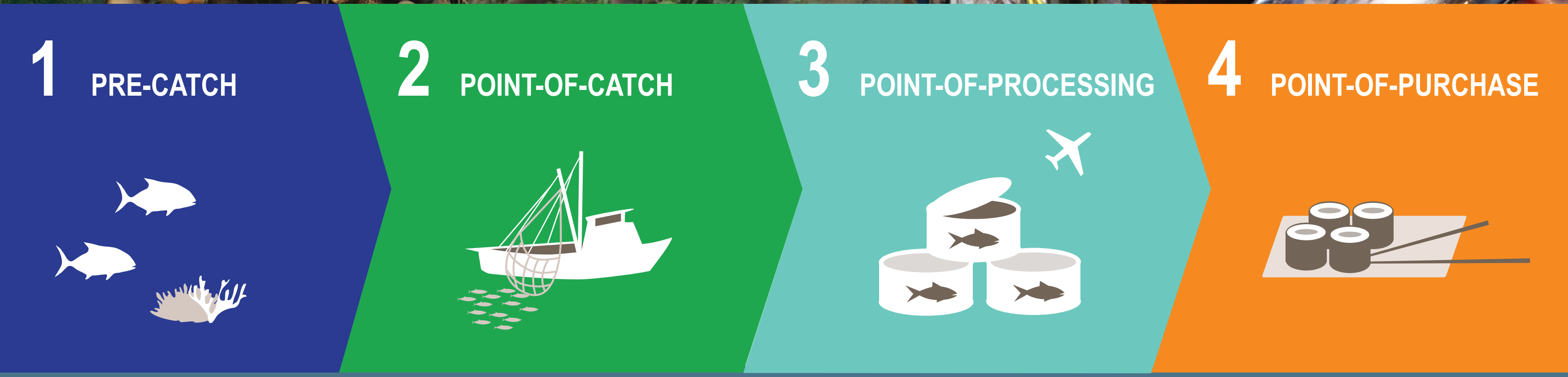
Science and technology to promote sustainable fisheries in Southeast Asia and the Coral Triangle



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Science and technology to promote sustainable fisheries in Southeast Asia and the Coral Triangle

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Acronyms and Abbreviations

AIS	Automated Identification System
ASEAN	Association of Southeast Asian Nations
AUV	Autonomous Underwater Vehicle
DFAD	Drifting Fish Attracting Devices
DNA	Deoxyribonucleic Acid
DOI	Department of Interior (US)
EAFM	Ecosystem Approach to Fisheries Management
EM	Electronic monitoring
ER	Electronic reporting
EU	European Union
HACCP	Hazard Analysis and Critical Control Point
IUU	Illegal, Unreported, and Unregulated (fishing)
NGDC	National Geophysical Data Center
NGS	Next Generation Sequencing
NMFS	National Marine Fisheries Service
NOS	National Ocean Service
NOAA	National Oceanic and Atmospheric Administration (US)
NWFSC	Northwest Fisheries Science Center
OTH	Over-the-Horizon (radar)
PAM	Passive Acoustic Monitoring
PIFSC	Pacific Islands Fisheries Science Center
RDMA	Regional Development Mission for Asia
RFID	Radio Frequency Identification Tags
S-AIS	Satellite-based AIS
S&T	Science and Technology
SOLAS	Safety of Life at Sea (convention)
SWOT	Strengths, Weaknesses, Opportunities, and Threats (analysis)
UAV	Unmanned Aerial Vehicle
USAID	United States Agency for International Development
VMS	Vessel Monitoring System
VTR	Vessel Trip Report

Executive Summary

This report provides recommendations on how science and technology (S&T) innovations can help to promote sustainable trans-boundary fisheries in Southeast Asia and the Coral Triangle. Here, we broadly define S&T as any tool that enhances the ability to efficiently collect scientific data (e.g., vessel monitoring systems, next generation genetic sequencing technologies, etc.) or analyze scientific information (e.g., stock assessment, ecosystem modeling approaches, etc.) that can be used to improve management of the region's fisheries.

Ensuring the sustainability of the region's fisheries is of great interest to the United States if it hopes to remain as both a consumer of those fisheries' products and a partner for sustainability in the region. The region's fisheries, however, continue to be threatened by global climate and ocean change as well as illegal, unreported, and unregulated (IUU) fishing. How to effectively address these threats remains a central question for scientists and policymakers alike, and S&T will prove essential in providing the best scientific information available for effective fisheries management policy decisions.

This study had two main objectives:

1. To develop a summary of the available S&T innovations that have the potential to provide, integrate, or analyze information used for the management of regional fisheries of the Association of Southeast Asian Nations (ASEAN) and Coral Triangle countries.
2. To utilize expert opinion to propose a prioritized list of S&T innovations that have the most potential to create a more sustainable ecosystem approach to fisheries management.

To this end, a core group of NOAA and Department of Interior (DOI) S&T experts were tasked with pre-identifying a list of advanced S&T for fisheries management, as well as developing a survey to collect and aggregate expert opinion on these S&Ts. The survey's framework was based on dividing the seafood supply chain into discreet management information needs (i.e., pre-catch, point-of-catch, point-of-processing/packaging, and point-of-purchase/consumption). Experts then provided their opinions on the S&T innovations that, if implemented in the next 5 years, would have the greatest impact on improving the management of the region's trans-boundary fisheries for each point along the seafood supply chain.

The main findings of the survey are outlined below:

- Pre-catch: Stock assessment analyses, with particular emphasis on data-limited methods, are important in providing the framework for guiding additional data collection needs and requirements. Many of the pre-catch recommendations are relevant to fisheries-independent data collection methods.

- Point-of-catch: Electronic monitoring, electronic reporting, and VMS technologies were highlighted as important technologies for point-of-catch management and have considerable promise for improving fisheries-dependent data collection.
- Point-of-processing: Seafood safety and quality testing, electronic reporting, and forensic labs were given relatively equal support as important technologies for providing information used for point-of-processing management.
- Point-of-purchase: Seafood safety and quality testing, forensic labs, electronic reporting, and smartphone and crowd-sourcing apps were given relatively equal support as important technologies for providing information used for point-of-processing management.

In addition, we asked survey participants to provide their opinions on the most impactful S&Ts for integrating or connecting information across the entire seafood supply chain. For this purpose, survey participants pointed to the following S&Ts: electronic reporting, ecosystem and socio-economic models, and smartphone and crowd-sourcing apps.

It is important to also note that while S&T has the potential to play a game-changing role in the management of the region's fisheries, many survey participants point to several barriers that could potentially hinder the successful implementation of certain S&Ts. These barriers include:

- Insufficient technical expertise
- Data management limitations
- Data deficiencies
- Financial cost
- Weak governance
- Stakeholder resistance
- Difficulty in scaling up to a regional, trans-national level

Overall, S&T innovations have the ability to provide management-relevant information while enhancing transparency and providing credibility to management actions and policies. When considering S&T solutions, however, it is important that the appropriate S&T be matched to a feasible solution that is dependent on the data collection objective and available resources (technical expertise and funding). Furthermore, stakeholder engagement and improved governance are of key importance to successful fisheries management. Thus, the implementation of S&T to improve the quality and credibility of scientific information must be matched with the promotion of good governance as well as an inclusive decision-making process that is based on both socioeconomic and ecological considerations.

Introduction

Fisheries, particularly when unregulated, are vulnerable to the 'tragedy of the commons', a dilemma whereby commonly-held resources become overexploited as a result of -individually-acting entities seeking to maximize their extraction (Hardin 1968). Contemporary fishery management typically attempts to maximize the total removals that can be sustained over the long term, thereby avoiding overexploitation. The numerous challenges facing fishery management, however, become exacerbated when multiple countries, institutions, political actors, and other stakeholders, each with their own objectives and systems of governance, try to manage a shared resource (Fidelman et al. 2012). Additionally, recent evidence has shown that illegal, unreported, and unregulated (IUU) fishing continues to be a major source of unsustainable fisheries consumption, thus making this an issue for both seafood exporting and importing countries (Pramod et al. 2014). When coupled with mounting evidence of the adverse effects that global and ocean climate change could have, particularly on reef fishes, it becomes obvious that more must be done to promote and empower regulatory agencies and conservation organizations to address these concerns collaboratively on regional and global scales.

Recently, officials and organizations at the highest levels have communicated their commitment and determination to addressing this matter (Williams 2013). Several regional organizations within Southeast Asia and the Coral Triangle region (e.g., the ASEAN-SEAFDEC Strategic Partnership (ASSP), the Coral Triangle Initiative for Coral Reefs, Fisheries and Food Security (CTI-CFF), and the Regional Plan of Action for IUU Fishing (RPOA-IUU) have incorporated the need for traceability schemes, catch documentation, and market incentives into their sustainable fisheries action plans, thus attesting to their recognition of fisheries sustainability as a trans-boundary issue that will require alignment and cooperation on an international level. Meanwhile, on June 17, 2014, U.S. President Barack Obama was quoted in saying, "It shall also be the policy of the United States to promote legally and sustainably caught and accurately labeled seafood and to take appropriate actions within existing authorities and budgets to assist foreign nations in building capacity to combat IUU fishing and seafood fraud."

The mobilization of innovative science and technology (S&T) can considerably enhance Asia's capacity to both monitor their own fisheries and respond to threats. Our task, as requested by the USAID-Regional Development Mission for Asia (RDMA) was to create a U.S. National Oceanic and Atmospheric Administration (NOAA) and Department of Interior (DOI) overview and prioritized list of S&T that, if implemented in the next 5 years, could potentially assist the ASEAN (Association of Southeast Asian Nations) and Coral Triangle countries in sustainable management of their trans-boundary (i.e., trans-national) fisheries.

By leveraging the U.S. NOAA and DOI institutional knowledge, we aim to provide our recommendations for the use of S&T tools for sustainable fisheries management. To this end, we established a S&T core group in January 2014. As its first task, they created a U.S.

government (NOAA, DOI)-identified list of 21 S&T for sustainable fisheries management as well as a non-technical description for each S&T (Appendix A). In addition, the core group was tasked with developing a survey to collect and aggregate expert opinion on these S&Ts as well as identifying relevant experts who should participate in the survey. The results of this survey were compiled, analyzed, and summarized here.

Methods

A total of 36 experts from throughout NOAA and DOI formed the S&T core group that would be consulted throughout the initial development of these methods. The selection of these experts was largely through word-of-mouth, but all individuals in the S&T core group are either technical experts or policy-level specialists on the implementation or management of at least one type of S&T for fisheries management. Based on guidance from USAID-Regional Development Mission for Asia, the S&T core group's first task was to create a list of S&T innovations that could: (1) be implemented in the ASEAN and Coral Triangle countries in the next 5 years and (2) address trans-boundary fisheries in the region. Using these criteria, a total of 21 S&T developments were identified as part of our final list.

Here, we broadly define S&T as any analytical or technological tool that can be employed towards monitoring the status of or threats to the region's fisheries. To provide an example of the potential scope and breadth of available S&T for sustainable fisheries management, we proposed the following major S&T categories:

1. field-based or remote data acquisition (e.g., habitat mapping products, nighttime lights satellite data for vessel detection, aerial drones for patrolling fisheries, electronic systems for supplementing fisheries observers, passive/active acoustics, vessel monitoring systems)
2. data analysis (e.g., socioeconomic decision-making tools, computer models for stock assessment, global climate change and ocean predictions, crowd information-sourcing opportunities via social media or cell-phone based technologies)
3. laboratory-based data acquisition (e.g., forensic tools for species identification, fish-processing techniques/technologies, seafood safety testing, genetic sequencing technologies).

The S&T core group was also tasked with writing non-technical briefings for each of these 21 S&T innovations (See Appendix A). These non-technical briefings were then used to develop a S&T website that would serve as an informational resource for survey participants. The purpose of the website was to ensure that all survey participants had at least a basic understanding of each S&T's capabilities before answering the survey questions. Each briefing includes:

1. a non-technical description of the S&T and
2. a strengths, weaknesses, opportunities, and threats (SWOT) analysis.

The S&T core group was also consulted in the development of the S&T survey (For complete survey see Appendix B). The survey's objective was to ask experts to compare and offer their opinions of different S&T innovations in terms of their importance and feasibility for managing regional fisheries in the Coral Triangle and Southeast Asian region. Thus, the survey had to be broad enough to encompass the complexity of the advice being sought yet specific enough to allow for clear recommendations to be summarized for USAID-RDMA. However, since there was no specific fishery that was identified as the focus, the survey's framework was based on the seafood supply chain, which we define here as the entirety of players that are involved in the production of seafood, from harvest to plate. Since management and regulation occur throughout the seafood supply chain, this provided an appropriate structure for categorizing management-information needs. Examples of management information needs at each of these categories are provided in Figure 1 and were also included in the final survey to help orient participants to the overall framework. Thus, the overall survey design was to ask participants to consider the potential of S&T to be applied to each of five management information needs:

1. pre-catch
2. point-of-catch
3. point-of-processing or packaging
4. point-of-purchase or consumption
5. integration of the seafood supply chain

The survey asked participants to select the one S&T innovation (based on the pre-identified list provided by the S&T core group), which, "if implemented in the next 5 years will have the greatest impact on information needs" at each point along the seafood supply chain. In addition to selecting the most effective S&T innovation for improving management at each point along the seafood supply chain, participants were asked to explain the main advantage and the main barrier of each S&T over other available S&T. Finally, biographical information of each survey participant was also collected in order to further characterize survey responses.

A request was sent via NOAA's International Affairs Council (IAC) to all six of NOAA's fisheries science centers. The request was to identify experts that have either: (i) technical or managerial experience on at least a few of the pre-identified S&T innovations or (ii) working experience in international capacity building for fisheries management. Additional survey participants were identified by reaching out to these experts and asking for recommendations of colleagues who would also be appropriate for the survey. In addition, the Department of Interior's International Technical Assistance Program identified individuals within DOI who would be appropriate for the survey. NOAA experts were then given six weeks to submit their responses, while DOI experts were given two weeks.

Figure 1. Seafood supply chain

1 PRE-CATCH

- Is the fishery depleted? And if so, what can be done to mitigate this?
- Do the current catch or size regulations allow for the fishery to maintain long-term high productivity levels (e.g., conducted in a manner that does not alter age, genetic structure, sex composition)?
- Is the biological (i.e., species or genetic) diversity of the fishery threatened?
- Are natural functional relationships among species allowed to continue or does the fishery extraction cause trophic effects?
- How will fishing grounds be impacted in the future by climate change?

2 POINT-OF-CATCH

- Which species is being caught and how much of it?
- Are any NON-target species, sizes, ages, or sexes being caught?
- Where is the vessel obtaining its catch?
- Are any illegal, unreported, or unregulated (IUU) fishing activities occurring?

3 POINT-OF-PROCESSING

- What species and which fishery (or in some case, what mixture of species or fisheries) does the catch come from?
- How long has the fish been kept in storage (i.e., inventory needs)?
- Does the seafood product contain any health hazards or defects?
- Are the methods of accepting, processing, packaging, storing, and exporting sufficient at reducing unnecessary discards/waste?

4 POINT-OF-PURCHASE

- Is the information on the product label accurate?
- Is the product sourced from a sustainable resource?
- Does providing information about a seafood's source and/or a fishery's sustainability, affect the purchasing behavior of consumers

5 INTEGRATION OF THE SEAFOOD SUPPLY CHAIN

Here, we are interested in S&T that:

(i) manages the transfer of information between various points in the supply chain;
(ii) allows a user from one point in the chain to obtain information about where the seafood came from or where it is going; OR
(iii) if integrated throughout the seafood supply chain, would have a major impact in promoting sustainable fisheries.

