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Using the DPSIR framework for transdisciplinary training and knowledge elicitation in the Gulf of Thailand

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Highlights:

- Coastal zones cross physical (land-sea) and administrative (between countries) boundaries.
- Coastal zone management requires connections across disciplines and areas of expertise.
- Coastal practitioners need tools and frameworks to support cross-boundary problem-solving.
- DPSIR provides structure for knowledge elicitation and sharing and integrated management.
- DPSIR works across socio-ecological systems at multiple scales.

1. Introduction

Coastal zones are recognized as areas that embody the term cross-boundary: land-sea boundaries, socio-institutional boundaries, focal areas for contrasting human enterprise, and interfaces amongst ecosystem types. Such complex systems create challenges for sustainability because the multitude of interacting biophysical, social, cultural, and economic drivers and processes require simplification to understand and manage. Coastal zones are threatened by a host of stressors that endanger their ability to persist (Adger, 2009), and worldwide, coastal zones are recognized as areas under siege. Pressures on these natural systems are likely to intensify due to climate change (Nicholls et al 2007; Ellison, 2015).

Tropical coastal systems are some of the most productive, densely populated, and biodiverse areas in the world (Halpern et al., 2009). While coastal areas are vital to the needs and livelihoods of local peoples, human activities are, in many cases, degrading these environmental conditions and systems in these areas. These stressors are well documented and include: overharvesting of fish, seafood, and mangroves; habitat degradation and increased erosion (due to aquaculture, forestry and upland deforestation), and rapid development (tourism, pollution) (e.g., Orchard et al., 2015; Ramesh et al., 2011; Cheevaporn and Menasveta, 2003).

These threats to coastal zones are evident throughout coastal Southeast Asia. Since World War II, increased exploitation of primary resources has been the foundation of economic development in many Asian countries (Chua and Garces, 1994). Rapid development coupled with an increasing human population in coastal areas has resulted in the degradation of coastal resources (Adger et al., 2001; MacKinnon et al., 2012). Within the coastal zone, there has been a remarkable increase in commercial fishing (Pauly, 2006). Immigration from overcrowded provinces into an open-access artisanal fishery has caused widespread overexploitation of fishery resources, leading to poverty and an atmosphere of desperation (Mathew, 2003; Pomeroy and Viswanathan, 2003, Bennett et al., 2014). Additional threats to coastal and marine areas such as air and water pollution and the loss of wetlands are brought about by increased urbanization, industrial, agricultural and aquaculture development (Yasue and Dearden, 2009, Hines et al., 2012).

To promote effective management of a cross-border coastal zone requires an understanding of the historical, institutional and social-cultural context. Thailand has experienced a period of unprecedented economic growth over the last 30 years. In addition, Thailand is the only country in the region that was not colonized by a western power. There is a long and intact system of government and institutions that persists, despite numerous coups that have seen governments change quite rapidly. In contrast, in Cambodia, traditional governance systems were displaced by French colonial rule, and the country experienced one of the most disruptive civil wars, genocide and dictatorial rule of any country in the recent past (De Walque, 2006). As local governance systems were destroyed, the bonds that hold many communities and families together were broken. In many respects Cambodia is starting anew in building governance systems and appropriate institutions.

Despite the differences in recent history between Thailand and Cambodia, there are also converging trends. Resource management in coastal zones in both Thailand and Cambodia faces substantial challenges and in both countries there is a growing appreciation of the need to enable a greater element of community-based natural resource management. Public participation and decentralized management has been a central element of recent constitutional rewrites in Thailand, and the Cambodian government is encouraging a wide variety of programs that support a community-based approach (e.g. Dearden et al., 2009). In both countries, coastal resources are intrinsically linked to local economies and community functions, demonstrating the complex interaction between social and ecological systems.

A framework to understand the complex socio-ecological interactions that can both mitigate threats to sustainable coastal zone development is pivotal. While the resilience of tropical and subtropical coastlines has been extensively studied across discrete fields within the social and natural sciences (Beger et al,. 2010), the lack of truly interdisciplinary research on resilience continues to limit (1) our understanding of the non-linear and complex processes that influence resilience between socio-cultural and natural coastal dynamics across time and space (Ostrom, 2009); and (2) the development of effective integrated management strategies to improve rapidly eroding conditions in tropical and subtropical coastal regions (Talley et al., 2003). We applied the Driver Pressure State Impact Response (DPSIR) framework in a workshop process to explore its potential as a tool to communicate transdisciplinary

systematic thinking, elicit local expertise on threats, and build capacity among multi-disciplinary workshop participants. We aimed for this process to support the development of solutions and management actions to address the complex and coupled social-ecological issues in coastal zones. Transdisciplinary training supports the development of scientists and practitioners who are able to synthesize the theoretical and methodological approaches of different disciplines to better recognise complex problems, building respect through learning the languages and cultures of different disciplines, along with learning how to navigate within and between disciplines (Nash 2008). Here, we explore the utility of the DPSIR framework as a tool for identifying sustainability pathways, through application to a cross-border coastal zone between Thailand and Cambodia during transdisciplinary training. Apart from assessing DPSIR as a tool, such training builds the foundation for development of locally relevant management actions and strategies by addressing issues we could identify at this point.

