (nesting, nursery, and feeding habitat). TT: Tachypleus tridentatus; TG: T. gigas; CR: Carcinoscorpius rotundicauda.

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Species</th>
<th>Habitats</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TT</td>
<td>TG</td>
</tr>
<tr>
<td>Trend</td>
<td>Nesting</td>
<td>Nursery</td>
</tr>
<tr>
<td>Increasing</td>
<td>32</td>
<td>18</td>
</tr>
<tr>
<td>Stable</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Decreasing</td>
<td>21</td>
<td>13</td>
</tr>
<tr>
<td>Unknown</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Level</td>
<td>Nesting</td>
<td>Nursery</td>
</tr>
<tr>
<td>Low</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Moderate</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Unknown</td>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>
through systematically executed field surveys. In terms of the sampling period, approximately half (19 of the 39 surveys, 49%) of the reported surveys were conducted after 2010 (Fig. 1b). Population data from India, Singapore and Taiwan, on the other hand, were obtained before 2010, and can be viewed as in need of update (Fig. 1b). Only Japan had conducted population monitoring that spanned across the two decades from the 2000s–2010s.

Accurate estimation of the population dynamics for broadly distributed marine organisms, particularly those with long lifespan such as horseshoe crabs, can be challenging. Distribution-related criteria in the IUCN Red List (i.e., criteria B; IUCN, 2001, 2012), however, can underestimate the population status. Habitat quality, including level of habitat destruction, may also serve as a potential proxy to population condition assessment. While historical information is sparse for most Asian horseshoe crab populations, Tsuchiya (2009) provided an overall magnitude of $T. tridentatus$ population in the Seto Inland Sea, which was known to support large population in Japan prior to widespread coastal reclamation occurred around Kasaoka Bay between 1969 and 1995. Similarly, the IUCN Red List report for $T. tridentatus$ (Laurie et al., 2019) also documented some historical information about population size of the species across the distributional range. Even though incomplete baselines could lead to inappropriate management, it is vital for conservation scientists and resource/habitat managers to act before all necessary baseline information is gathered (i.e., the crisis discipline essence of conservation biology; Soulé, 1985), particularly when the local population declines have been widely perceived. Considering the prevalence of shifting baseline syndrome, in which people gradually accept the present condition of the natural environment resulting from the lacking of past knowledge and experience (Pauly, 1995), the real situation of Asian horseshoe crab populations and their habitats may be even worse than that the scientific communities perceived. Thus, a more precautionary and proactive attitude towards horseshoe crab conservation is needed.

### 3.3. Major threats

Threats to the persistence of focal species should be evaluated systematically, while differences in scale of evaluation such as spatial extent could lead to different assessment results (Woolmer et al., 2008; Di Marco et al., 2013). Most respondents perceived that “residential and commercial development” along the coast was the major threat to Asian horseshoe crab populations across their distribution ranges (Fig. 2a). Other threats, including “human intrusions and disturbance”, “pollution” and “agriculture and aquaculture”, were frequently reported as the minor threats among the ten types of threats, following the IUCN Threats Scheme Classification (Fig. 2a). These threats were primarily viewed to be ongoing rather than prevailing in the past or foreseeing to occur in the future (Fig. 2b). Collectively, coastal land use for human settlement, commercial/industrial development and agricultural/aquaculture utilization have persistently affected the remaining Asian horseshoe crab populations. Such activities, involving large-scale, observable landscape/seascape modifications, can have direct, irreversible impacts on coastal ecosystems (Crain et al., 2009; Defeo et al., 2009) as well as inhabiting organisms (e.g., Teichert et al., 2018).