After reviewing the short answer responses to the survey, we developed two sets of categories to describe participants' responses regarding the main advantages and barriers to implementing their chosen S&T. Broadly categorizing participant responses allowed us to compare expert opinion across the different S&T innovations. In describing the main advantages of their preferred S&T innovation, participants' responses fell into one of four categories:

1. credibility
2. integration
3. relevance
4. feasibility

For the main barriers, responses fell into one of seven categories:

1. data availability/accuracy
2. technical skill
3. data management infrastructure
4. cost
5. institutional inertia
6. stakeholder resistance
7. scalability

If a single response gave multiple advantages/barriers that could not be encompassed by a single category, two or more categories were assigned. Only results for the most popular S&T choices are reported here. Responses that could not be categorized are labeled as "unclear" in the results. See Tables 1 and 2 below for a description of all categories.

Table 1: Advantage categories used in summarizing short answer responses

Category	Description
Credibility	The S&T provides information that is standardized, reliable, scientifically valid, and unbiased. The S&T allows for information provided by one source to be independently verified.
Integration	The S&T covers multiple data collection needs, or, in the case of data analyses, unifies multiple objectives or data sources.
Management relevance	The S&T is directly tied to a management need, allowing for more efficient or timelier (e.g., real-time) action to be taken. The S&T could also be important to providing baseline or pre-requisite information that will lead to management decisions or prioritization of actions down the road.
Feasibility	The S&T can be easily implemented. It is amenable to the region and can be scaled up to a trans-national level.

Table 2: Barrier categories used in summarizing short answer responses

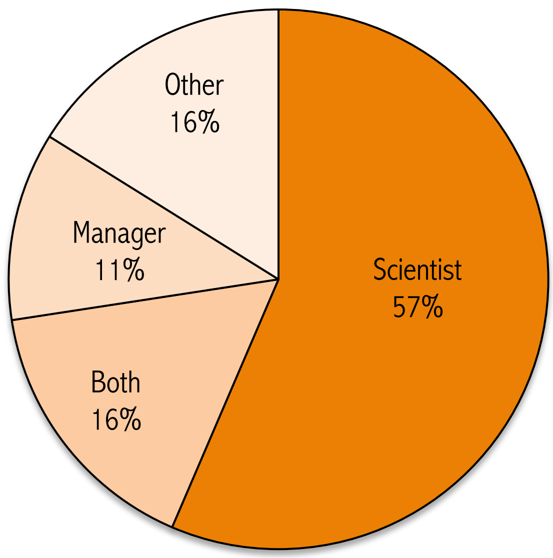
Category	Description
Data deficiencies or inaccuracies	There may not be sufficient data sources to fully realize the S&T's potential.
Technical constraints	There may not be sufficiently trained or skilled people to implement the S&T, either currently or in the long-term.
Data management limitations	There may not be sufficient means (e.g., infrastructure or facilities) or standards for archiving or disseminating the information produced by the S&T.
Financial cost	The cost of the S&T is expensive.
Weak governance	There may not be an appropriate or effective enough legal, management, or institutional framework to drive policy or action despite having the information provided by the S&T.
Stakeholder resistance	The S&T may face significant resistance, skepticism, apathy, and/or an overall lack of support from the public or industry.
Scalability challenges	Implementing the S&T is limited by scale. For example, implementing over a large geographic area or coordinating the S&T across multiple countries could pose a significant challenge to its success. In addition, the S&T may also face challenges being implemented on smaller scales (e.g., artisanal fisheries).

Survey results

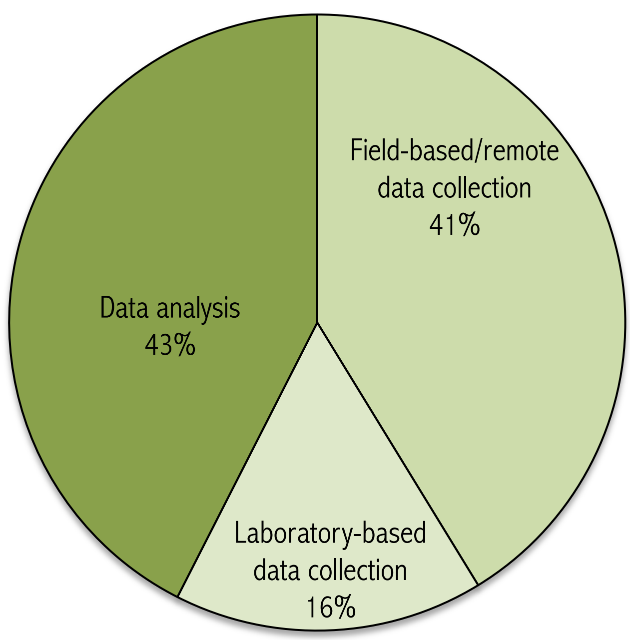
The survey collected input from a total of 62 participants (53 from NOAA and 9 from DOI). DOI survey participants came from DOI's International Technical Assistance Program, U.S. Fish and Wildlife Service, U.S. Geological Survey, and Bureau of Ocean Energy Management. Within NOAA, survey participants came from all six fisheries science centers as well as the National Marine Fisheries Service's (NMFS) Office of Science and Technology, NMFS Office of Law Enforcement, NMFS Office of International Affairs, and the National Environmental Satellite, Data, and Information Service's (NESDIS) National Geophysical Data Center. The majority of survey participants (57%) were scientists. The remaining participants identified themselves as either: (i) a fisheries manager (11%); (ii) both a fisheries manager and scientist (16%); or (iii) other (16%; mostly consisting of fisheries law enforcement officials or lawyers). In terms of the survey participants' familiarity with different categories of S&T, data analysis and field-based or remote data collection were fairly evenly represented (43% and 41%, respectively), with laboratory-based data collection being underrepresented (16%). One potential limitation to these results is that only about half (47%) of respondents were extremely or moderately knowledgeable with fisheries issues in the Southeast Asia and Coral Triangle region. Pie charts of this self-reported biographical information can be found in Figure 2 below.

Figure 2. Pie charts of survey participants' self-reported biographical information, depicting their (A) overall fisheries or conservation expertise, (B) S&T expertise, and (C) experience with fisheries issues in Southeast Asia and the Coral Triangle.

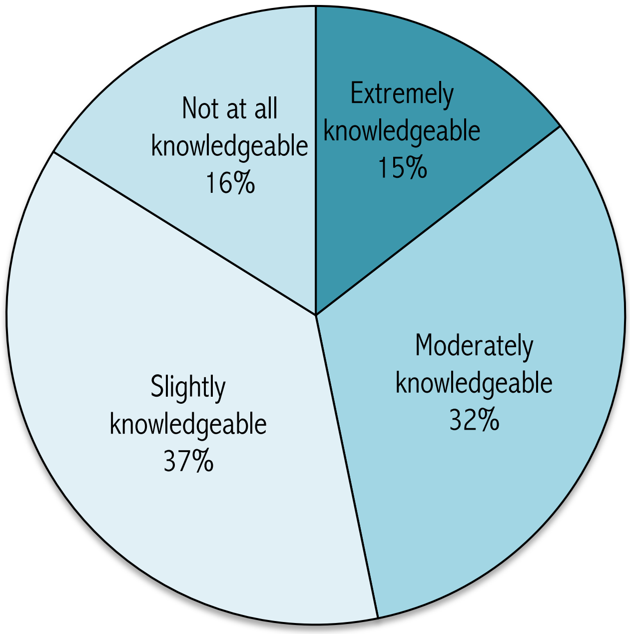
(A) In terms of my fisheries or conservation expertise, how would you describe yourself?



(B) Which S&T category best describes your area of expertise?



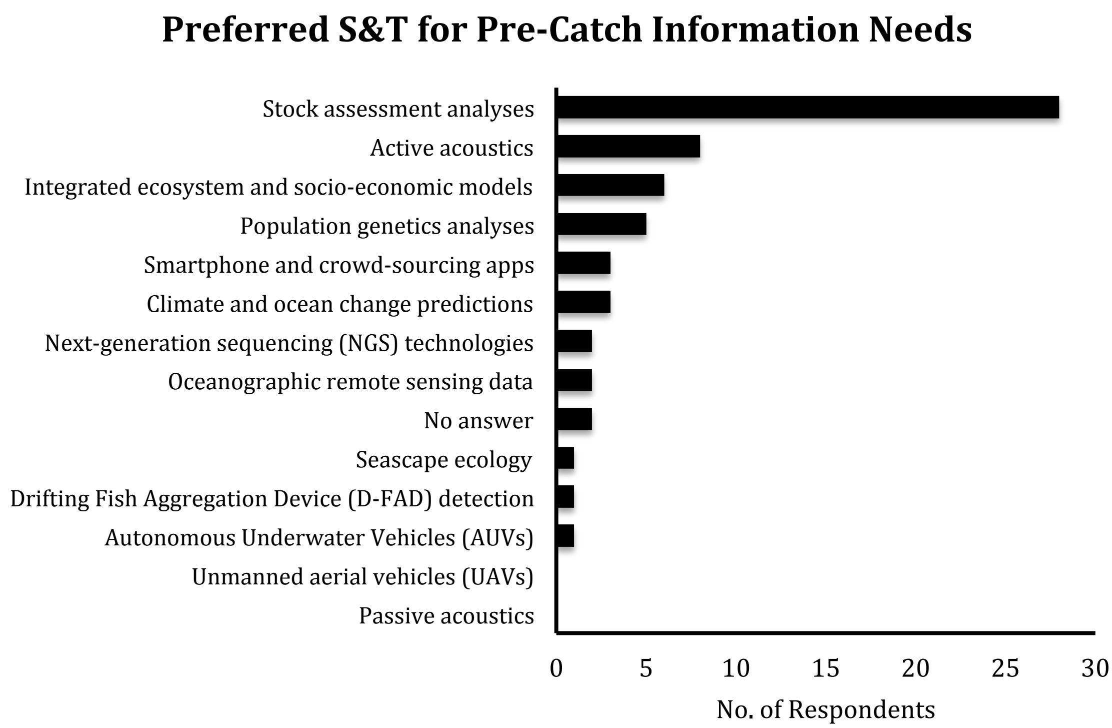
(C) How would you describe your overall experience with fisheries issues in Southeast Asia and the Coral Triangle?



Pre-catch Results

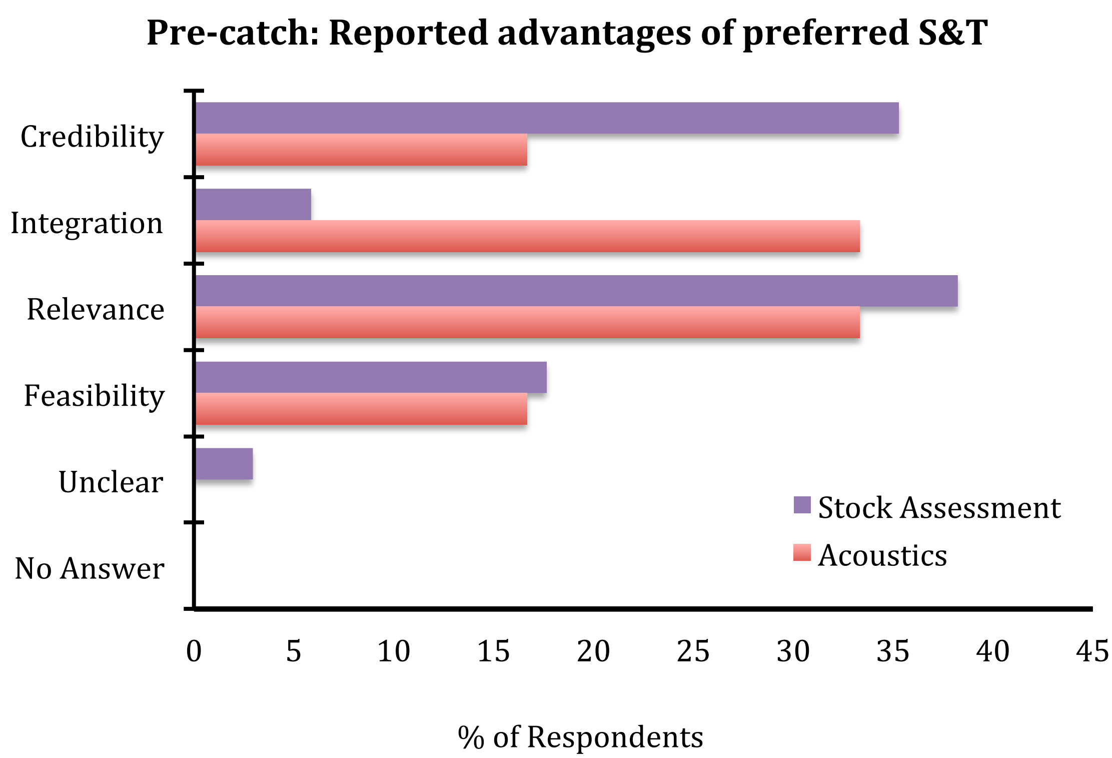
Overall, for pre-catch information needs, the most popular S&T innovation was stock assessment analysis (Figure 3; n=28; 45.2% of survey participants). Below, however, we divide pre-catch S&T results into two categories: S&T assessments and S&T fishery-independent data collections. S&T that were primarily relevant to the collection and analysis of fishery-dependent (i.e., catch and catch-per-effort) information are explained in the next section as part of the point-of-catch results.

Figure 3. Bar graph depicting the number of survey participants who selected each S&T as their preferred tool for pre-catch management.



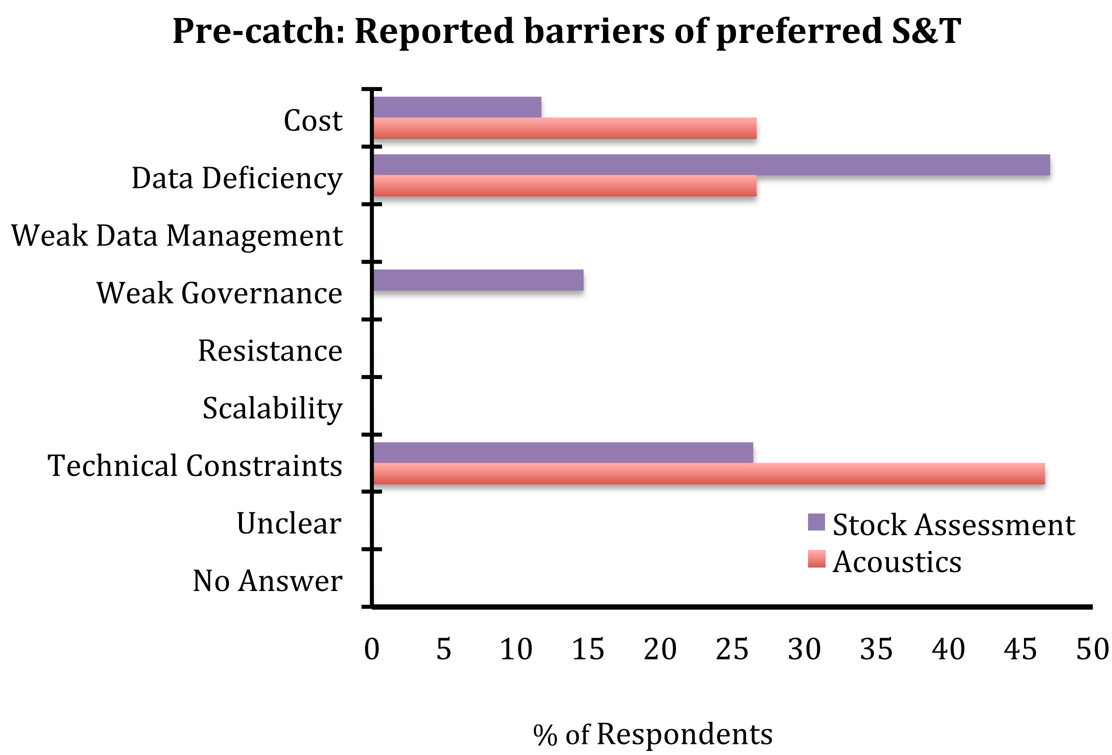
S&T as an Analytical Tool: For pre-catch information needs, the most popular S&T innovation was stock assessment analysis (n=28; 45.2% of survey participants), and one of its most reported advantages over other S&Ts was its credibility (Figure 4). Many respondents pointed to stock assessment's authority as a "well-established process" and a "tried and true method" that is "proven to be an essential component of effective fisheries management." There were many comments that pointed to the importance of stock assessments in guiding data collection requirements and survey design. For example, catch and abundance data are important for these analyses, and thus, stock assessment programs can help to highlight data gaps and guide future data collection and technology investments.