2. Background: the Driver–Pressure–State–Impact–Response (DPSIR) framework

The DPSIR framework has been adopted to structure environmental problems and connect conceptual exploration across social and natural science (Ness et al., 2010, Bell, 2012, Gregory et al., 2013, Lewison et al., 2016). The DPSIR framework, which evolved from an earlier Pressure State Response (PSR) structure, was introduced by the European Environment Agency in the 1990s to help policy makers identify cause–effect relationships between environmental and human systems (Smeets & Weterings, 1999). It remains popular for government policy purposes and is used to frame international environmental monitoring and reporting (e.g., UNEP, 2012).

Traditionally the DPSIR framework includes Drivers which are often defined as global, regional or local social, demographic and economic factors, that act as causal links to exert Pressures on the environment. These pressures can lead to unintentional or intentional changes in the State of the environment, which then lead to changes in the quality and functioning of the environment causing Impacts on the welfare or well-being of natural systems and human communities. Responses are actions taken by groups or individuals in society to prevent, compensate, ameliorate or adapt to changes in the state of the environment

by changing drivers or pressures through actor driven shifts in behavior, prevention, mitigation or regulation (Figure 1). Refinement of the DPSIR framework continues in more recent applications (e.g. Fletcher et al., 2014; Gentry-Shields and Bartram, 2014; Lewison et al., 2016).

It is crucial to gain information about how decision-makers, scientists, and citizens perceive and define environmental challenges (Rudd 2011, 2015; Wise et al. 2014). The application of a DPSIR framework involves problem-structuring that effectively simplifies structure and function but maintains enough complexity to enable addressing issues through evidence about social and ecological systems.

Part of the appeal of the DPSIR framework is that it was developed in response to direct policy and management needs in the context of sustainability. DPSIR takes a complex systems approach while maintaining conceptual simplicity and transparency, focusing on causal relationships among disparate factors. This means that the DPSIR framework has considerable potential for bridging the gap between scientific disciplines as well as linking science to policy and management by engaging stakeholders (Tscherning et al., 2012, Gari et al., 2015, Lewison et al., 2016) because of its ability to integrate knowledge across different disciplines and visualize different decision alternatives.

Figure 1 - Schematic outline of the DPSIR framework

A recent review of the application of DPSIR to coastal socio-ecological systems (SESs) found it has been used successfully to structure environmental problems and serve as a tool for research in coastal zones (Lewison et al., 2016). To date, DPSIR models of coastal systems have been used mainly to support and develop conceptual understanding of complex coastal SESs and to identify drivers and pressures in the coastal realm. Several limitations of the DPSIR framework have also been identified, including lack of explicit hierarchy or scales, inconsistent use of terminology and unidirectional relationships (as originally structured) (Gari 2015).

In spite of these criticisms of DPSIR, a key strength of applying DPSIR to coastal areas lies in bringing together different scientific disciplines with the range of stakeholders to derive sustainable and feasible solutions (Gari et al,. 2015, Lewison et al., 2016). This transdisciplinary cooperation involves development of new language and ways of thinking. Lewison et al. (2016) noted that the DPSIR framework has been applied across numerous boundaries: between disciplines by linking natural and social scientists (e.g., Lowe et al., 2014); between the scientific and non-scientific community (e.g., Butler et al., 2014; Espinoza-Tenorio et al., 2010); and among science, management, and policy (e.g., Fletcher et al., 2014). Importantly, recent literature recommends the use of different methods and models to demonstrate synergistic and cumulative cause-effect relationships among coupled elements within coastal systems, and a clear need to include relevant stakeholders to bridge the policy-science gaps and ensure Responses are appropriate (i.e. practical) for a particular coastal system (Cook et al., 2014; Lewison et al., 2016).

3. Methods

Here we describe a case study to apply the DPSIR framework as an interactive workshop tool to both define and examine coastal sustainability challenges and train local decision makers and stakeholders who engage with management. This work was conducted in a workshop "Workshop on Integration of Management and Sustainable Usage of Marine and Coastal Resources in the ASEAN Region by using DPSIR Frameworks" convened in the Trat province of Thailand (near the border of Cambodia) from 9 to 14 January 2015. The goal of the workshop was to explore the utility of DPSIR as an instrument for transdisciplinary learning and discussion and investigate its possible application to sustainable coastal management within the Association of Southeast Asian Nations (ASEAN) member countries. The workshop was designed to build capacity in the ASEAN region with a wide range of stakeholders through exposing participants to the DPSIR framework. The framework provided participants with an opportunity to share knowledge and expertise to visualize and organize the connections among human decisions, the pressures that socio-economic factors create on the environment, and the potential consequences for provisioning of ecosystem goods and services. Forty-eight scientists, policy-makers, and coastal and fishery managers,

and community organizers from Thailand, Cambodia, Vietnam and Malaysia participated. The workshop was facilitated by a group of eight cross-disciplinary experts: marine biologists, social scientists, governance, GIS and digital communication specialists from North America, Thailand, and Australia.

Figure 2 -Workshop Location and Participant ASEAN Countries

In the first part of the workshop, local NGOs and management agencies introduced and educated participants on the key coastal management challenges for the communities and coastal ecosystems of the Cambodia-Thai border region of Trat Province in Thailand and Pream Krasop Wildlife Sanctuary and Koh Kong Province in Cambodia. These sites share rich ecological and biophysical conditions but have different governance, socio-economic structures, and ongoing research and management activities. While countries varied in their extent of coverage of relevant spatial and scientific data and history of community-based planning and management, there were some common themes. These included coastal habitat degradation (beaches, mangroves, seagrass, coral reefs); overfishing, destructive and illegal fishing; coastal development including tourism; pollution and effects of sedimentation; as well as the influence of market conditions and poverty. The status of and effects of human activities on marine mammals and both the need for, and challenges associated with Marine Protected Areas (MPAs) were highlighted. From the variety of issues covered, participants agreed that studying protected species and designating MPAs was necessary but not sufficient to tackle the range of challenges experienced in this cross-border coastal zone.