Laurie et al. (2019) claimed that “climate change and severe weather”, “biological resource use” and “natural system modifications” should be responsible for the decline in $T. tridentatus$ population. These threats, nonetheless, were not equally perceived by our respondents (Fig. 2). This divergence should not lead to further arguments, but we should learn to consider multiple potential threats and their synergistic effects when formulating precautionary management initiatives (Conversi et al., 2015) for Asian horseshoe crabs. In previous studies, permanent coastal habitat destruction (Mishra et al., 2015;
and unsustainable biological resource use (Fu et al., 2019; Liao et al., 2019; Meilana and Fang, 2020) were frequently cited to have deleterious effects to the local horseshoe crab populations. In addition to the intentional harvest, in this survey, the respondents also reported potential threats derived from the unintentional bycatch. Large numbers of Asian horseshoe crabs were persistently found entangled on abandoned gillnets or in cages along the intertidal flats in Southeast Asia and Southern China (Fazrul et al., 2015; Mohamad et al., 2015; Supadminingsih et al., 2018; K.Y. Kwan’s pers. observ.). The bycatch individuals were not returned to the sea, but being abandoned onshore to minimize the destructive potential of horseshoe crabs to the nets. Some fishers also blamed the horseshoe crabs for adversely affecting their fishing efficiency and productivity.

Not all the anthropogenic stresses, however, can cause obvious “footprints”. For instance, beachcombing, i.e., searching and harvesting food sources such as clams through small-scale, localized sediment digging on intertidal mudflats during ebb tide, is popular among the coastal communities in Chinese regions. Recently, the activity has gradually transformed into an intensive, organized ecotourism activity, particularly during the summer when peak spawning and feeding activities of horseshoe crabs occur. The disturbance derived from vigorous sediment disruption to horseshoe crabs and benthic biological communities can be enormous (AFCD, 2014). However, most people, including the scientific communities, may perceive this to be minor since the impacts would be “diminished” in the coming flood tide. The impacts of bycatch, beachcombing and other coastal anthropogenic activities to horseshoe crab populations deserve closer investigations in the future.

3.4. Availability and effectiveness of MPAs/legislation

Marine protected area (MPA) is an explicit section of the ocean that built for protecting not only specific species/population, but also supporting biodiversity from potential threats through management interventions (Margules and Pressey, 2000; Stolton et al., 2013; Day et al., 2019). MPAs are based on and mainly maintained by legislation, therefore MPAs and legislation should be considered simultaneously. The coverage of horseshoe crab habitats by existing MPAs was mostly unavailable/unknown (14 out of 20 responses, 70%), according to the respondents’ perception (Table 2). Six respondents were aware of the relevant MPAs in India, Indonesia and China (including the Mainland and Taiwan), in which these MPAs include the beaches and shallow coastal waters that potentially cover important habitats for horseshoe crabs. However, half evaluated them to be only partially effective (Table 2). Twelve of the 19 respondents (63%) perceived relevant legislation to be unavailable or unknown, and most (63%) also doubted the effectiveness of their enforcement (Table 2). Overall, the available MPAs and legislation were perceived to play very limited roles in protecting Asian horseshoe crab populations across their ranges.

To validate the claims, we overlapped the Indo-Pacific coastal water zones within 30 m depth, as an indicator of the potential distribution range of Asian horseshoe crabs (Chen et al., 2015; MARSPEC, modern data), with the established MPA locations (UNEP-WCMC, 2017) (Fig. 3). Apparent overlaps only occurred in the Seto Inland Sea, Japan where the known northernmost boundary of T. tridentatus population occurs (Sekiguchi and Shuster, 2009) and in Southern Vietnam where all three Asian horseshoe crab species are distributed (Vestbo et al., 2018). The finding is consistent with the general perception of the expert communities that MPAs and legislation were mostly unavailable/unknown and ineffective, especially under the background that MPAs often do not meet the criteria of effective management globally (Gill et al., 2017; Tulloch et al., 2020).
The low effectiveness of MPAs in protecting the declining horseshoe crabs in most Asian regions was possibly due to the limited financial resources, scientific knowledge, and capacity to enforce environmental legislation (Xie et al., 2020). Recent population surveys within the six MPAs in Guangdong province, China that targeted on horseshoe crab conservation revealed only one of them has active nursery habitats for *T. tridentatus* and *C. rotundicauda*, while no (or less than five) juvenile(s) was found in other horseshoe crab MPAs (Xie, unpublished data). Since mangrove fringes serve important nesting and nursery habitats for Asian horseshoe crab populations (Fairuz-Fozi et al., 2018; Xie et al., 2020; Kwan et al., 2020), the established MPAs for preserving mangrove ecosystems in Asia such as Gahirmatha Marine Wildlife Sanctuary in India (Basudev et al., 2013), and Beihai Binhai National Wetland Park and Beilun Estuary National Nature Reserve in China (Xie et al., 2020) may play a vital role in safeguarding the horseshoe crab habitats from destructions. However, we have little information to justify whether the existing MPAs can protect feeding habitats of Asian horseshoe crabs from overharvest and bycatch due to the limited monitoring information on adult populations (Fig. 1a) and the lack of knowledge regarding their movement patterns and residency in the coastal regions.