Figure 4. Bar graph depicting the main advantages as reported by survey participants for each of the most preferred pre-catch S&Ts.



The main barrier to implementing stock assessments, as reported by the survey participants, was data deficiency and technical constraints (Figure 5). The optimization of data-limited assessment methods is one way forward. As one participant pointed out: “Innovative approaches are being developed for the data-poor fisheries typical of the region.” Another concern was that there may not be sufficient, in-country technical knowledge. For example, one participant wrote, “It may prove challenging to maintain a trained cadre of technical experts to conduct on-going assessments.” Overall, however, technical skill was a secondary concern to data availability.

Figure 5. Bar graph depicting the main implementation barriers as reported by survey participants for each of the most preferred pre-catch S&Ts.



S&T for Fishery-Independent Data Collection: The pre-catch survey results also pointed to fishery-independent survey technologies such as active acoustics that have the potential to cost-effectively survey fish aggregations (Figure 3). The main advantages for active acoustics (Figure 4), as identified by survey participants was in its integrative capabilities, meaning that participants highlighted this technology's ability to be used in the collection of multiple data types. While there are some limitations (e.g., complex benthic environments can complicate the interpretation of acoustic data), survey participants pointed to the ability of active acoustics to conduct quantitative surveys of fish biomass in both pelagic and benthic habitats, locate foraging areas, and in some cases provide species-specific abundance estimates. In addition to the need to estimate fish abundance from fishery-independent surveys, length frequency and other life history population demographics parameters provide the means to utilize data-limited assessment methods. Thus, an active acoustics program would nicely complement the implementation of a stock assessment program, particularly one that is focused on data-limited situations.

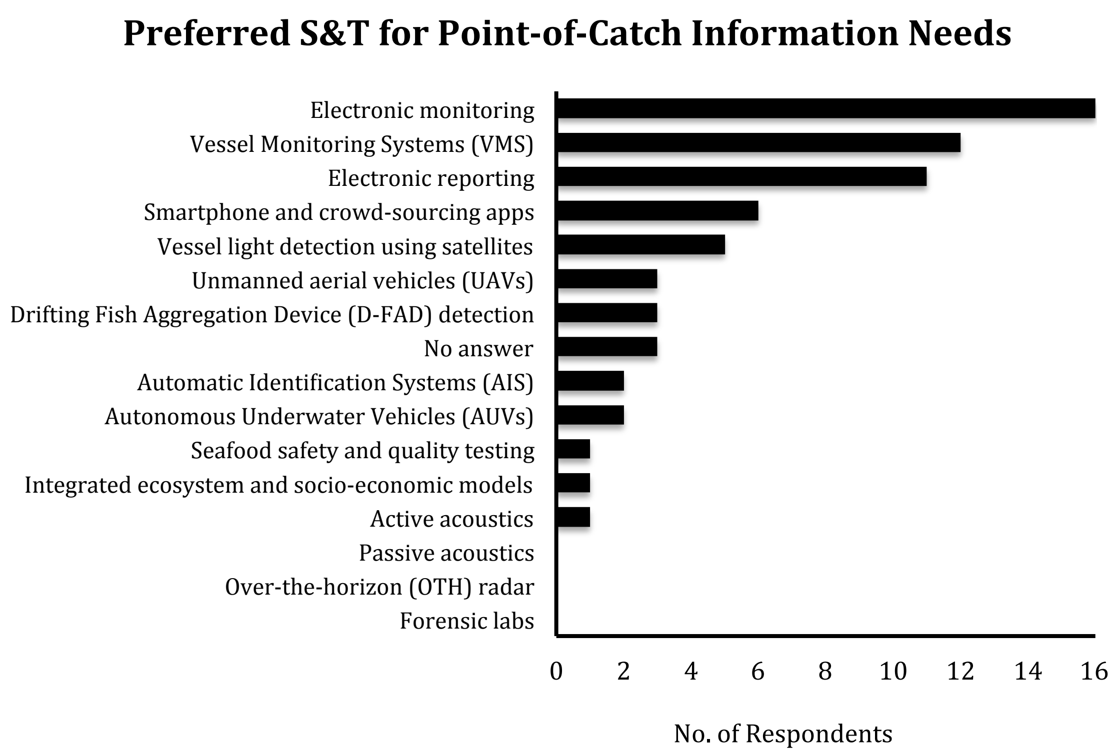
On the other hand, the main barrier (Figure 5) identified for the implementation of active acoustics is the need for skilled people to implement the S&T and to analyze and interpret the data that is collected. For example, "the conversion from acoustic quantities to biological quantities", particularly when the interest is in quantifying species-level abundance was seen as a major challenge. Indeed, the tremendous diversity in fish species found in the Coral Triangle is a major hurdle to obtaining species-specific abundance estimates from wide-scale acoustic surveys in the region. However, specific objectives, such as providing relative biomass estimates for specific complexes, like grouper-snapper spawning aggregations, could potentially be addressed by fisheries acoustics surveys. Thus, the specific survey objectives and available expertise must be given consideration for S&Ts such as active acoustics, whose potential application is highly dependent upon these factors.

S&T for fishery-dependent data collection, such as electronic reporting for catch landings and fishing effort data, were also selected by some participants for pre-catch management, but these were more strongly identified for point-of-catch management as discussed below.

Point-of-catch Results

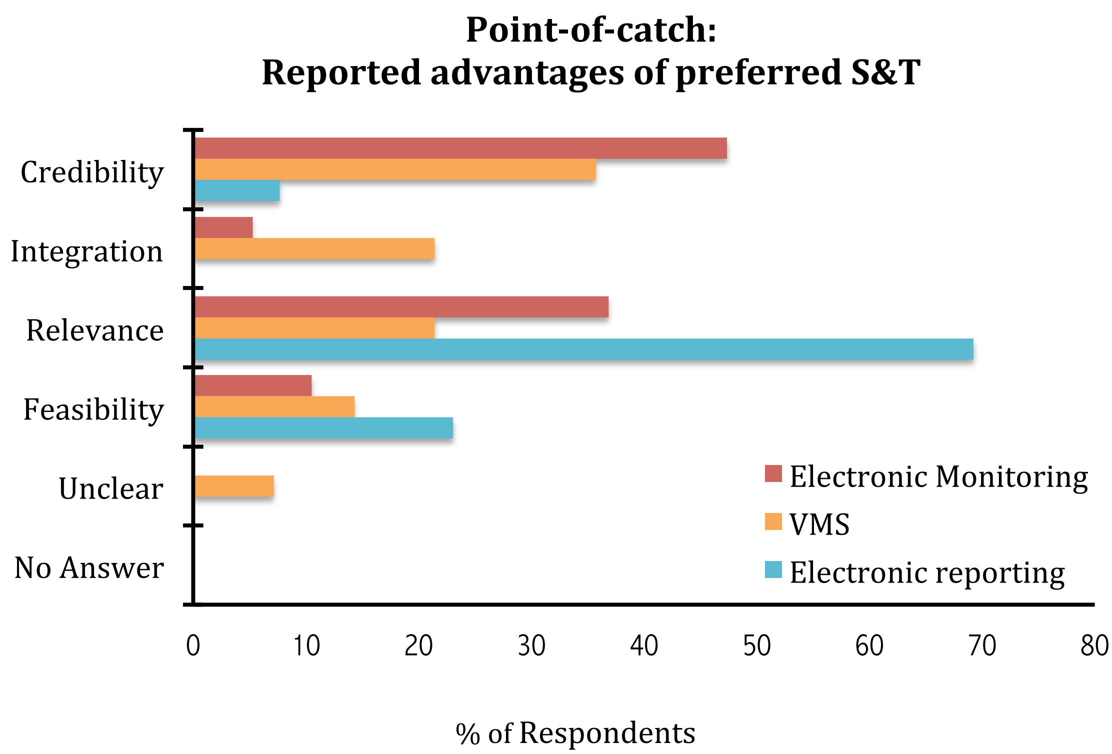
S&T for Fishery-Dependent Data Collection: Point-of-catch information needs were aligned primarily with fishery-dependent data collections such as catch landings and catch per unit effort information. As such, survey participants identified electronic monitoring (EM; n=16; 25.8%), vessel monitoring systems (VMS; n=12; 19.4%), and electronic reporting (ER; n=11; 17.7%) as S&T priorities for this point of the seafood supply chain (Figure 6). Comments provided recognition that fishery-dependent data collections were commonly used for stock assessments for fishery management in regions with data-limited situations and trans-jurisdictional sampling programs. EM and ER were identified as important technologies for addressing misreporting and improving the quality of catch data. The collection of biological data, such as random sampling of length frequency data, from fishery catch landings also provided useful information that can be applied to data-limited assessment methods.

Figure 6. Bar graph depicting the number of survey participants who selected each S&T as their preferred tool for point-of-catch management.



Out of those who favored electronic monitoring (EM), almost half of the responses pointed to its credibility as a major advantage over other S&Ts (Figure 7). For example, EM technologies can resolve misreporting and improve fishery-dependent catch data. In addition, “data-limited regions require stakeholder participation in sampling, and electronic monitoring can help with the need for verification of reporting". Many participants noted that human observer programs should be included as an important component to point-of-catch monitoring, and point out that EM, if implemented, would only be useful in limited situations. For example, one advocate of EM pointed specifically to the appeal of electronic monitoring in transnational fisheries, where using human observers could sometimes be costly or impractical. Another participant clarified that they would like to see human observers equipped with better technology: "Humans are still the best visual inspectors and if equipped with the proper technology will provide the best data". Thus, funding human observers programs and creating career paths for observers was seen as an important complement to this S&T.

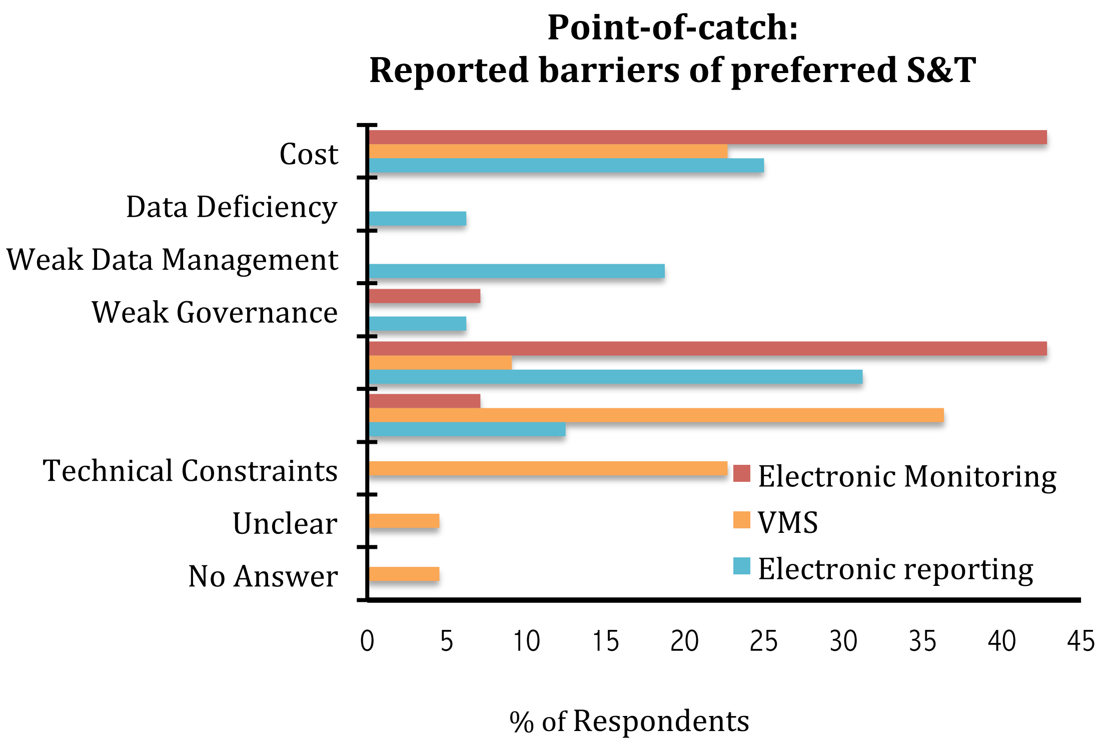
Figure 7. Bar graph depicting the main advantages as reported by survey participants for each of the most preferred point-of-catch S&Ts.



In contrast to EM, credibility was not seen as an important advantage for electronic reporting (ER). Indeed, for those who selected ER as their preferred S&T, a common thread in their comments was the need to encourage fishers to comply with reporting. Instead, nearly all responses regarding ER advantages fell into the relevance category. Most comments centered on ER's ability to increase the efficiency of information delivery. For example, one participant reported that while "VMS does its job well… it provides only "inferred" activity. [On the other hand] ER provides near real-time activity data to scientists, management, and enforcement".

Regarding point-of-catch barriers (Figure 8), cost was seen as a common barrier for both EM and ER. With respect to ER, however, one participant optimistically noted that "if governments or non-governmental organizations could fund initial implementation costs (probably less than $3K/boat), [ER] could be up and running tomorrow." In addition to cost, both EM and ER were largely reported as potentially being hindered by stakeholder resistance. In terms of stakeholder resistance, for both EM and ER, survey participants cautioned that there could be fishermen concerns regarding data confidentiality as well as an overall lack of trust and willingness to adopt these technologies. And specifically, with ER there is the potential for intentionally inaccurate reporting by fishermen.

Figure 8. Bar graph depicting the main implementation barriers as reported by survey participants for each of the most preferred point-of-catch S&Ts.



Another S&T identified was VMS technology that provided advantages for obtaining fishing effort and compliance information, and this was reported by the survey participants to be equally spread among credibility, integration, feasibility, and relevance. VMS has diverse strengths in supplying point-of-catch information needs. Some VMS applications reported by survey participants include the geographic scope of fisheries, effort distribution, marine boundary compliance, as well as biological (e.g., fishing pressure) and sociological inference (e.g., fishing behavior). Many participants also pointed to the importance of VMS for enforcement purposes and as a deterrent to IUU-fishing.