To assist in problem structuring, trainers presented a range of tools that could be used to integrate and synthesize knowledge and engage stakeholders. Because of its ability to integrate knowledge across different disciplines, help structure complex environmental problems and formalize different decision alternatives, the application of the DPSIR framework was identified as having potential to bridge the gap among scientific disciplines, promote translational science by supporting clear communication outside of the scientific community and link science to local policy and management (Svarstad et al., 2008; Tscherning et al., 2012).

Following an introduction to the DPSIR framework, and noting the coastal challenges identified by local participants in the first part of the workshop, 33 of the attendees formed into four groups each comprised of representatives of the various countries and the range of roles represented. Groups applied and documented their discussions of the five components of the DSPIR framework to a coastal zone management issue of their choice relevant to the Cambodia-Thai border region.

Two guiding questions related to the objectives were used to stimulate discussion:
1) What are the processes that influence resilience between socio-cultural and natural coastal dynamics across time and space?
2) How can the DPSIR framework be used to support the development of effective integrative management strategies to improve rapidly-eroding environmental and social conditions in tropical and subtropical coastal regions?

Each group addressed issues that were common between the specified Cambodia-Thai border region and could benefit from a trans-boundary approach to management. Group one (G1) focussed on tourism sustainability; group two (G2) on coastal mangroves; group three (G3) on cetaceans, in particular tropical coastal dolphins and porpoises; and group four (G4) on fisheries, in particular crab fisheries management. They also identified research needs and specific actions to address issues and knowledge or data gaps. After completion of the group DPSIR activity, participants were asked to reflect on and document what they learned through the DPSIR development process, what potential they see for DPSIR applications generally, how this could directly help with their everyday job/research, and what they see as most valuable next steps given this experience.

Output from the break-out groups was analysed and compared thematically according to the components of DPSIR (drivers, pressure, state, impact, response) with particular focus on responses in relation to spatial scale, governance, social-ecological relationships and interactions, information management and information exchange. Common and contrasting patterns were identified by the workshop facilitators by reviewing the workshop outcomes,

reflecting, comparing, revising and discussing, leading to a corroborated consensus analysis according to accepted qualitative research methods (Denzin and Lincoln, 2011).

4. Results

The results are reported in two tables which are analysed and discussed in more detail in section five. Table 1 illustrates each group's application of the structured DPSIR approach to its particular issue, as reported by the groups (see figures 3-6 for examples of reporting). To succinctly illustrate the complexity of the issues and causal relationships of social-ecological systems characterised by each of the case studies in Table 1, we briefly describe the context of Group Four's (G4) discussion and output focused on the local crab fishery.

235 Table 1: DPSIR characteristics of four case study issues that challenge sustainability of the Thai-Cambodia coastal zone. The ** symbol
236 represents a section that a group was unable to complete due to time constraints.
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	Group 1 (G1)	Group 2 (G2)	Group 3 (G3)	Group 4 (G4)
	Tourism sustainability	Coastal mangroves	Coastal dolphins	Crab fishery management
Drivers	-Lack of planning -Limited education -No regulations on tourism activity -No zoning / area designation -Hierarchical governance (top down)	-Cross-border trade -Climate change -Population growth -Increased consumption -Increased urbanization -International market access e.g. shrimp -Underdeveloped waste and sewage disposal infrastructure -Limited understanding waste and sewage impacts	- Population growth -Economic development - Climate change	-Increased demand from local subsistence users -Climate change -Increase quality of life -Corruption
Pressures	-Overfishing -Destructive resource use (bombing) -Illegal activity (within and across boundaries) -Conflict with outside investment -Rapid development -Illegal hunting -Climate change -Lack of waste infrastructure -Lack of potable water	-Land-use change -Shrimp farming -Logging/wood harvest -Charcoal -Fishing and bivalve collection -Development -Dredging -Coastal erosion -Sea level rise -Increased storms and waves -Pollution (garbage, sewage, fuel spill, marine debris)	-Intense fishing effort, bycatch, decline in resources -Pollution (marine debris, water quality) -Diseases / bacterial infections - live capture for aquarium black market -Dolphin tourism -Declines in fish population	-Year round crab harvest even during spawning season -Use of illegal crab traps -Conflicts between local and commercial fishing -Conflict on use of gear e.g. trawling locations and crab traps Illegal fishing efforts and illegal gear -Marine mammal bycatch -Lack of enforcement
Impact	-Debris waste -Pollution	-Coastal erosion -Fisheries decline from lack of nursery	-Conflicts between groups of fishers when dolphin death	-Local economy (community) -Property