### Table 2
Responses on perceived types and effectiveness of marine protected areas (MPAs), and availability and enforcement strength of legislation.

<table>
<thead>
<tr>
<th>MPAs</th>
<th>Legislation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types</td>
<td>Availability</td>
</tr>
<tr>
<td>No harvest</td>
<td>Available</td>
</tr>
<tr>
<td>Sustainable use</td>
<td>Unavailable</td>
</tr>
<tr>
<td>Unavailable</td>
<td>Unknown</td>
</tr>
<tr>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Effectiveness</td>
<td></td>
</tr>
<tr>
<td>Partial</td>
<td>Weak</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Full</td>
<td>Strict</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
</tr>
</tbody>
</table>

3.5. Impediments, strategies and priorities

There were 58% (68 of the 117 replies) and 25% of the respondents who mentioned the current insufficiencies in management efforts and local community awareness/stakeholder participation, respectively, which were believed to impede the
progress of conservation for Asian horseshoe crabs (Fig. 4a). Comparing those from East Asia (Japan, Mainland China and Taiwan) who mostly indicated the limitation in resource and habitat management, respondents from Southeast and South Asia (Malaysia, Indonesia, Myanmar and India), on the other hand, tended to attribute the ineffective conservation outcomes to the low stakeholders’ awareness and participation (Supplemental Table 2). Explicit gaps in population and habitat baselines were also perceived as one of the main impediments, accounting for 14% responses to this question. Conversely, very few responses addressed the issues of ineffective captive breeding/reintroduction (~2%) and invasive species control (~1%). Respondents’ experiences on the cultural and governmental regimes, as well as their ecological knowledge on populations and habitats, seemed to cause the deviations in perceived impediments.

Consistent with the impediments perceived, most respondents pointed out that more inputs into conservation management (54%, 71 of the 132 replies) and community awareness/stakeholder participation programs (26%) are important to conserving the Asian horseshoe crab populations (Fig. 4b). These two initiatives may act in complement as the top-down and bottom-up approaches. The perceived most prominent threat, i.e., commercial/industrial development along the coast is generally based on the institutional spatial planning process, in which the local governments can play a primary role in the lead and rule (Hersperger et al., 2018). Thus, more powerful management tools supported by legal protection would be needed to justify the trade-off between coastal development and species/ecosystem conservation (Techera and Klein, 2011; McClenachan et al., 2012; Beninde et al., 2015). For conservation management options, restoration and enhancement of the destructed habitats should be prioritized (Fahrig, 2001; Barbier et al., 2011), given the already shifted baselines of Asian horseshoe crabs. Considering the degraded nursery habitats of Asian horseshoe crabs, restoration and revegetation with mangroves, seagrass and salt marshes may benefit the survival and growth of the juveniles, as a higher abundance of the juveniles was found in intertidal areas accompanied with these vegetations (Morton and Lee, 2010; Chen et al., 2015; Xie et al., 2020). Seagrass detritus was also demonstrated to considerably support the intertidal benthic food chains, which in turn, contributed to the abundant food sources to juvenile horseshoe crabs (Kwan et al., 2015; Fan et al., 2017; Kwan et al., 2020). This approach can also support other alternative management tools such as captive breeding and restocking programs, which were frequently cited to be useful by the experts from East Asia countries/regions (in 11 of the 12 responses in the regions). Many previous studies also concluded that restocking will not succeed without habitat restoration or fishing effort control (Penman and McAndrew, 1998).