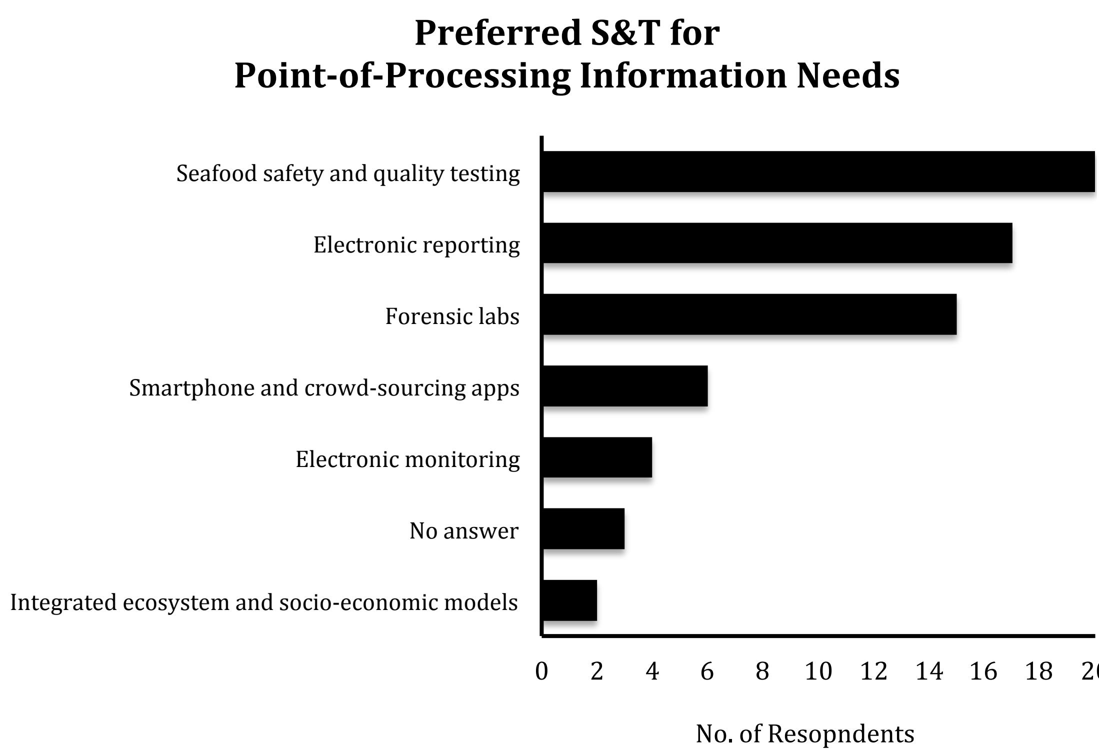
For VMS, two other concerns besides cost were technical constraints and scalability. In terms of technical constraints, some participants pointed to the need for personnel who are not only trained in the analysis and synthesis of VMS data but who also have an understanding of fishing operations and regulations. This is necessary in order for the VMS data to be interpreted correctly. As one participant noted: "The higher technological burden falls on the managers of the VMS system, who will observe the activity of the vessels, and make decisions as to whether or not to deploy enforcement assets."

Finally, for VMS, another concern besides cost was scalability. Interestingly, the scalability issue for VMS was a two-fold concern. On one hand, some participants' concerns were focused on how VMS would be scalable for smaller vessels. For example, one participant noted the "cost and difficulty of disseminating or mandating [VMS] to the largely artisanal fleet of [the region]". On the other hand, some participants were more concerned on how VMS could be scaled up to a regional level. The need for a centralized VMS-data collection system as well as the need for trained personnel that are evenly geographically distributed throughout the region all point to the need for international coordination for this S&T. It is unclear why most advocates of ER and EM did not voice similar concerns of scalability for their technologies. One possibility is that their concerns of stakeholder resistance may override their concerns of scalability.

Point-of-processing/packaging Results

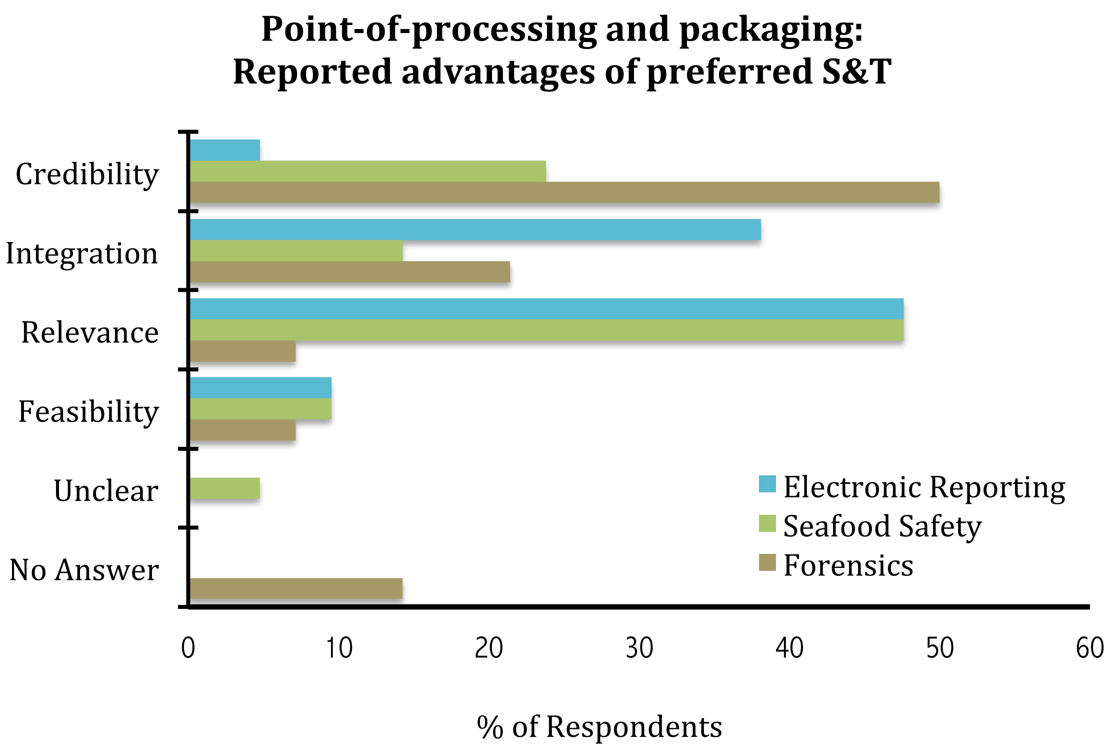
For point-of-processing/packaging (Figure 9), relatively equal support was given to seafood safety and quality testing (n=20; 32.2 %), electronic reporting (n=17; 27.4%), and forensic labs (n=15; 24.2%).

Figure 9. Bar graph depicting the number of survey participants who selected each S&T as their preferred tool for point-of-catch management.



The main advantage for both seafood safety and quality testing and electronic reporting (ER) was management-relevance (Figure 10). The difference between advocates of seafood safety and quality testing and advocates of ER, however, was in what they considered to be a management priority at this point in the supply chain. For supporters of seafood safety and quality testing, their priority was to reduce wasted seafood and increase seafood quality and value. On the other hand, supporters of ER noted its importance for enforcement purposes, regional fisheries management organization (RFMO) agreements, and the prevention of IUU-fishing products from entering the markets. Furthermore, ER supporters stressed the importance of this S&T in providing near real-time information for adaptive management purposes.

Figure 10. Bar graph depicting the main advantages as reported by survey participants for each of the most preferred point-of-processing S&Ts.

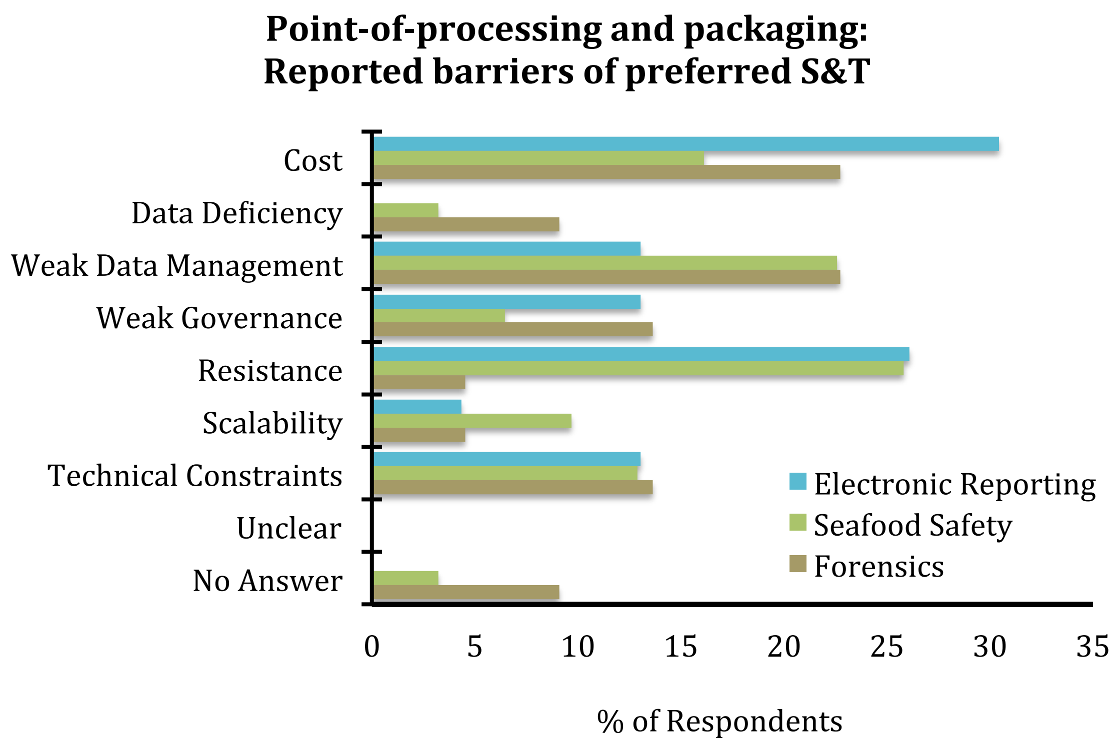


Another difference between the reported advantages for seafood safety and quality testing versus ER was that only ER was reported to have data integration capabilities, or in other words, the ability to collect information for multiple purposes. For example, in addition to its utility for enforcement, ER would also help to improve the overall quality and quantity of catch data, thus making this S&T important for stock assessment analyses and pre-catch information needs. Thus, if standardized correctly, ER could fulfill a diverse set of management needs, providing information to scientists, management, and enforcement.

In contrast, for supporters of forensics, the main advantage cited by them was the credibility forensics over other S&T. For example, one participant reported that “with many paper or electronic tracking systems, there is the potential for [seafood identification] fraud, which can sometimes be detected by forensic analysis”. Another reported that “forensic data is essentially irrefutable and therefore provides a high level of confidence in identifying species of fish”.

In terms of implementation barriers (Figure 11), the main barriers reported by supporters of ER was stakeholder resistance. Responses noted a variety of potential issues including overly complicated reporting systems, lack of a standardized system, and/or unfamiliarity with electronic devices, all of which could lead to an overall lack of industry support that is already resistant to regulation. Furthermore, seafood processors may simply be unwilling to report accurate information.

Figure 11. Bar graph depicting the main implementation barriers as reported by survey participants for each of the most preferred point-of-processing S&Ts.



For seafood safety and quality testing, survey participants also indicated that stakeholder resistance could similarly pose a significant barrier to implementation. In this case, most responses related to stakeholder resistance indicated a potential lack of cooperation from seafood processors, manufacturers, and distributors. Indeed, one characteristic of seafood safety and quality testing is that implementation would follow a HACCP (hazard analysis and critical control point) format – a gold-standard endorsed by the United Nations Food and Agriculture Organization, but which also places more responsibility on industry to ensure compliance. Interestingly, one respondent also noted consumers as a potentially "resistant" group to seafood safety and quality testing. Here, "resistance" comes in the form of potentially conflicting priorities between consumers and the fishing industry. Ultimately, consumer will have influence on the point-of-processing stage as "consumers with variable standards will drive disparate standards [in seafood safety and quality]". This type of sentiment resurfaced throughout the survey, and highlights the interconnectedness of the seafood supply chain.

A common barrier between seafood safety and quality testing as well as forensic labs is the critical need of a data management infrastructure. For example, one participant noted that “documentation [of product and its origin] will be critical” for forensic labs to be effective. “Somehow each batch of fish would also need to be associated with its lab results”. In other words, in order for forensic lab and/or seafood safety and quality testing to be effective, data management infrastructure must first be established. Thus, while ER may be hindered by cost and stakeholder resistance, its ability to collect multiple types of data as well as its ability to provide real-time information directly address one of the main barriers identified for other S&Ts. Indeed, throughout the survey, several participants advocate for the coordination of several S&Ts as the ideal choice.

Finally, cost was seen as a major implementation barrier for all three S&Ts (ER, seafood safety and quality testing, and forensic labs). The financial burden of each of these technologies is obvious once one considers their implementation and coordination on a regional level. For forensics labs, in particular, there is the added cost of having to establish adequate genetic baselines for identifying taxa, species, or populations. At some point, however, a cost-benefit analysis must be taken into consideration. As one survey participant put it, the “long-term benefit is unarguable”.

Point-of-purchase/consumption Results

Among the different points along the seafood supply chain, there was the least consensus among survey participants for point-of-purchase/consumption information needs. Four S&T innovations were frequently chosen by survey participants (Figure 12): seafood safety and quality testing (n=17; 27.4%), forensic labs (n=15; 24.2%), electronic reporting (n=11; 17.7%), and smartphone and crowd-sourcing apps (n=10; 16%). The main advantages (Figure 13) for seafood safety and quality testing, forensic labs, and electronic reporting (ER) were broadly similar to the advantages previously pointed out for those S&Ts for point-of-processing/packaging information needs.

Figure 12**.** Bar graph depicting the number of survey participants who selected each S&T as their preferred tool for point-of-purchase management.