	-Coastal erosion from development -Local people marginalized people (economically, culturally / socially) -Reduced beach access for people and wildlife -Economic instability/vulnerability	-Loss of natural waste water treatment functions sediment retention -Economic loss from decrease in fishing income -Loss of carbon storage -Loss of protection from storm and tsunami -Decrease in biodiversity -Threatened species e.g. horseshoe crab; river otter -Seawater intrusion	occurs -Non-compliance with international regulations -Decline / instability in ecosystem health -Balance in marine food web -International trade embargo -Religions / culture heritage loss	-Unemployment -Local fishery community -Local conflicts
State	-Water quality -Change in mangrove, coral, seagrass cover -Loss of biodiversity -Decline in marine threatened wildlife (sea turtles, dolphin, dugongs) -Community health	-Change in area -Change in diversity (mangrove and animals in mangroves) -Change in tree density -Increasing forest fragmentation	-Mortality rate 4% per annum -Thai status: Endangered (official)	-Smaller size caught -Smaller population caught -Degradation of seagrass and mangrove habitat -
Responses	-Local education programs - Tourist education (public awareness) -Implementation of monitoring programs for all states -Restoration of habitat -Signage / light reduction on beach -Build governance capacity -Independent coordination body -Alternative livelihoods -Zero waste system -Climate change resilience programs activities	-Community restoration -Reforestation -Build collaboration with villages, NGOs, agencies -Enforce laws that protect mangroves and manage fishery -Education in schools and communities -Manage development and tourism through zoning and spatial planning (e.g. biosphere reserve) -Calculate values of ecosystem services in $ -Reducing emissions from	-Zero waste -Effective / improved / policies -Effective implementation -Research efforts increase -Public outreach + awareness -Government guidelines (best practice) -Enforcement -Transboundary collaborations -Fisheries observer program	-Blue crab bank: - use trap -6cm mesh size - dynamic population trend - support from FAO - incentives - bycatch- other species - stewardship - enforcement. -Alternative livelihood -Habitat rehabilitation -Awareness of regulations -Local agreement between fishing communities -Mariculture

		deforestation and forest degradation -Carbon trading REDD+ and offsets -Alternative livelihoods -Integrate traditional, local, national law and practices		-Empowerment of fishery communities
Data gaps identified	-Need to link past and current monitoring to responses, pressures and drivers framework - Coastal users behaviour and adaptation. capacity to climate change - Governance mode assessment -Coastal tourism carrying capacity, coral reef carrying capacity -At larger scale, strategic environmental assessment (SEA) needed	- Data on trend in cover, density and fragmentation - field and satellite analysis -Fishing surveys collecting mudcrab, charcoal and threatened species (horseshoe crab and river otter); - Biodiversity monitoring - Ecosystem function for wastewater treatment - Trends in fishing incomes carbon storage, seawater intrusion -Level of protection from storm and tsunami	- Dolphin population trend - Transboundary movements - Bycatch rates - Causes of mortality -Environmental toxicology -policy development - Genetics (regional) - Foraging and dietary studies - Social structure and affiliations -Transboundary outreach - Build transboundary database	**

In the crab fishery case study, the Driver was described as overharvesting of fish and shrimp that occurred along this section of the coast due to the rising coastal population and increasing number of large commercial fishing vessels. This in turn put Pressure on the crab fishery as a source of local income and protein, and the State of stocks started to decline, leading to fishermen with unsustainable incomes, moving out of the industry (Impact). Thai regulations that restricted commercial fishing vessels from within three kilometres of the coast were introduced in Response to reduce interference between the commercial trawl fishing and crab fishery. However locals reported that some trawlers (often not from Thailand) used illegal gear and the limit was not enforced, leading to destruction of crab pots in trawl gear. The Impact - Response cycle was repeated as regulations that were introduced to improve crab stocks, restricting crab catch in the spawning season, heavily impacted local fishermen who could not make a living or subsist on seafood during these months. An innovative low technology local response was to continue to harvest out of season, but place female crabs caught with eggs into jetty-side aquaculture tanks (basically buckets with flowing water) until the females released the eggs. Local fishermen then released the larvae into the coastal waters with a resulting increase in the crab stock. With widespread knowledge of improving stocks, some existing fishermen added more pots and new crab fishermen entered the crab fishery, thus increasing the threat to the sustainability of the resource. As a cross-border issue, it was clear that a response solely by Thai government or communities was not a solution in the long term. In addition, the unique local response to building crab stocks and consequent outcomes supported knowledge sharing and transfer among workshop participants.

Insert Figures 4, 5, 6, 7 here as a group of four

After constructing a DPSIR framework for each case study, these interdisciplinary cross-cultural groups were asked to reflect on their experience of using DPSIR in terms of:

- what they learned through the DPSIR development process,
- what potential they see for DPSIR application generally,
- how this could directly help with their everyday job/research, and
- what they see as most valuable next steps given this experience.

Not all groups responded thoroughly to each reflective question as some groups took longer than others to accomplish the first task. However the reflection is considered to be representative of the cross-section of participants, given the composition of the groups. Table 2 reports on the feedback received, which is analysed and discussed in section five.

273 Table 2: Group Reflection on DPSIR training (The ** symbol represents a section that a group was unable to complete due to time constraints)

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	Group 1	Group 2	Group 3	Group 4
What did we learn?	-Learned a new tool for management -Working together, we understand the tool better and how it can support coastal management -We learned to organize our thinking by assigning the elements to DPSIR -DPSIR helped with systematic and critical thinking.	-Systematic thinking - Interdisciplinary and international collaboration -DPSIR – meaning, elements, application -Networking, group working - Experience from local community	-How to develop a DPSIR framework -Helps with systematic thinking -Shared understanding -Causality (cause and effect relationship) -Identify responses to a situation -Identify situational needs and state of knowledge	How to develop and use DPSIR framework -Understand its flexibility -No one tool will fit all issues, problems, situations -Transboundary and transdisciplinary - Direct links to adaptive management
Potential application: How can we apply what we have learned?		**	-Report to the boss or upper management -Share with team -Develop proposals to address responses and needs -Transboundary resource planning and collaborations -Prioritize resource needs -Effective communication through simplification	-MPAs -Fishery -Resource management -Tourism
Assistance with job: How can we use this in our job or study?	-Can use DPSIR framework to create a specific activity, e.g. protect nesting beach -To develop a tourist management plan -Use it to identify problems and the causes in the systems that we work in	**	-DPSIR is a credible method -Systematic way to develop project	**