Facing the increasingly emerging and diverging anthropogenic stresses, management measures that solely stem from the governance cannot be immediately and adaptively effective. A bottom-up approach that originates among relevant stakeholders from diverse backgrounds with vested or conflicting interests, including fishers, habitat managers, local government officials, property developers and general public, may be useful in complementing the inherent insufficiency of institutional management (Noble et al., 2018). For instance, community-based patrol and surveillance, rather than that organized from the local wildlife protection departments, can be more practical and effective in controlling illegal fishing efforts targeted on Asian horseshoe crabs (Mohamad et al., 2015; Fu et al., 2019; Liao et al., 2019; Meilana and Fang, 2020).

Fig. 4. (a) Perceived impediments, (b) strategies, and (c) priorities of future studies to the conservation of Asian horseshoe crabs. Management and awareness/participation programs represent the majority in current insufficiency and further improvement. Future researches are suggested to focus on the issues relating to baselines and threats.
Conservation education programs can also act as the more proactive alternative to raise the conservation awareness of stakeholders, reverse the shifting baseline syndrome and reshape pro-environmental attitude towards the overexploited wildlife and environment (van der Ploeg et al., 2011; O’Byrhim and Parsons, 2015; Soga and Gaston, 2018). However, the gap between conservation knowledge/attitude and practice/behavior often exists (Habel et al., 2013; Nilsson et al., 2020). In addition to shaping awareness on “why do we need to protect wildlife and environment?”, specifying understandable action guidelines for leading people on “what should we do?” and “how can we do?” can facilitate the gradual transformation from disciplinary attitudes to actual behaviors (Schulttler et al., 2018). Measures that foster more direct contacts with target organisms/environments can generate positive feedbacks that further enhance motivations of behaviors (Zhang et al., 2014; Kwan et al., 2017; Prevot et al., 2018; Schulttler et al., 2018). Conservation scientists should also actively engage themselves into community education and stakeholder participation programs for filling the gaps not only between attitudes and behaviors, but also between theoretical research and practical conservation action (Arlettaz et al., 2010). For the bycatch issue, horseshoe crab researchers can assist the local fishers minimize the conflicts by identifying possible fishing hotspots outside the core distribution area of horseshoe crabs or developing eco-friendly fishing methods, for instance. Meanwhile, the bycatch data should be compiled systematically to support population trend evaluation (John et al., 2020). However, there should not be a “one-size-fits-all solution” for Asian horseshoe crab conservation across the geographic regions, which was in agreement with the inconsistencies in reported impediments and possible strategies perceived in the questionnaire surveys. Local adaptation and modification in response to societal, economic and governmental factors are equally important to lead the strategies to be regionally and locally practicable.

We anticipate that the establishment of new MPAs and environmental legislation to cover the entire distribution range of Asian horseshoe crabs would be unrealistic. We do not attempt to rebut the vital roles of MPAs and relevant legislation in biodiversity conservation. In fact, the intervention of legislation enforcement can be effective as a behavioral control to restrict disturbances from intensive anthropogenic activities. For example, harvest of _L. polyphemus_ is actively regulated in Delaware Bay, USA through imposing a system of harvest level reductions, seasonal closures, male-only harvest, and voluntary use of bait-saving devices (Smith et al., 2009). In 2001, the National Marine Fisheries Services established a 3885 km$^2$ no-take sanctuary, known as the Carl N. Shuster Jr. Horseshoe Crab Reserve, at the mouth of the Delaware Bay to protect older juveniles and newly mature females. The harvest regulations and MPA establishment are effective in reverting the declining population trend caused by overharvest of _L. polyphemus_ in the region (Hata, 2008; Michels et al., 2008; Smith et al., 2017). For Asian horseshoe crabs, ecologically sound management options such as closing certain coastal areas during horseshoe crab peak spawning period and regulating artisanal bivalve aquaculture and beachcombing activities within their critical nursery grounds, can be attempted.