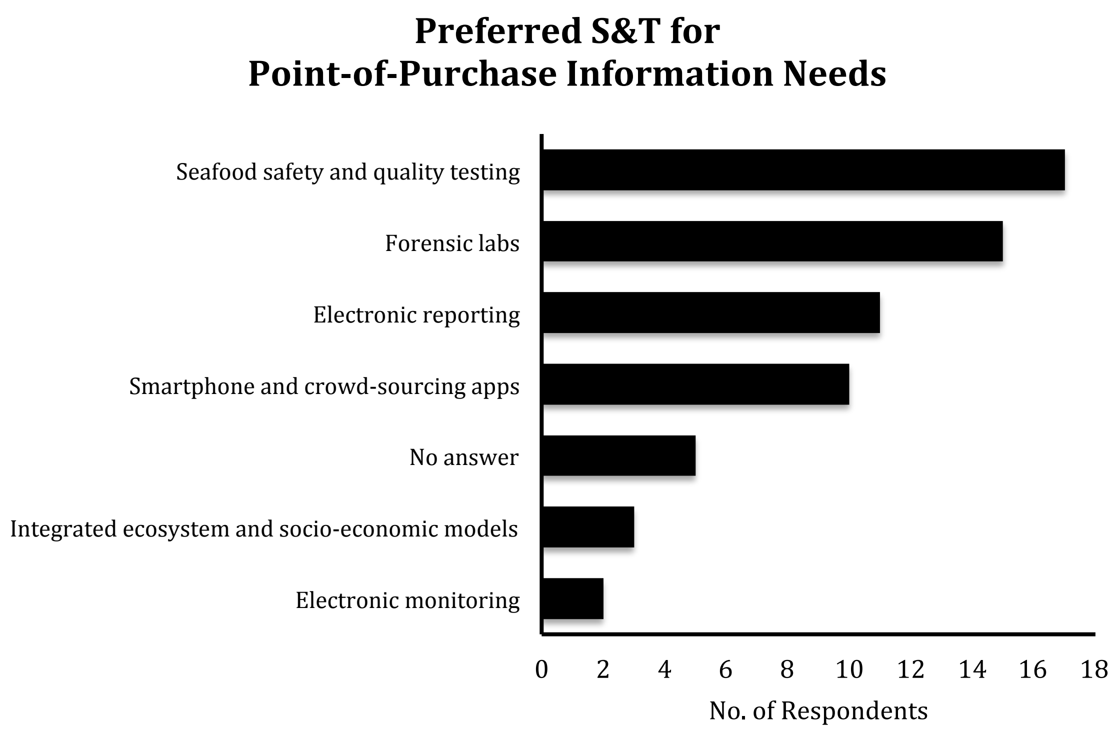
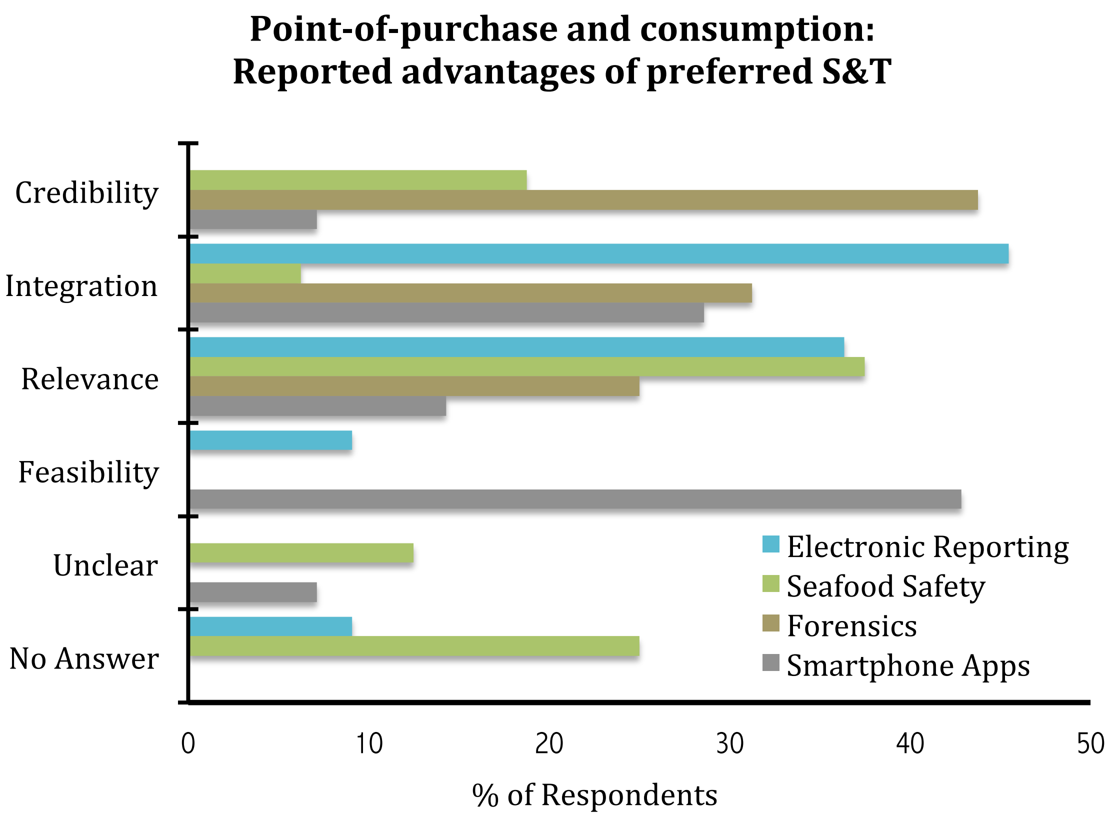
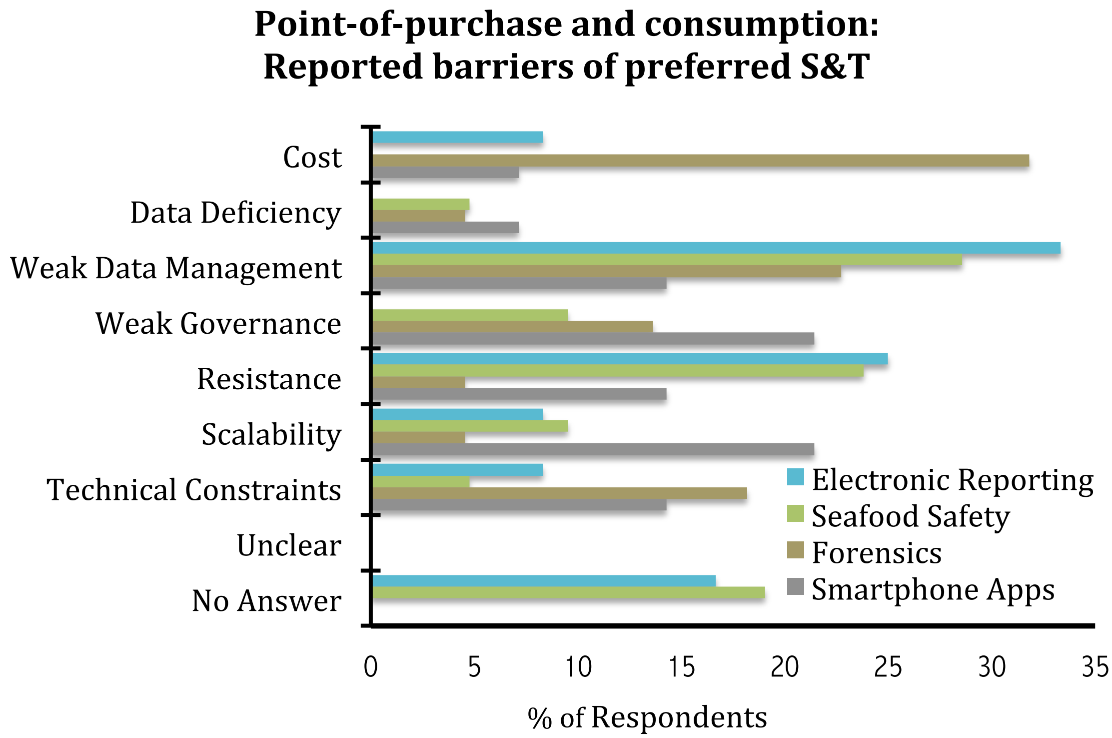


Figure 13. Bar graph depicting the main advantages as reported by survey participants for each of the most preferred point-of-purchase S&Ts.



Similarly, the main barriers (Figure 14) identified here for seafood safety and quality testing and forensics were discussed previously. The only exception to this was for ER. Here, at the point-of-purchase/consumption stage, data infrastructure arose as a new barrier not previously emphasized for that S&T. The reason for this concern is likely due to the fact that at the point-of-purchase stage, the information provided by ER would only be useful to consumers if electronic monitoring was in fact carried out and integrated throughout the chain. Thus it appears that the role of S&T for point-of-purchase are closely tied to the role of S&T for overall integration of the seafood supply chain (next section). As one participant noted: "The main barrier is a documented and verifiable electronic file that includes the relevant information on the species, location, method and date of catch and processing as well as test results." In other words, full chain of custody is crucial for electronic monitoring to be meaningful at the point-of-purchase.

Figure 14. Bar graph depicting the main implementation barriers as reported by survey participants for each of the most preferred point-of-purchase S&Ts.



For smartphone and crowd-sourcing apps, the main advantage was feasibility. Many comments about smartphone and crowd-sourcing apps highlighted their popularity and familiarity amongst the public as well as their ability to deliver a "sea of information" in an accessible manner. As one participant noted, the main advantage of smartphone and crowd-sourcing apps over other S&T technologies for point-of-purchase/consumption needs is that it has the ability to deliver "user-friendly information on sustainable fisheries and profoundly affect consumer choices by integrating the data from other S&T methods into a single, understandable action." It was less clear what the main barrier would be for smartphone and crowd-sourcing apps (all barrier categories were cited by participants), likely because there are multiple applications for this S&T. Survey participants envisioned this S&T being used by many different stakeholders including: observers/crowd-sourcing public (e.g., recording species and size of imported fish entering the market), buyers/sellers (e.g., documenting the seafood's chain of custody for the purpose of product evaluation), as well as consumers (e.g., supplying background information for making well-informed consumer purchase decisions).

Integration of the Seafood Supply Chain Results

Electronic reporting (ER) was the most popular choice among survey participants for integrating information needs across the seafood supply chain (Figure 15; n=20; 32.2%). The main advantages (Figure 16) to implementing electronic reporting across the seafood supply chain are similar to those already discussed previously for ER. Based on their comments, survey participants envisioned ER not just as a data collection tool but also as an enabling technology that would allow for the "ease of storage and transfer of information". Seafood supply chains are long and complicated, and the many steps from catch to dinner plate provide opportunities for fraud and misreporting. Each time seafood is imported, exported, or otherwise changes hands, there is an opportunity for illegal catch to be mixed in with legal catch, and for other information to be misreported. With traditional paper records, delays in data reporting and validation as well as the lack of real-time, centralized information means that vessels that exceed their annual quotas can more easily sell their fish to other boats, thus hiding the illegal origin of the catch. Furthermore, printed documents can easily be altered. All of these shortcomings of paper documentation systems provide opportunities for illegally caught fish to enter the market.

Thus, as several comments indicated, ER would be extremely relevant to integrating the entirety of the seafood supply chain. ER "could be used to store and access information across the entire supply chain" and enhance "accountability and traceability at the greatest efficiency". Furthermore, ER "provides a record of the movement of the product so its source and destination can be determined", thus helping "to ensure that illegally harvested fish does not make it to the retail level".

Figure 15. Bar graph depicting the number of survey participants who selected each S&T as their preferred tool for integrating the entire seafood supply chain.

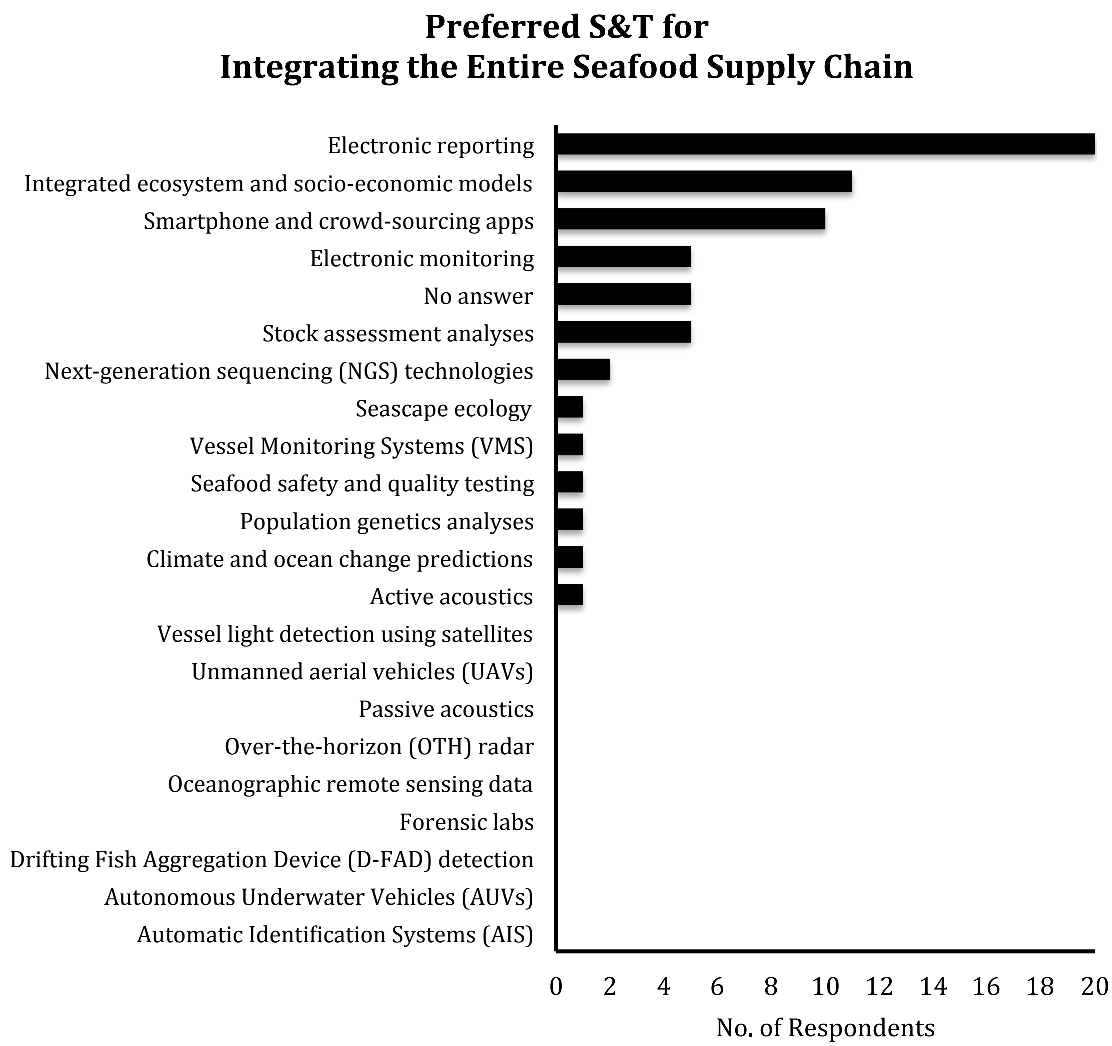
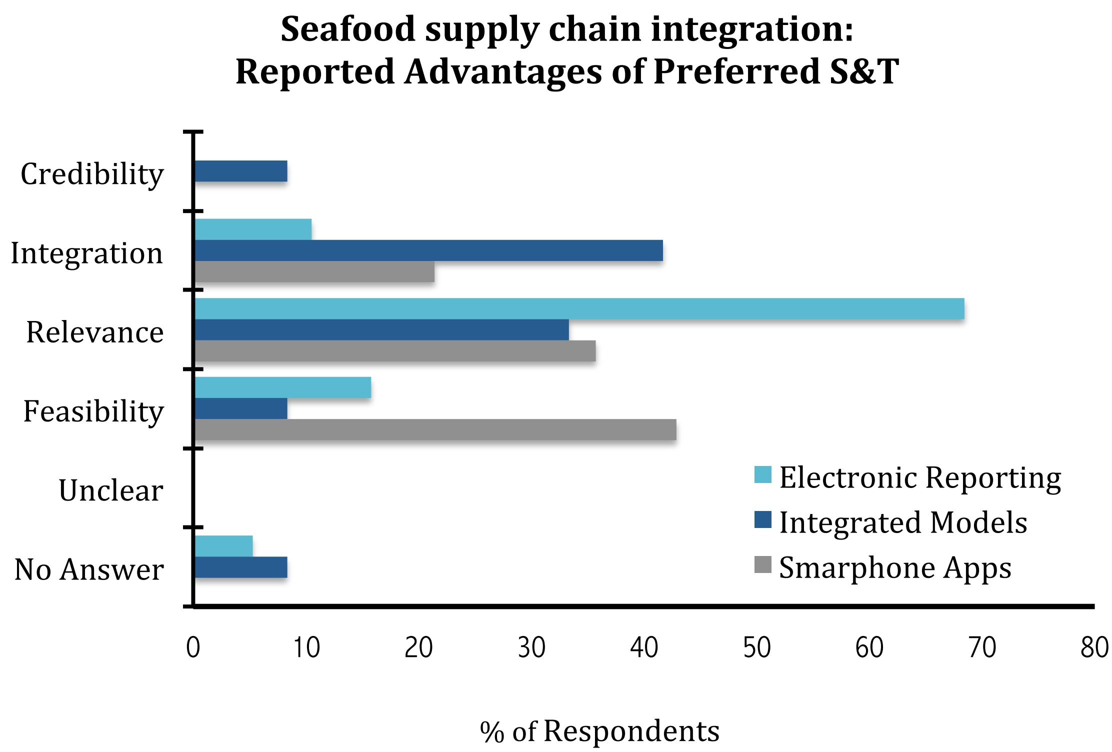
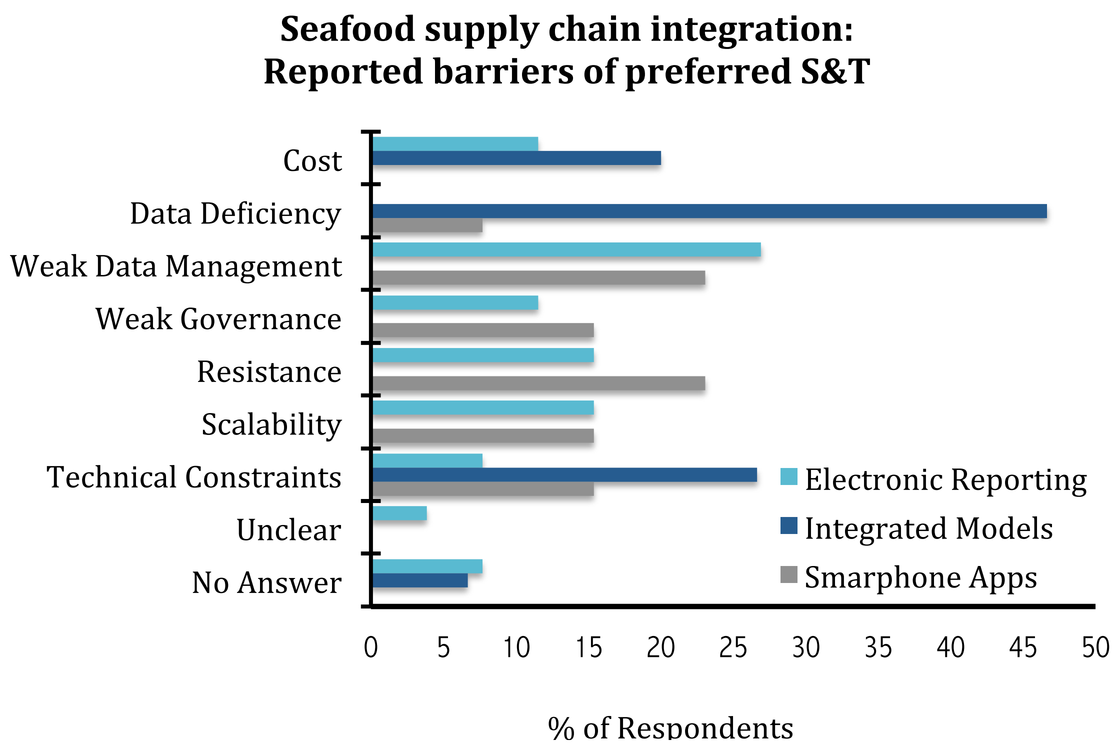


Figure 16. Bar graph depicting the main advantages as reported by survey participants for each of the most preferred S&Ts for integrating the seafood supply chain.