5. Discussion

This analysis of four coastal zone sustainability issues in Thailand (Table 1) revealed the utility of the DPSIR framework to facilitate and guide systematic and critical thinking in a diverse stakeholder group, multi-disciplinary knowledge exchange, identification of causal relationships, the flexible application at different spatial scales, and the identification of data gaps and actionable strategies. Further, each groups' assessment of their experience of applying the DPSIR framework to a transboundary system (Table 2) provided valuable insight into the learning experience of participants. Below we summarise these findings according to the strengths and limitations of this particular application of DPSIR to a coastal transboundary environment.

5.1 Strengths of application of DPSIR in this workshop

We identified five ways in which DPSIR was useful in organizing coastal management problems and identifying potential sustainable solutions. One of the inherent strengths of DPSIR is its ability to simplify and structure complex problems (Gregory et al., 2013, Svarstad et al., 2008). In this regard, the groups identified that DPSIR was a useful tool to help with systematic and critical thinking (Table 2: Groups G1, G2 and G3) about their chosen transboundary coastal management problems (Table 1). While in a traditional DPSIR model, the Drivers can be global, regional or local (Lewison et al., 2016), in all the workshop case studies, Drivers were described as matters that are beyond control of the local area/region scale such as population growth (G2), increased consumerism (G3), lack of regulation (G1), and climate change (G 4). These were seen as causing more specific local and cross-border Pressures such as intensive fishing or overfishing (G1, 3, 4), illegal activity (G1, 4), pollution (G2, 3), and land use change (G2). Resulting changes to the State are typical of most models (Lewison et al., 2016), reporting primarily in terms of the physical environment: habitat decline (G1, 2, 4), water quality (G1), status of endangered species (G1,3), and fisheries resources (G4). Group one was the only group that included a social factor, community health. The Impacts described by each group illustrated the interconnected social-ecological relationships and impact on natural and human well-being. They included decline in ecosystem health and biodiversity (G2, 3), resulting in the economic

loss from decreased fishing income (G 1,2, 4) as well as disruption to the social systems described in terms of marginalised locals (G1), and conflicts between groups (G3, 4).

The use of DPSIR to structure problems and promote critical thinking was well illustrated by Responses, which highlighted actions that could be taken to affect the Drivers and Pressures. These primarily included social-community-governance aspects such as education and awareness programs for local communities, tourists, and schools about the environment, management and regulations (G1, 2, 3, 4); community empowerment and climate change resilience (G1, 2, 4); improved collaboration across borders and among villages, NGOs and agencies, and fishing communities (G2, 3, 4); and building governance capacity including in relation to policy, enforcement, and planning (G 1, 2, 3, 4). Environmental responses included direct action in habitat and fisheries restoration (G1, 2, 4) and research and monitoring (G1, 3). Economic measures were also suggested: carbon trading to reduce emissions from deforestation (G2); valuing ecosystem services (G2); and developing alternative livelihoods (G1, 2, 4). All of the groups agreed on the need for governance capacity building for a more coordinated cross-border enforcement response to improve fisheries management.

Analysis of the case studies also demonstrates a second strength of DPSIR, as an analytical tool to clarify and understand causal linkages of disparate elements or factors within the coastal system (Lewison et al., 2016). The use of DPSIR in the workshop enabled illustration of social-ecological complexities to more appropriately target practical management Responses. In reflecting about the training (Table 1), G1 and G3 specifically mentioned how DPSIR enhanced their ability to identify cause and effect relationships. Although not mentioned by the other groups, evidence from workshop outputs (Table 1) illustrate that participant groups were able to identify linkages between human activity and environmental issues, such as the link between deforestation and coastal erosion (G2); or overfishing and decreasing stocks and ability to sustain a livelihood (G4). While some of the common Impacts identified across the case studies illustrated the inter-connected social-ecological relationships, a major outcome was the recognition of the importance of social-governance solutions in terms of education, awareness, and capacity building of communities and government, as reported in the broadly agreed Responses.

In terms of this second strength of DPSIR, other authors have found that such cause and effect relationships are often not recognized at the local level. For example Bennett et al. (2015) found that although coastal communities in Thailand identified increasing number and severity of storms, rising sea levels and amplified coastal erosion as major problems, they did not relate these occurrences to global climate change. Lack of ability to make such linkages can inhibit formation and implementation of successful adaptation strategies.

A third strength of DPSIR demonstrated from this effort was its ability to integrate knowledge across different disciplines (natural and social scientists) and roles (science, policy, and management) (Lewison et al. 2016). Participants reported that working together in groups was considered advantageous in building a shared understanding (G3, Table 2) and improving transboundary knowledge about the common issues, drivers and responses across the ASEAN countries represented (G2, 3, 4, Table 2). The contribution of transdisciplinary expertise (G2, 4, Table 2) was reported as helpful in identifying the causal linkages and determining appropriate Responses. Involving stakeholders from different scientific disciplines meant that Responses, data gaps, and indicators to measure/ monitor included SES systems (Table 1). Involving those with different roles, such as those from local NGOs who work in communities, meant that common issues and relevant strategies were able to be discussed. For example, the solution implemented by the local crab fishing community in conjunction with an NGO in response to depletion of crab stocks represented an innovative integration of scientific and lay knowledge and a lesson to all attendees. Responses captured the need for better policy, community capacity-building as well as research, and placed priorities and feasibility of strategies in context (Table 1). G1, for example, indicated their next step was to train more people in DPSIR and use it to support cooperation among researchers, scientists, managers, and other stakeholders (Table 2).