To facilitate future conservation initiatives, the expert communities viewed baseline collection (46%, 56 of the 121 replies) and threat identification (25%) to be of the top priorities in future studies (Fig. 4c). Baseline data would serve as the reference for population status assessment and MPA planning (Margules and Pressey, 2000; Krebs, 2014). Continuing population and habitat baseline samplings help optimizing conservation management to address ongoing and future threats. A more comprehensive understanding of the baseline of habitat physicochemical characteristics can also benefit the restoration of degraded habitats (Borja et al., 2010; Wang et al., 2019). Since the nursery baseline of Asian horseshoe crab was the most reported (Fig. 1a), a considerable increase in the frequency and extent of monitoring in both nesting and feeding habitats is needed. Knowledge of distribution, configuration and connection of the three habitat types will also contribute largely to the holistic conservation framework for Asian horseshoe crabs.

To speed up population baseline collection in developing countries, the identification of potentially important habitats for horseshoe crabs through local knowledge-based surveys can be more feasible and cost-effective (Liao et al., 2019; Meilana and Fang, 2020). Collaboration with governmental and/or non-governmental organizations by adding horseshoe crab population monitoring into the existing programs can also be attempted to lower the labor cost (John et al., 2020). Collected baseline data should be not only documented in academic publications, but also incorporated into a centralized repository for data retrieval with permissions.

4. Summary: the BTPAE action framework

Herein, we integrated all critical components from the expert questionnaire survey into the BTPAE framework—B (baseline), T (threat), P (purpose), A (action) and E (evaluation) (Fig. 5). This action framework which aims at bridging the missing link between theoretical research and practical conservation action, constitutes to our best hope for the future of Asian horseshoe crab conservation. The important framework concepts and survey results are summarized as follows.

**Baseline (B):** Baseline information typically comprises population dynamics in terms of population size and growth, distribution and characteristics/status of habitats. Conservation expert communities perceived baseline collection as the top priority in future research. Systematic and well-structured methods for baseline samplings are strongly recommended to obtain scientifically sound data.

**Threat (T):** The experts ranked threat identification as the second priority in future studies. Despite evidence of declines, comprehensive investigations on the type, scope and severity of potential threats to Asian horseshoe crabs are largely lacking. Most respondents pointed out in the survey that while permanent land-use changes due to residential/commercial developments were possibly the most predominant threat to Asian horseshoe crab populations, only a very limited number of
studies looked into the actual causal relationships between the human disturbance and species survival. Potential threats derived from bycatch, beachcombing and other seemingly harmless activities also deserve closer inspections.

**Purpose (P):** Purpose is an indivisible part of an action. Any meaningful conservation action should be based on explicit, specific purpose(s) that defines the goal of action on the baseline. We separate the purpose into three categories, i.e., prevention, mitigation and restoration. Prevention of identified threats and avoidance of irreversible outcomes following the precautionary principle would be the first step. For those ongoing threats, to mitigate their negative impacts is the fundamental goal. Restoration of the severely shifted baseline was the last resort to account for the worsen scenarios.

**Action (A):** Most experts suggest greater investments in governmental/legislative management efforts and community awareness/participation that may enhance the current conservation progress. The top-down management approach through legislation enforcement can be responsive in regulating human disturbances, while the bottom-up initiative originated from local communities may require a longer-term investment in conservation education and awareness programs. A combination of these two dimensions may lead to more promising conservation outcomes.

**Evaluation (E):** Evaluation is the connector among baselines, threats and actions. The primary objective of monitoring is to evaluate the baseline changes, development of threats and effectiveness of actions taken. To periodically evaluate effectiveness of conservation actions is fundamental for further improving the future planning and management measures. Through systematic evaluation, elements of the baseline-threat-purpose-action loop are concatenated.

**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.

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Appendix A. Supplementary data

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