In terms of barriers to the implementation of ER (Figure 17), both stakeholder resistance and data management infrastructure were once again highly cited. With regards to resistance, one participant noted, “There is entrenched (primarily industry) sensitivity to sharing fisheries activity data between countries. That stance is carried forward by government delegations at international forums.” Participants also recognize the need to invest in data management infrastructure, as ER would have to be developed specific to the needs of the region, thus requiring the engagement of stakeholders as well as the development of reporting standards and custom software. Many participants also pointed to the challenge of data standardization. The diversity in languages, technical capacity, and interests among stakeholders of ASEAN and the Coral Triangle makes standardization of electronic reporting systems particularly challenging. In fact, one participant, cautions that “standardization can be much more difficult than expected,” citing challenges in the development of electronic systems for Bluefin tuna catch documentation (eBCD).

Figure 17. Bar graph depicting the main implementation barriers as reported by survey participants for each of the most preferred S&Ts for integrating the seafood supply chain.



Furthermore, new comments arose with regards to data confidentiality. One participant noted that if electronic reporting is integrated throughout the seafood supply chain, that there will be a need to ensure "data security at the same time as allowing data sharing across multiple users and agencies". All of these comments point to the importance of engaging stakeholders early-on when developing electronic systems. Doing so will not only allow for the development of standardized systems that reduce data redundancy and the overall reporting burden required of stakeholders, but will also allow for improved perceptions and buy-in regarding the data collection process.

Smartphone and crowd-sourcing apps were also given moderate support (n=10; 16.1%) for integrating the seafood supply chain. The main advantage for smartphone and crowd-sourcing apps for seafood supply chain integration were similar to those already discussed above at the point-of-purchase/consumption. Similarly, barriers to implementing smartphone and crowd-sourcing apps were once again spread across several categories. Once again, this seemed to be due to the disparate uses envisioned for this S&T by survey participants.

Interestingly, integrated ecosystem and socio-economic models arose as another moderately supported S&T for seafood supply integration (n=11; 17.7%). Many comments, as expected, were focused on its integrative capabilities. For example, "seafood harvest and sales involves many players, and modeling these systems can best reveal how to manage the entire process". In this way, integrated ecosystem and socio-economic models may in fact be more appropriate than the single-species stock assessments that survey participants advocated for in the pre-catch information stage. The ecological, political, and socio-economic context of trans-boundary fisheries in Southeast Asia and the Coral Triangle is more complex than the context within which NOAA must manage U.S. fisheries. The staggering diversity of fish assemblages in the region is just one example of why solely relying on single-species stock assessments would be inappropriate for these fisheries. Integrative modeling, therefore, may be more suitable because it has the ability to link multiple systems together. Human activities (e.g., fishing pressure, consumer behavior), ecological processes (e.g., recruitment, mortality, migration), and changing environmental conditions (e.g., ocean and climate change) can all be integrated as part of the model to predict how fisheries will be affected. Just as with stock assessment analyses, however, the main barriers cited for integrative models were data availability and technical skill. As many participants noted, these models are difficult to develop and in order to be reasonably predictive, the models require a large amount of data that may not be available.

Conclusions

The opinions collected in this survey can be used to: (1) learn how specific points along the seafood supply chain and how integration throughout the seafood supply chain can be strengthened by S&T and (2) identify S&T solutions with broad applicability as well as their main advantages and barriers to implementation. We highlight further considerations below.

It is important to point out that using the seafood supply chain as the framework for our survey also created a natural division in the S&Ts chosen for pre-catch versus point-of-catch information needs. S&Ts that were chosen for the pre-catch category were mainly for data analysis (e.g., stock assessments) and fishery-independent data collection (e.g., active acoustics), while S&Ts that were highlighted at the point-of-catch category were mainly used for fishery-dependent data collection (e.g., EM, ER, and VMS). Thus, one curiosity about the format of our survey design is that it created divisions in the seafood supply chain, when in reality there is overlap in the information needs across the chain.

To some, it may also seem counterintuitive to place such a strong emphasis on stock assessment analyses at the pre-catch level, given that it relies on the availability of both fishery-independent and fishery-dependent data. Indeed, many participants highlighted data deficiencies as a major barrier to the implementation of this S&T for ASEAN and Coral Triangle fisheries. There are two implications to this. First, as many survey participants recommended, data-limited stock assessment methods should be further developed and appropriately matched with the available data region (Cummings et al. 2014). Doing so allows for management decisions to be made based on the best available data. Secondly, many survey comments pointed to the ability of stock assessment scientists to help with prioritizing future data collection activities and pointing to specific S&T investments based on a consideration of the data gaps. Thus, it is important to clarify here that the recommendation to prioritize stock assessments over data collection, while seemingly misordered on the surface, is actually a call for stock assessment scientists to become more proactive in providing the guidance to data collection programs in terms of both survey design and S&T prioritization.

Indeed, many of our survey participants found it challenging to make their own judgments on which S&Ts should be prioritized. In their comments, many respondents indicated that they felt compelled to choose multiple S&Ts even though the survey only allowed them to choose one. For example, for integrating the seafood supply chain, one participant suggested that electronic monitoring be combined as electronic monitoring and/or smartphone and crowd-sourcing apps. For integrative ecosystem and socio-economic models, one participant noted that while these models are particularly powerful for integrating information from diverse data sources, it will still require data inputs about fisheries and ecosystems, which in turn would require the coordination of multiple S&Ts. Thus, while the survey only asked participants to indicate their preferred S&T, one major shortcoming here is that it is actually the coordinated implementation of complementary technologies that has the greatest potential.

When considering the results of this survey, one must also keep in mind that survey participants were asked to make broad, internal judgments for each question. Survey participants were only pointed to a specific geography (i.e., regional fisheries of the Coral Triangle and Southeast Asian countries), but it is important to note that the applicability as well as the associated advantages and barriers of any one S&T over another becomes more specific only as we look for solutions to specific fisheries, political contexts, and capacities. For example, as one participant noted, it is important "to focus on depleted species first [and then] implement whatever technology is most appropriate for managing or studying it". Thus, if a specific fishery was identified, a follow-up survey could potentially be developed to explore in more detail how S&T can be coordinated to inform management priorities and fill gaps.

In some cases, respondents commented on the limited ability of S&T to provide sufficient solutions. For example, for point-of-catch monitoring, one participant noted, "there is resistance to effective monitoring, and maybe even strategic preference for ineffective, lucrative, high-tech alternatives". However, investing in human observer programs would not only enhance point-of-catch information needs in the region, but also "provide employment and fishery science training to a cadre with potential to build science capacity as a result of their experience." This was further echoed by several comments regarding the institutional barriers of the region. For example, several supporters of stock assessment for pre-catch information needs commented on the "inadequate and ineffective legal and regulatory support to implement fishery conservation polices". These challenges are further amplified when scaled up to a regional level. For example, in advocating for forensic labs as a favored solution at the point-of-processing stage, one participant noted the "need to have a set of international standards, oversight, and verifications of the [forensics] results". Other challenges facing fisheries in the region are overcapacity and lack of transparency. As one participant noted: "These point to governance issues which are difficult to address via S&T". Overall, these comments point to the limited ability of S&T to address institutional barriers and highlight the importance of the ecosystem approach to fisheries management (EAFM), which the region has recently begun to embrace and apply (Pomeroy et al. 2014).

Central to EAFM is the need for stakeholder engagement. This is particularly relevant for the management of ASEAN and Coral Triangle trans-boundary fisheries. Regional scale management must be inclusive of the various stakeholders as well as coordinated across the various scales of governance and institutions that are involved. As pointed out by Fidelman et al. 2012, inclusiveness is necessary to: (1) resolve trade-offs (e.g., biodiversity conservation versus development goals of poverty reduction and food security) and (2) promote scientific dialogue, collaboration, and credibility around the information being used to make decisions. This is where the implementation of science and technology for fisheries management ties into the framework of an EAFM: the credibility of the information being produced or collected by S&T is directly tied to the credibility of the decision-making process that uses it.

S&T, if designed and implemented appropriately, has the potential to solve the information needs of policy makers. It has been said, that S&T for sustainability is most successful when they manage the boundaries between knowledge and action, while demonstrating the relevance, scientific credibility, and overall legitimacy (i.e., non-biasness and fairness) of the information they produce (Cash et al. 2003). In other words, effective S&T is not just about the high-tech acquisition of information, but also about providing accountability to those who produce and use this information as well as transparency of the decision-making process. Thus, the implementation and coordination of fisheries S&T in the region runs complementary to the region's movement towards an EAFM. Whichever S&Ts are ultimately chosen to be implemented in the region should therefore be considered in the larger context of balancing human and ecological well-being, increasing transparency and accountability, and the encouragement of participatory management.

APPENDICES

Appendix A. The following section contains non-technical description and SWOT (strengths, weaknesses, opportunities, threats) analyses for 21 pre-identified advanced S&T for fisheries management.

Note: The SWOT framework is a commonly used method for strategic planning. In our case, strengths and weaknesses were defined as characteristics *of the technology* that place it at an advantage or disadvantage, respectively, over other similar technologies. On the other hand, opportunities and threats were defined as characteristics *of the required infrastructure* (whether, political, institutional, physical, financial, or human resources) that could potentially advance or hinder, respectively, the successful implementation of this technology.

Active acoustics can be used to monitor marine organisms by taking advantage of the reflective properties of different organisms based on their composition, density, shape, and size, as well as the characteristics of sound at specific frequencies, bandwidth, and power. Sound with known characteristics are produced by a General Purpose Transmitter (GPT) and emitted by a transducer that can be installed on various platforms such as ships, buoys, gliders, and autonomous underwater vehicles (AUVs). Characteristics of the reflected sound are used to provide information on the reflecting object. This information can include identification of species, size, aggregative behavior, swimming pattern, aggregation shape, size, and density, as well as large and small scale movement patterns. Furthermore, this technology allows for the identification of ocean floor substrate type, allowing for the identification of substrate associations of various underwater species.

Strengths

- Provides biomass and abundance estimates for stock assessment that are independent of catch and observer data, and thus unbiased by fishing location, fishing gear, species catchability, or bait preferences (i.e., fisheries independent).
- Can observe individuals as well as many organisms simultaneously (e.g., schooling pattern and aggregative behavior, predator/prey interactions).
- Non-lethal, efficient (relatively low effort per data volume), and capable of observing entire water column to ocean floor.

Weaknesses

- Species identification can be challenging without complimentary methods such as trawling or visual observations.
- Identification of organisms to species level can be inhibited in environments where organisms with similar sizes and acoustic characteristics highly intermix.
- Limitations of acoustics to detect targets that are too near (usually 10-15m or less) to the transducer or at the ocean floor with high rugosity.

Opportunities

- Active acoustics is widely used for research around the world, including in support for fisheries sciences (e.g., to estimate fish abundance). Data from various regions of the world can be compared and shared between institutions.
- Processing active acoustic data has a relatively mild learning curve and most steps can be automated.

Threats

- Active acoustics is a relatively new field that is rapidly evolving. Personnel expertise must be kept updated with most recent advancements in instrumentation and methodology.
- Keeping up with advances in latest technology can be costly.

The Automatic Identification System (AIS) is a system used on ships and by vessel traffic services for tracking, identifying and locating vessels. Unlike other vessel tracking systems (e.g., VMS), AIS is already required by the Safety of Life at Sea (SOLAS) Convention to be fitted aboard ships with gross tonnage (GT) of 300 or more and all passenger ships engaged in international voyage. Since safety at sea was the primary goal of AIS, the system works by automatically broadcasting and exchanging position, course, speed and other vessel identification data with all similarly-equipped ships and land-based stations that are nearby. Data from terrestrial-based systems can be augmented through the use of satellite-based AIS tracking (i.e., S-AIS). Thus, local data can be collected using receivers on boats and on land, while global data can be accessed by subscribing to centralized data centers that pool together satellite data.[1] Equipment cost to add AIS to a ship is $600 to $5000. In November 2014, Sky Truth announced that it is launching a global AIS based fishing boat tracking service in conjunction with Oceana and Google.[2] The aim of the service is to detect IUU fishing and provide data for improved enforcement of fishing regulations.

Strengths

- Infrastructure to collect and distribute the data already exists (for example, see the U.S. government sponsored Maritime Safety and Security Information System).
- Because of its original intention for mitigating collisions and enhancing situational awareness, AIS has a higher reporting rate (every few seconds to minutes) compared to other similar tracking systems (e.g., VMS).

Weaknesses

- AIS is a cooperative system (i.e., AIS cannot monitor non-participating vessels); furthermore, units can be disabled or tampered.
- The limited number of civilian satellites in orbit capable of receiving and processing AIS signals (i.e., S-AIS) may result in gaps in offshore coverage of transmissions (although these gaps will continue to be reduced as more satellites are deployed).
- AIS carriage is currently not required on the vast majority of fishing vessels.

Opportunities

- Increasing the number of land based receiving stations, particularly in ports supporting fisheries product offloads, would improve port state measures to counter IUU fishing.
- In some cases, a combination of strategically placed terrestrial, buoy, and aircraft AIS receivers may allow for the monitoring of remote locations; thus forgoing the need for more expensive, S-AIS.
- Unlike VMS, AIS is backed by the SOLAS convention.
- Better integration of data between VMS and other vessel tracking systems (e.g., AIS) would allow for global tracking of most types of cooperative vessels (i.e., vessels that agree to use these systems) as well as better detection of anomalous activity (e.g., through geo-fencing, whereby zones or boundaries are created which when crossed result in alerts being issued).

Threats

- There could be pushback from the fishing industry due to lack of data confidentiality. Few fishing boats are inclined to use AIS when fishing for fear of losing competitive advantages.
- Lack of reliable power supply or internet connectivity in remote locations could hamper some coastal states' utilization of, or contribution to, this technology.
- Yearly subscription fees to S-AIS data are on the order of a few million dollars.