The final two benefits of the DPSIR framework that were identified were its ability to foster communication and transparency among stakeholders (Lewison et al., 2016) through simplification of complex problems, and identify knowledge gaps and needs. G1 and G3 (Table 2) suggested that DPSIR would enable them to communicate a complex problem within their team, and among agency staff and local community. Participants learned how to

use a tool that would enable them to discover solutions for themselves: groups acknowledged the desire to share it with others in their workplace and community.

While many countries aim to monitor the State of the environment, DPSIR is often a starting point for development of appropriate indicators to measure the five components of the framework (Lewison et al., 2016). Workshop groups acknowledged a scoping role by suggesting that applying DPSIR would help identify which factors to measure and prioritise resource needs (G1, 3, Table 2). Detailed research gaps or needs were identified separately as well as in the Responses phase of the DPSIR application (Table 1). It was generally acknowledged that there were less environmental data available in Cambodia. While two of the groups (G2, 3) focussed on environmental data gaps, G1 took greater advantage of the DPSIR analysis. G1 indicated that Thailand has good environmental monitoring data of the State but needed to make better linkages with pressures, drivers and responses. This would include understanding coastal users' behaviour and ability to adapt to climate change, and determining which governance modes would enhance sustainability. An interdisciplinary study of coastal tourism carrying capacity was also suggested. There are many examples of these kinds of initiatives in the literature, including this geographical area (e.g. Roman et al., 2007). Without the prompting of the DPSIR framework it is unlikely that this research need would be identified or the literature explored.

Finally, one of the best indicators of workshop impact is the process of change initiated in the host country of Thailand since the workshop. Even though the Thai Department of Marine and Coastal Resources (DMCR) has been monitoring the State of the coast's biophysical features (coral, mangrove and seagrass health) for more than ten years, there had been little linkage of these States to Drivers, Pressures and Responses. This limited the appropriate targeting of management actions. Applying the DPSIR framework in the workshop highlighted these relationships. After participating in the workshop, DMCR held two DPSIR workshops with all 24 provincial marine and coastal resources committees (MCRC) early in 2016. DMCR aims that MCRCs will apply the DPSIR framework to produce marine and coastal status reports for all 24 coastal provinces in Thailand by end of 2016. Once completed, the Responses will be combined in a strategic plan with priority actions for managing marine and coastal resources at the provincial level.

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404 5.2 Limitations of DPSIR for workshop training

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406 The previously described (Gari et al., 2015) limitations with DPSIR were not as apparent in
407 this application. While DPSIR has been criticised for lack of explicit hierarchy or scales, this
408 flexibility was appreciated as a benefit in this study. Flexibility enabled a plurality of
409 approaches (e.g. scales) to identify actions that might have the most effect across a range of
410 issues. G4 (Table 2) highlighted the tool's flexibility in application: it was applied
411 successfully to four different coastal issues, characterised by both large spatial scale (e.g.
412 mangrove destruction and introduction of shrimp farming) and local scale (crab fishery)
413 issues, as well as highly mobile species (e.g. dolphins, fish) and sessile ones (e.g. corals,
414 mangroves) (Table 1). It resulted in a range of social, environmental and economic
415 Responses. A possible issue with inconsistent use of terminology was minimised through
416 training, by ensuring a common understanding of terms early in the workshop and trainers
417 being part of each case study group. Otherwise the workshop did not reveal instances of
418 some of the other limitations of the framework that have been identified such as
419 unidirectional relationship and an inability to generate neutral knowledge. In hindsight
420 though, more structured time should be allocated to reflection and evaluation at such
421 workshops.

422

423 The facilitators' observation was that the DPSIR framework was suitable for bringing
424 together the range of stakeholders from different disciplines, roles, and countries, to derive
425 sustainable solutions for the coastal zone. Four days was considered the minimum time for
426 such a workshop, given it was the first time most of the participants had met each other and
427 time was spent sharing information about common issues in each country. Furthermore
428 participants conversed in English, the common regional language, but second or third
429 language of most of the SEAsian participants. Feedback from the groups indicated a desire to
430 take the tool back to their own colleagues, where it is expected that building understanding of
431 DPSIR and exploring the causal relationships could be done quickly among those who
432 already work together and/or understand local issues. In Thailand, it is expected that
433 embedding DPSIR within a formal institutional process for coastal reporting and strategic and
434 action planning will enhance its effectiveness. A next step at the multi-country level would be