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[1] E.g., see http://www.exactearth.com/products/exactais/ or http://www.orbcomm.com/networks/ais

[2] http://skytruth.org/mapping-global-fishing/

Autonomous underwater vehicles are a diverse set of computer-controlled (i.e., self-guiding) platforms that operate mostly underwater and can be pre-programmed to navigate using either GPS (when on the ocean surface) or acoustic positioning systems (when underwater). Rather than being tethered to a ship by a cable, AUVs are capable of changing course autonomously based on input they receive from their sensors. Otherwise, they can also be outfitted with bi-directional communication systems that allow for operators to provide simple commands (e.g., “stop” or “return to the ship”). As an ocean-monitoring tool, AUVs combines the spatial resolution of ship-based surveys with the endurance and temporal resolution of moored instruments. Depending on the specific research or management objective, AUVs can be outfitted with a variety of sensors, including but not limited to acoustic (both passive and active), optical, chemical, and temperature sensor devices. Thus, AUVs can be designed to collect information for oceanographic (e.g., conductivity, temperature, water quality), ecological (e.g., fish or habitat surveys), or fisheries (e.g., vessel or catch monitoring) research. The length of time that an AUV can be deployed depends on its power source, but some (e.g., those that are powered by wave energy or solar power) have several months of endurance; thus, making them a cost-effective tool for monitoring objectives, such as fisheries enforcement, that would benefit from the ability to conduct 24-hour surveillance.

Strengths

- Given the wide variety of instruments they can potentially carry, AUVs can be customized to very specific research objectives and information needs.
- Unlike other remote (e.g., oceanographic remote-sensing) or unmanned (e.g., UAV) platforms used for ocean sensing, AUVs are actually in the ocean, allowing for in situ (i.e., more direct) sampling and measurement.
- Low detectability (underwater).
- Relatively low costs, especially considering that they are "unmanned" (i.e., lower operational costs) and do not require complex support equipment (i.e., lower deployment cost).

Weaknesses

- Long-term missions will be limited by both data and power storage capabilities as well as by slower vehicle speed (thus, possibly limited by strong currents).
- Mostly limited to upper ocean, though deep sea AUVs are increasingly being developed.
- High risk of loss.
- AUVs most often used for fisheries science have low endurance (about 24 hours); larger AUVs with longer endurance, but these tend to be too costly for fisheries research and surveys.

Opportunities

- AUVs can augment existing survey operations.
- Despite being historically less deployed and have received less research and development funds than UAVs (unmanned aerial vehicles), interest and funding for research is increasing for AUVs.

Threats

- Technical expertise is needed for operational and maintenance purposes.
- Requires engineering lab space and infrastructure

Climate and ocean change predictions. Model predictions and analyses can provide a framework for understanding and planning for future ocean and climate change scenarios and their effect on fisheries.

Strengths

- Climate predictions provide information about future oceanographic conditions applicable to local and regional fisheries management.
- Ocean climate projections provide information from past to future ocean conditions (every year from 1850 to 2100).
- The quality of ocean climate simulations has improved steadily in recent years, owing to better numerical algorithms and more realistic assumptions concerning the mixing occurring on scales smaller than the models' grid (i.e., we have more confidence in the these climate and ocean change predictions compared to past analyses).

Weaknesses

- Different models may produce different results due to regional variability.
- Multiple data sets with different scales of resolution must be combined in order to generate local-scale predictions.

Opportunities

- Efforts are currently underway to process and generate specific ocean predictions results for the Asia-Pacific region.
- Future capacity building is possible through collaborations and organizing trainings on satellite-derived data analysis to inform local and regional fisheries management.

Threats

- Computational effort can be intensive, depending on the size of the data set.
- The most appropriate ways to translate ocean simulation uncertainty into confidence in climate projections remains a subject of active research (i.e., the analyses are not straightforward and are constantly evolving).

Industrial **drifting fish-attracting-devices (DFADs)** are man-made drifting buoys or rafts that attract and aggregate fish and other marine organisms. They are usually used on the high seas, and are gaining popularity in the fisheries of the western Pacific (e.g., it is estimated that in the Philippines, 75% of tuna caught using purse-seine, ringlet, and handline are FAD-asociated). They are usually deployed for the exclusive use of the boat or fleet that set them afloat and often equipped with radio beacons that send specific, pre-set signals, so that they can be tracked and relocated only by those who know what signal to look for. For example, signals may be broadcast only at a specific time of day and/or encrypted to evade detection. Thus, the numbers of DFADs and their locations remain largely unknown, however, detection of a signal from multiple stations may yield locations by triangulation. In fact, the same receivers used by the fishermen are off-the-shelf equipment and could also potentially be used by government agencies in detection and tracking of DFADs. The uncontrolled growth and largely unmanaged use of DFADs have created international concern with regards to their environmental impact. For example, by-catch from DFAD fish practices is high. Thus, interest has grown among fisheries managers in detecting DFAD locations, particularly in cases where industry has been unwilling to cooperate.

Strengths

- The signals from DFADs may be detectable for up to 800 nautical miles.

Weaknesses

- A survey of signals, detection options and clutter from other radio sources has not been conducted (i.e., this technology is still in the "research & development" stage).

Opportunities

- The satellites that collect AIS and other ship based communications may already be collecting the FAD radio beacon signals, but filtering them out as noise.
- Monitoring could be done from land-based stations, on vessels, or by satellite.

Threats

- The fishing industry may be largely unwilling to cooperate with any effort to detect drifting FADs.

Electronic monitoring (EM) systems refers to the combination of hardware, software, and infrastructure used to collect fishery dependent data aboard fishing vessels. Closed-circuit cameras and gear sensor systems (e.g., winch rotation sensor, hydraulic pressure transducer) installed on fishing vessels can be used to passively monitor fishing operations. Furthermore, tags (e.g., radio frequency identification tags (RFIDs) or passive integrated transponders (PITs)), can be attached to fishing gear or even individual fish to track their movement. When combined with GPS (e.g., Vessel Monitoring Systems), these various electronic monitoring systems can then be used to monitor compliance with fishing methods and gears, validate fishing locations and times, as well as quantify catch and bycatch (including discards). EM systems also require installation of a control center to record and integrate data from the system. Once activated, it runs automatically, mapping the cruise track, logging fishing times and locations, monitoring winches, pumps and lifts, and creating a video record of all key fishing operations. As such, EM systems are considered to be independent of, and thus, can be used to audit self-reported data (e.g., captain's logbook of fisheries catch data).

Strengths

- Although there have been many pilot projects in the U.S., EM is successfully being used primarily for compliance in accounting for prohibited species prior to discarding.
- Logistically simpler than human observers which require a berth on the ship while electronic systems only require deck space and a power source; furthermore, EM has the potential to monitor onboard vessel activity 24 hours per day.
- Considered to be most applicable to monitoring fisheries where the catch is brought on board individually (e.g., gillnet, longline, hook and line).

Weaknesses

- Species-level identification of catch may not always be possible, particularly on vessels that haul in large catches all at once (e.g., trawl gear); thus, in general, EM is only able to replace human observers in a limited set of circumstances.
- Equipment must be able to withstand exposure to harsh weather conditions.
- Does not provide real-time information, and in fact, considerable time and money must be invested to process video data.
- EM systems can be physically tampered with or neglected (e.g., vessel crew might have to cooperate with regularly cleaning the camera lenses); furthermore, illegal activities might deliberately be performed out of view of the cameras.

Opportunities

- Overall interest and support from the fishing industry.
- Data from EM systems can be integrated with more traditional, human-observer programs.
- The systems can be costly, and acceptance of such an effort onto a fishing community may partly lie with who (regulatory agency vs. fishing industry) would be responsible to pay for the initial system setup costs and the ongoing annual maintenance costs.
- Recent research and development efforts are looking to automate the processing and analysis of video data.

Threats

- Depending on the monitoring goal, the cost of implementing EM systems can be similar to, or higher than, the cost of having human observers on board (mainly due to the cost of analyzing video footage and other data).
- The level of EM technology could become "obsolete" at the time implementation takes place.
- Data storage infrastructure will be necessary, in order for evidence to be stored, archived, and accessible for further review for use in the prosecution of violations.

Electronic reporting refers to any technology used by fishermen, dealers, and/or processors to electronically collect and report fishing trip, vessel identity, catch, landings, and purchases data. Examples of existing systems include eVTR, eTrips, eLogbooks, and eLandings. For example, the traditional handwritten logbooks used to create vessel trip reports (VTRs) can be replaced by electronic logbooks (eVTRs). Data are collected using web-based or computer-based applications, with the option of transmitting the data via satellite or a secured Internet connection. If designed properly, these electronic systems can be more user-friendly, efficient, and streamlined than non-electronic systems, allowing for multiple users (e.g., fisheries managers, enforcement authorities, and fishermen) to receive timely, updated information as well as access historical, archived information.

Strengths

- Potential for real-time reporting of data, allowing for compliance violations to be addressed in a more timely fashion as well as for more dynamic and adaptive monitoring and management; this could be especially important for catch share programs where (individual fishermen) are allotted a secure share of fish which they are responsible for not exceeding.
- Systems can be designed to have quality control checks in place, thus allowing for automated data validation; in addition, ER eliminates the transcription (paper to computer) step and any errors associated with it.
- Reduces redundancy in data reporting if multiple users can access the data remotely; for example, fishermen can view their own data with confidential access to aid in future planning.

Weaknesses

- Data will still only be as accurate as the information provided and could be intentionally or unintentionally inaccurate.
- There is the possibility of technology failures, particularly in harsh environmental conditions.
- If implementation is not coordinated at the appropriate governance scale, there could be incompatibility issues and thus barriers to integration among multiple systems.

Opportunities

- There could be an opportunity for agencies to work more closely with industry in offering technology trainings.
- ER systems can increase their utility by integrating with electronic monitoring systems.
- ER technologies if fully integrated across the industry can be used to validate seafood products as they pass between various stakeholders; for example if reporting by fishing vessels is integrated with electronic reporting by commercial dealers, there is the opportunity to cross-check catch data with landings data.

Threats

- There could be potential resistance from industry to new or unfamiliar technology.
- Vessels must have the necessary hardware and personnel to install, secure, operate electronics, while government agencies will need the ability to receive, analyze, and archive data.
- Data should have a clear and secure "chain of custody" (e.g., e-signatures) from collection point to final user in order to confirm its reliability for enforcement and prosecution purposes (i.e., tamper-proof records).

Forensic Labs. The evidence in fisheries-related crimes—whether it is fish fillets, shark fins, or sea turtle steaks—is often altered when landed, making it difficult to determine the species or its geographic origin. Forensic science is the application of scientific techniques to the investigation of potential crimes. Species can be identified via genetics, chemistry, morphology, or other forensic techniques. Genetics and/or chemistry may also provide information on the geographic origin of the catch, the number of individual animals represented in a box of fillets, or whether the animals were aquacultured or wild-caught. Genetic technology can also identify individuals with DNA fingerprinting, which is useful in traceability or in matching items such as blood on a speargun to steaks in a freezer, or fillets to a carcass.

Strengths

- Forensic analyses can identify individuals, populations, and species to help determine whether a catch was legal or not.
- Forensic analyses can be used as an investigational tool to determine where (geographically or taxonomically) enforcement efforts should be focused.

Weaknesses

- All forensic methods require a well-documented collection of “voucher” specimens identified by experts and of known geographic origin.
- As the required resolution increases from species to individual to population, the amount of research and development needed also increases. Thus, technologies for individual or population identification may only be practical for certain high value species, such as Bluefin tuna.
- Populations of organisms do not necessarily correspond to political and legal boundaries (e.g., a shipment of fish might be identified as coming from the Coral Sea, but not necessarily from a specific nation’s waters).

Opportunities

- Because of its diverse set of applications, many opportunities for collaboration and mutual education exist. For example, academic and government research laboratories can collaborate in characterizing species and populations. Forensic scientists can provide input towards crafting effective enforcement and management strategies. International collaboration on research and development can decrease each nation’s individual cost.

Threats

- Wildlife forensic scientists require a unique skill set not generally available in either fisheries research or human forensic settings.
- Stringent access and quality controls in the lab are needed to ensure success in court; furthermore, differences in legal systems and legal requirements for what constitutes "evidence" could present a challenge in the standardization of scientific methods.
- CITES and other agreements/legislation that govern wildlife trafficking make it difficult to collect and share voucher specimens across international borders.
- Purchasing laboratory equipment, building new or modifying existing laboratory space, and training personnel may be costly.

Integrated ecosystem and socio-economic models. Ecosystem models track nutrient or energy flows through the main biological groups found in the system and consider a variety of primary ecological processes such as consumption, production, waste and cycling, migration, predation, recruitment, habitat dependency, and mortality. Through the coupling of these flows with an oceanographic model that simulates the fluxes of water, nutrients and plankton, ecosystem models can produce realistic simulations of ecosystem dynamics and thus reflect or project changes to the system. In fact, the uses of ecosystems models are very diverse. Ecosystem models can also include human activities and reveal insights to human and climate impacts on the system including fisheries, changes in land-use, non-point sources of pollution, and climate change. Ecosystem models can even be focused towards policy assessment. For example, one can simulate and evaluate the efficiency of a fishery dependent monitoring programs and determine whether, for example, monitoring frequency is adequate. If coupled with socioeconomic data, they can even be used to visualize projected economic (e.g., fishermen's profit) and ecological (e.g., fish biomass, coral cover) tradeoffs of alternative management scenarios and thus aid managers in making informed decisions.

Strengths

- The integration all available biological, oceanographic, and socio-economic data in one database will also reveal gaps in data on which monitoring programs should focus.
- Through the integration of the various stressors on a system, synergistic impacts will reveal themselves and maybe unexpected consequences show up.
- Allows for: exploring ecological hypotheses; simulating climate scenarios with or without additional human impacts (such as fisheries or pollution); or Management Strategy Evaluation where simple output graphs can show the economic and ecological benefits of the identified alternative management strategies (e.g., SCUBA fishery ban vs watershed restoration).

Weaknesses

- Complex ecosystem models (e.g. those that include climate, biophysical and oceanographic processes, and human industries) take a long time to develop (approximately 3 years depending on the data available).
- The accuracy of the model depends on the availability of ecological (biomass and life history of all main groups), oceanographic and fishery data and the existing empirical relationships of the key dynamics of the system (e.g., relationship between sediment stress and coral growth; or the mortality and recovery of corals after a bleaching event).

Opportunities

- Allows for strong interdisciplinary relationships to develop between public and private research institutes, resource managers (local, regional, national and international), and representatives of the various resource users (e.g. fisherman, mining industry, forestry).
- Allows for resource managers to set clear objectives, ecological/economic indicators for the desired system state, and thresholds for when management action must be taken.

Threats

- Uncooperative stakeholders.
- Expertise needed for each of the main data streams (i.e. oceanographer, ecologist, socioeconomist) for model development and validation.
- Expertise needed in model development depending on the ecosystem model framework to be used (e.g., Ecopath with Ecosim is free software and has extensive documentation versus Atlantis which is also free but has very limited documentation).

Next generation sequencing technologies. Genetic sequencing is the process of determining the order of nucleotide bases (i.e., A, C, T, or G; the genetic "code") of a DNA sample. In the past, large costs of producing this information meant that large-scale acquisition of genetic data (e.g., sequencing an entire individual's genome) was limited to a select number of organisms (e.g., humans, mice). "Next generation sequencing" (NGS) is a blanket term for describing the newest suite of genetic sequencing technologies capable of producing huge amounts of genetic data at a considerably reduced cost. In other words, NGS allows for non-model organisms (e.g., fish, marine invertebrates) to be described at a genetic resolution once reserved for lab-based "model organisms", thus giving conservation biologists new avenues for better understanding the ecology and evolution of these organisms.

Strengths

- Allows for genetic studies and analyses once reserved for model organisms to be applied to non-model organisms (i.e., organisms of interest to conservation biologists).
- Compared to other sequencing technologies, cheaper cost per genotype, particularly if used for large scale studies.

Weaknesses

- Technology advances rapidly, potentially making equipment purchases obsolete in only a few years.
- Data volume is too large for manual analysis. Processing of data requires access to skilled bioinformaticists.