435 to bring the group together again once more data have been gathered and work through each
436 step in greater detail in relation to specific issues. This need was effectively enunciated by
437 G2 in its identification of existing data and data gaps for each stage of DPSIR (Table 1).
438
439 **6. Conclusion**
440
441 The inherent strengths of the DPSIR framework make it suitable to engage stakeholders from
442 different disciplines and roles to discuss coastal management sustainability. The utility of the
443 DPSIR framework was identified by participants as a tool that supported systematic and
444 critical thinking, recognition of causality, transdisciplinary knowledge exchange, and the
445 identification of data gaps and other needs, such as capacity building. In this context, we
446 show the suitability of DPSIR as a tool for analysis and communication, and to promote
447 discussion. The application of DPSIR to challenges of cross-border, socio-ecological systems
448 in Thailand and Cambodia demonstrated: the strengths and limitations of the framework; the
449 support for multidisciplinary knowledge sharing; the utility of scientific and stakeholder
450 participation; the individuality and flexibility of approaches (e.g. spatial scales); and its
451 potential use to identify both data-gaps and actionable management strategies. Our results
452 suggest a role for applying the DPSIR framework to a problem iteratively as more data
453 become available, to more finely direct decisions at both cross-border and local levels.
454 Further monitoring of institutional processes in Thailand will reveal whether causal linkages
455 and the range of social-ecological data are well identified through embedding DPSIR within
456 the provincial coastal planning processes.
457
458 Our workshop enabled an international team of researchers and local stakeholders to refine a
459 model of the interactions between primary drivers among coupled ecological, biophysical,
460 social, governmental, economic factors that influence resilience in two geographically
461 adjacent study sites, which typify the challenges faced in tropical coastal zones worldwide.
462 As a critical instrument for strategic decision-support, DPSIR provided the foundation for
463 prioritising data needs and investigating feasibility of site specific actions.
464

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Figure 1

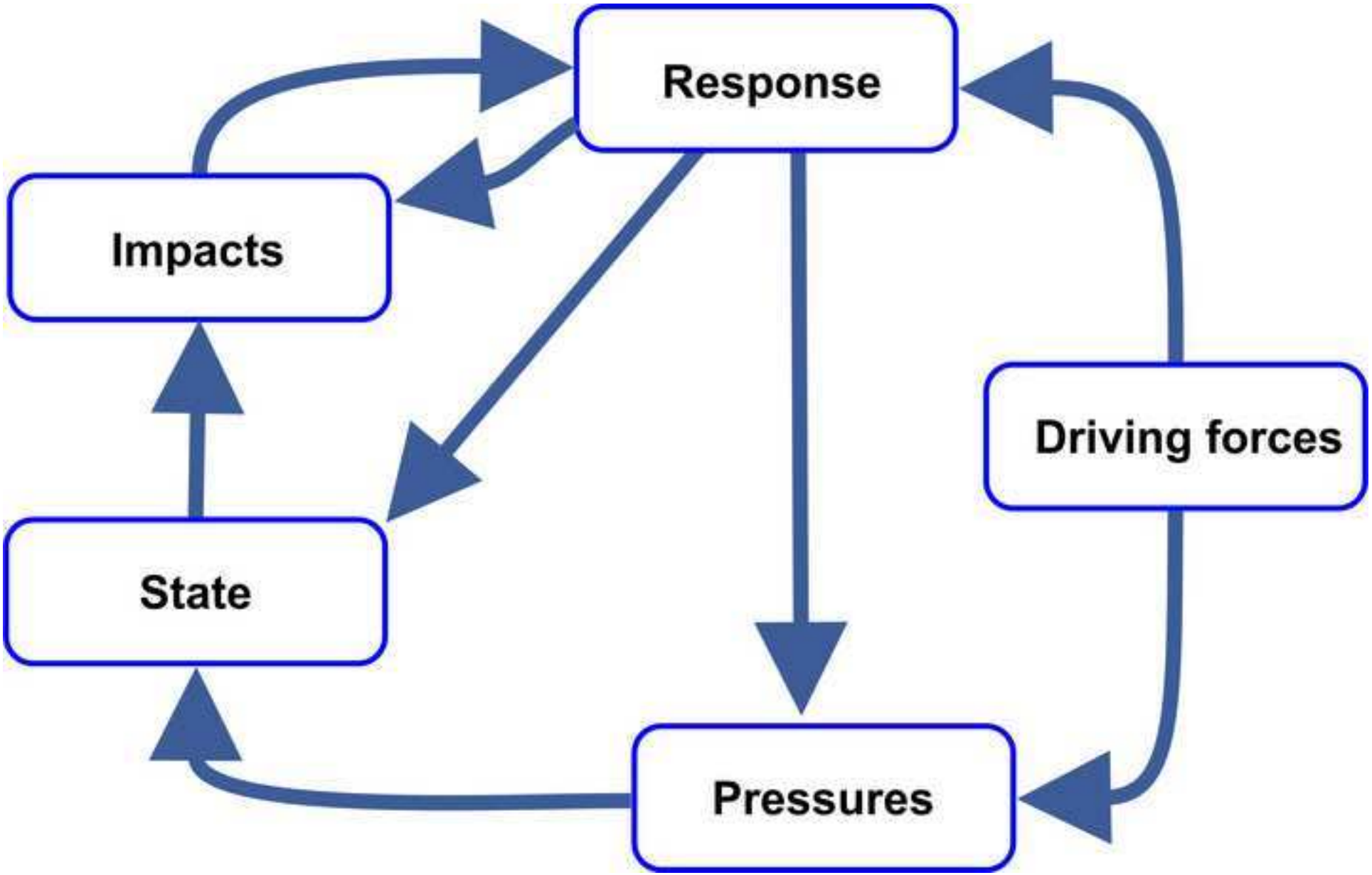
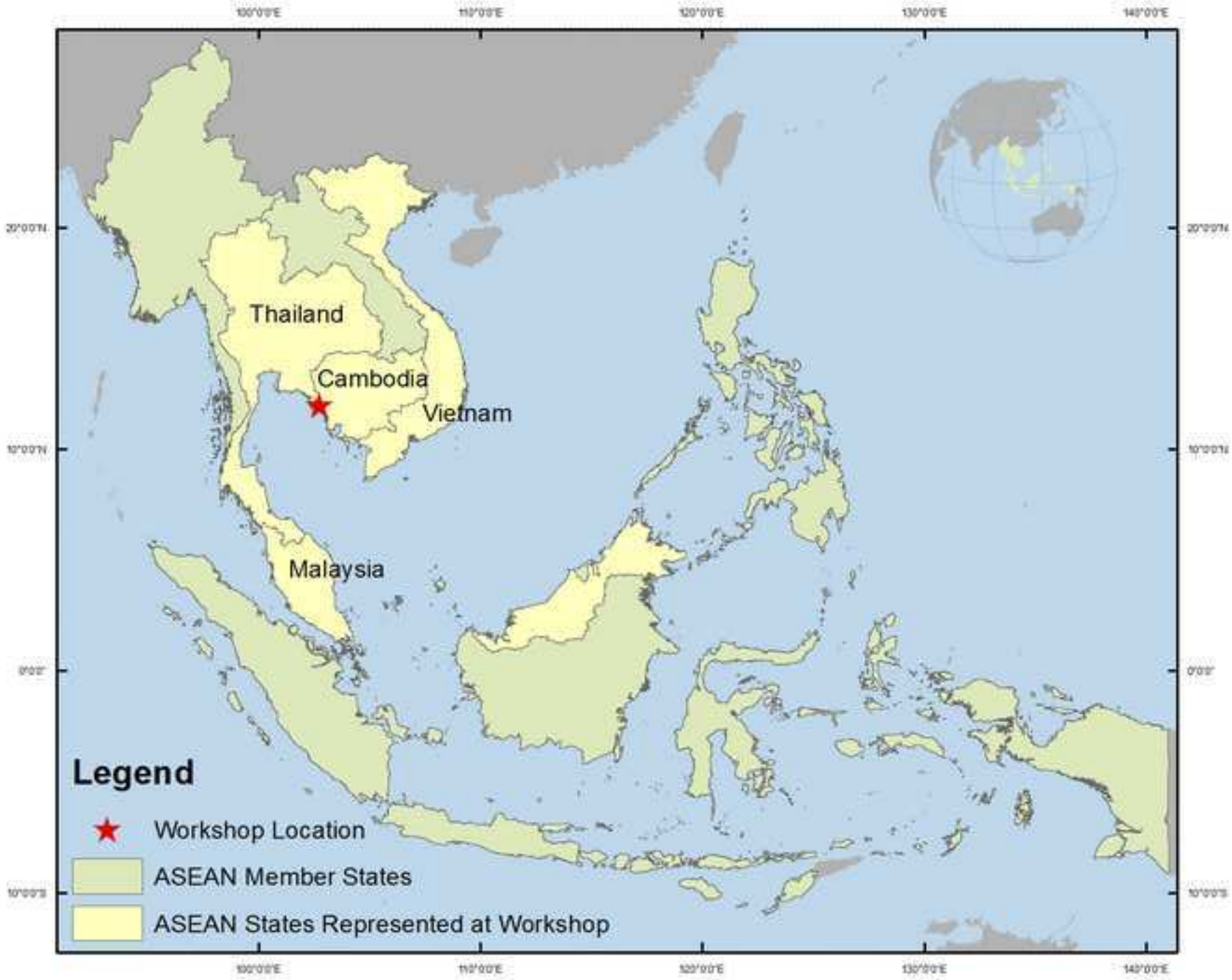


Figure 2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Cambodia
Vietnam
Malaysia
Legend
Workshop Location
ASEAN Member States
ASEAN States Represented at Workshop

Figures 3,4,5,6

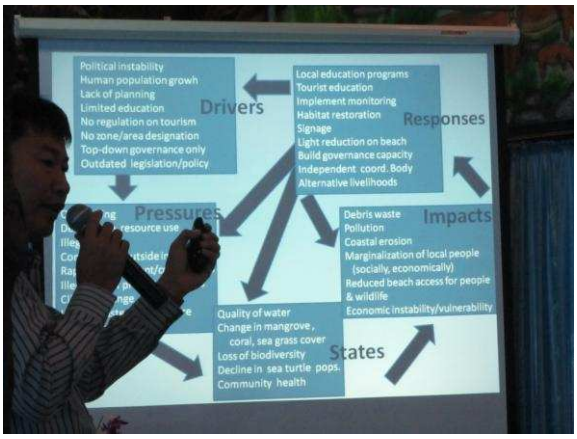

Figure 3 - Group one reporting on application of DPSIR to tourism sustainability

Figure 4 - Group two reporting on 'Response' to coastal vegetation issues

Figure 5 - Group three reporting on application of DPSIR to cetaceans

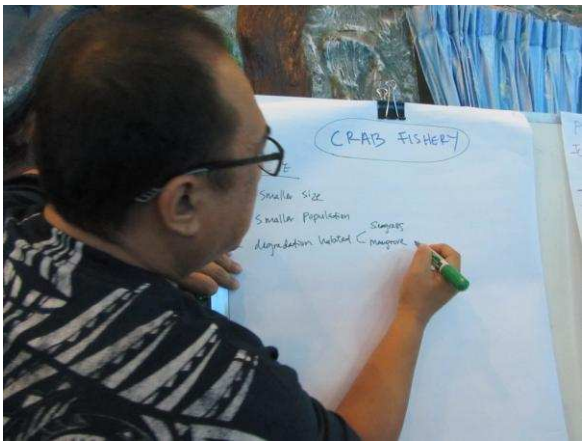

Figure 6 - Group four comments on 'Pressures' on the crab fishery