Opportunities

- Sequencing services are available on a fee-for-service basis from many universities; this opens the doors for collaborations with research institutions that may either want to purchase/lease use of the technology or collaborate in other ways.

Threats

- A molecular genetics laboratory is needed (either with purchased equipment or contracted services) in order to create DNA libraries to be sequenced.
- Purchasing NGS technologies ranges from $70K to more than $1M.
- Once the genetic data are obtained, analyzing them will require expertise in genomics and bioinformatics and access to computational resources.

Oceanographic remote-sensing data for various oceanographic variables are taken using satellites. The satellites are launched and maintained by a variety of organizations, which make the data available for download in near real-time. The data are global in scale, and can capture variability on timescales of weeks to years. These data sets are powerful tools to examine a variety of ocean processes that are critical to understanding fisheries. Sea surface temperature, primary productivity, ocean currents, and salinity are all examples of available satellite data that provide a background to better understand the oceanographic processes that affect fisheries.

Strengths

- Satellite-derived products provide data about physical and biogeochemical ocean conditions needed for fisheries management.
- Maps can be produced for various oceanographic variables at different temporal and spatial scales; also, able to image large areas at once.
- The data are free and readily available.

Weaknesses

- Application of remote sensing to fisheries requires previous knowledge of habitat preferences of the fish, biological quality of the water, oceanography of the area, behavior of a given species at various temperatures, and catch rates occurring under those conditions.
- Spatial resolution of data varies from meters to degrees, and temporal resolution varies from hourly to monthly temporal scales; therefore, analyzing these data requires expertise in geospatial statistics. Furthermore, gaps in the data can occur due to clouds obscuring the ocean surface.
- Remote sensing data can only measure the surface characteristics of the ocean; therefore it may be necessary to ground truth the data, especially when using remote sensing data to extrapolate beyond the ocean surface.

Opportunities

- Efforts are currently underway to download, process and generate specific satellite-derived ocean parameters and products for the Asia-Pacific region.
- Future capacity building is possible through collaborations and organizing trainings on satellite-derived data analysis to inform local and regional fisheries management.

Threats

- Yearly updates on new data versions are needed to verify that the most current data set is used, as improved data versions are released occasionally.
- Computational effort can be intensive, depending on the size of the data set.

Over-the-horizon radar (OTH radar), is a type of high-frequency radar system with the enhanced ability to detect targets typically up to thousands of kilometers away. Traditional radar, which travels in a straight line, is limited by obstacles and in particular, by the Earth's curvature. On the other hand, OTH radar is a long-range radar detection system that uses the ionosphere (a region of the upper atmosphere) as a "mirror in the sky" to bounce radar signals beyond the horizon.

Strengths

- Enables local detection and monitoring of vessel movements.
- Works day or night and in all weather conditions.
- Portable systems can be moved based on seasonal shifts in fishing activity.
- Unlike other vessel tracking technologies (e.g., VMS, AIS), this is a "non-cooperative" system, allowing for the detection of vessels activities without their knowledge or participation.

Weaknesses

- Requires installation of an antenna array and data processing facility.
- Provides limited information on the type or characteristics of vessels.
- The technology (i.e., the frequency of the transmitted signal) must be fine-tuned depending on changing atmospheric conditions, and thus requires continuous adjustment.

Opportunities

- Australia operates a set of three OTH radars along its northern coast, collecting data deep into Indonesia. It may be possible to evaluate OTH radar capabilities for fishery monitoring through collaboration with the Australians.

Threats

- As a "non-cooperative system" (see "Strengths" above), the technology may encourage suspicion between countries and therefore care must be taken to develop the system in geo-politically "tense" regions.

Passive acoustics. Sound travels exceptionally well underwater and therefore is well suited for both signaling and detecting acoustic events at long ranges. Marine biota and humans alike exploit the properties of underwater sound for communication and sensing in the marine environment. Passive acoustic monitoring (PAM) of marine habitats is a powerful way to investigate and monitor biological processes and anthropogenic activities that would be either difficult or prohibitively expensive to study using other methods. Technological advances over the past decade have made the collection of long-term time series of acoustic data both affordable and reliable. Acoustic data can be used to answer a wide range of questions about the presence and activity of sound producing species (e.g. fish, invertebrates and marine mammals), the long-term stability and biodiversity of marine habitats, and the effects of rising levels of anthropogenic noise on marine organisms. PAM also offers a low-cost means of tracking anthropogenic activities (e.g. vessel traffic, blast fishing) in remote areas where conventional monitoring and enforcement methods are not feasible.

Strengths
- Hardware is low cost compared to traditional vessel/aircraft-based surveys.
- Can provide 24/7, year-round monitoring presence at remote locations.
- Once deployed, PAM tools are minimally affected by weather constraints.

Weaknesses
- Some data analyses can be labor intensive, depending on the level/detail required; Furthermore, data are usually archival and must be physically recovered. Obtaining certain types of data in real-time is possible (e.g. by mounting on AUVs), but at a substantially higher cost.
- Ground-truthing efforts may be required to fully answer certain questions.
- Multiple instruments are usually required to achieve broad spatial coverage.
- In terms of fish stock assessments, the methods for Passive Acoustics are not nearly as well-developed as those for Active Acoustics.

Opportunities
- Automated hardware/software tools allow for effective data collection & processing.
- PAM data are collected widely around the world. Data from different locations can be linked and compared via collaborations and sharing agreements.
- PAM data can be tied and integrated with other long-term data streams, such as remotely sensed oceanographic data, vessel AIS, and surveys.

Threats
- PAM data analysis tools are rapidly evolving. Expertise is required to exploit all the advantages of the latest methods.
- The benefits of PAM increase with the duration of data collection. Long-term investments and planning are necessary to maximize the benefits of PAM.

Population genetic analyses. As populations evolve, they develop unique genetic signatures that can be assayed via genetic markers such as microsatellites or single-nucleotide polymorphisms (SNPs). By developing and using these genetic markers, population genetic analyses are able to identify groups of fish (or other marine organisms) that are currently behaving as a biological unit. Generally, this means that the fish within the biological unit are distinguishable from other similar populations of fish (e.g. geographically, behaviorally, genetically, etc.), and that they are not generally interbreeding with other populations of fish. Conversely, fish within the same biological unit are genetically connected and thus, interbreeding with each other. Ultimately, these analyses have the ability to identify discreet management units (e.g., stocks) and inform the creation of management policies that complement natural processes (e.g., preserving local adaptations).

Strengths

- Genetic “tags” are encoded by the fish’s own DNA (i.e., no physical tagging is required).
- Genetic and analytic techniques are well developed. This type of analysis is being done for multiple fisheries in the United States and the EU.
- Laboratory methods are amenable to automation/robotics; particularly useful for when there is a large number of samples to process.
- Once developed, genetic markers can often also be used in conducting pedigree analyses, providing a tool for looking at reproductive success in aquaculture or hatchery settings.

Weaknesses

- The analyses are not “plug-and-play”; they require trained population geneticists to produce and interpret data.
- Interpretation of the data and their management implications are not always straightforward.

Opportunities

- Techniques are well-established in the scientific community. Large university Biology departments are often implementing these techniques on a regular basis and can provide expertise and guidance.
- Dominant fisheries species will likely already have genetic data and well-developed genetic markers published in the scientific literature that can be used as a starting point.

Threats

- A genetic database of populations is required for compilation, standardization, and long-term curation of data. This can be costly and logistically difficult to put into place.
- Biologically discreet units may span across political boundaries, presenting challenges for their management.

Seafood safety and quality testing. Hazard Analysis and Critical Control Point (HACCP) is a preventative science-based system that aims to prevent food safety problems and thus, reduce wasted seafood and ensure seafood quality. It is a more scientific, analytical, and economical approach than that provided by traditional inspection and quality control methods and has been become the international-standard for ensuring food safety. It is applicable to the handling, production, storage, export, import, and sale of seafood products. HACCP involves the identification of specific hazards (i.e., seafood safety) and defects (i.e., seafood quality) and the implementation of control measures and monitoring systems to prevent these. Hazards and defects can be biological (e.g., parasites, bacteria, viruses, biotoxins), chemical (e.g., heavy metals, veterinary antibiotic drugs particularly in aquaculture facilities), or physical (e.g., fish hooks) in nature, and thus an effective HACCP system should also have access to appropriate microbiological and chemical laboratory testing facilities. Whenever possible, HACCP, however, seeks to emphasize continuous, cheap, and real-time monitoring at multiple points (e.g., time and temperature recordings, pH measurements, sensory observations), while de-emphasizing the reliance on end-product testing. For example, HACCP emphasizes the identification of precise operational requirements (e.g., determine the maximum time a product can be kept at ambient temperature without significant quality loss) instead of end-product requirements (e.g., food must reach an internal temperature of X).

Strengths

- Preventative, rather than reactionary system for ensuring seafood safety and quality.
- A major challenge in seafood safety is that the processor generally has no information about the history of the raw material; HACCP addresses this by making sure monitoring systems are in place on the receiving end of seafood processing facilities.
- The monitoring system is controlled by those who are directly involved with the food.
- Emphasis is on efficiency: directing energy and resources to points in the system where they are necessary and most useful.

Weaknesses

- In order to be effective, HACCP needs to be applied from the origin of food (sea/farm) to consumption – a scenario that may not always be possible.

Opportunities

- The Food and Agriculture Organization of the United Nations (FAO) has adopted HACCP as the international standard for food safety.
- Having an HACCP in place can help reduce barriers to international trade.

Threats

- No universal agreement on what constitutes a hazard (possible need to establish a non-biased advisory group on these issues).
- Requires processors/manufacturers/distributors to accept greater responsibility for ensuring food safety, which may be met with some resistance.
- In some developing countries, the food processing industry simply does not have access to the pre-requisite tools, supplies, and services needed to develop an effective HACCP plan (e.g., pest management, cleaning, and sanitizing services; monitoring equipment; laboratory testing facilities).
- Systems must be designed to keep up with the increasing number of new food-born pathogens.

Seascape ecology is an emerging discipline which provides an analytical framework for examining ecological functions, processes and conditions based on the geographic (i.e., spatial) patterns of environmental characteristics in the coastal ocean environment. The objective is to locate, describe and explain the mechanisms and linkages that influence ecological considerations such as species occurrence, diversity, abundance and sustainability. Existing bathymetry and bathymetric derivatives (e.g. texture, slope) derived from vessel-borne multibeam sonar and satellite-borne sensors form the basis for this approach to ecosystem analysis. These data can also be combined with field data collected by divers and other devices (e.g. underwater cameras, buoys, measurement devices), ultimately allowing for spatial analyses and the visualization of geographic patterns. Furthermore, dynamic web-based maps and graphics enable visualization of these geographic patterns in an interactive fashion. Through statistical and other forms of spatial analysis, these patterns provide insight into the relationships between the physical environment and marine species characteristics, as well as environmental considerations such as the impacts of coastal development on water quality.

Strengths

- Provides tools for the measurement and quantitative analysis of spatial patterns.
- Rather than just studying averaged or "global" relationships, spatial analyses allow for the examination of how relationship varies across the map (i.e., "local" analysis).

Weaknesses

- As with any complex ecological system, the ability of a model to explain patterns, linkages, and especially mechanisms are limited by: availability and quality of the data; whether the appropriate methods/tools are available or have been chosen for the analysis; and difficulty in confidently identifying direct linkages, mechanisms and causes of an outcome.

Opportunities

- Discovery and inventory of existing data can reveal gaps in data that monitoring programs should focus on.
- Often calls for collaboration amongst government agencies to share data and make efficient use of funds to collect data.

Threats

- Requires advanced level knowledge of spatial statistics.
- Requires suitable software and hardware in order to store, manage, and process large geographic data sets (i.e., Geographic Information Systems).

Smartphone and crowd-sourcing apps. Mobile technologies (e.g., smartphones and digital tablets) can be used to integrate widely available technologies and hardware accessories (e.g., camera, GPS, accelerometer, etc.) as well as to access customized software (i.e., "apps") that allow for the automatic processing, analysis, and/or transmission of data. Widely used across diverse scientific and educational fields, mobile apps have recently and increasingly been designed for fisheries research, data collection, as well as public outreach and education. Furthermore, the technology allows for two-way, real-time communication; for example, allowing fishers to provide catch data to managers and government agencies to provide real-time fishing/boating/weather information to fishers. Examples include enabling fishers to provide catch data to managers, photograph suspected illegal fishing activities, and identify migratory patterns of protected species. On the other hand, government agencies can provide fishers access to historical catch data; local, real-time fishing/boating/weather information; and regulatory information (e.g., marine protected area boundaries, catch and size limits). Thus, the potential applications for fisheries are diverse but the overarching goal is to develop user-friendly software that can reduce the burden of data collection and dissemination as well as help to bridge the communication gap between fishers and scientists while providing managers with essential information.

Strengths

- New hardware technologies allow for diverse data collection capability (e.g., camera/microscope, temperature sensor, light sensor, digital barometer, altimeter, accelerometer, gyroscope, etc.) while eliminating the need to carry multiple devices.
- Provided that there is internet access, data can be immediately uploaded and accessed by managers, minimizing time spent and errors associated with reentering data.
- Electronic data entry and storage allows for that data (e.g., catch records) to be archived, version-controlled, and accessed subsequently by both managers and fishermen.

Weaknesses

- Water damage, impact, and battery life are thought to be limitations (however, protective and waterproof casings as well as solar-charging options can help to prevent these).
- Compared to traditional methods (e.g., paper logbooks, in the case of catch reporting), total cost of outfitting a fishing fleet or fisheries agency with all the necessary electronic equipment and protective gear can be prohibitive.
- The subsequent increase in data may overwhelm the ability for government agencies and others to analyze and manage the information.

Opportunities

- By allowing catch data to be reported in a more real-time fashion, this could enable managers to implement more timely, adaptive management strategies.
- Small scale, developing country fishers and farmers have used cell phone/text message functionality to find the best markets and get better prices for their products, resulting in a more efficient market and less wasted fish.
- Depending on the country, cell phones and smartphones are likely already widely used throughout the population, meaning that the technology can be more broadly applied to crowd-sourcing information and citizen science projects (e.g., reporting of marine mammal strandings).
- Because smartphones do not directly connect to (and in many cases are banned from physically connecting to) agency computer networks, they are less burdened by government agency IT policies and able to grow more quickly.
- For mobile technologies that are being used for the purpose of collecting fisheries data, there is an opportunity for integration with electronic monitoring and electronic reporting systems.

Threats

- To maximize the effectiveness of many apps, it will be important for countries to have adequate communications infrastructure as well as regulatory/management frameworks that can process new data provided by fishers.
- Government agencies and internal bureaucracies may be hesitant to embrace new technologies.

Stock assessment analyses. Fish stock assessments can be used to determine sustainable catch levels for harvested species as well as other important information desired by fisheries managers. Conducting a stock assessment, however, requires data (usually catch or abundance trends at a minimum), as well as moderate to advanced analytical skills. Training local scientists in stock assessment modeling would create/build regional capacity with regards to the development of fisheries management plans (e.g., setting and managing fishery extraction levels).

Strengths

- Stock assessment science training will not become outdated. In fact, this transfer of knowledge could help establish the foundation on which an assessment program could develop.
- A range of modeling techniques is available for stock assessments, depending on the amount and quality of data available.

Weaknesses

- Given the steep learning curve for stock assessment science, a successful training program needs to be relatively comprehensive.
- Analytical skills are not useful unless there are data to analyze. Thus, benefits of stock assessment training might be limited to fisheries where data collection programs already exist or are being developed.

Opportunities

- NOAA Fisheries employs many of the world's leaders in fish stock assessment. Thus, highly qualified scientists could be made available for developing and conducting a stock assessment training program.
- Stock assessments can be implemented using standard computing power and software packages that are readily available for free download.
- Training programs facilitate communication and establish partnerships.

Threats

- Training in stock assessment science requires a relatively strong background in mathematics and statistics.
- Analytical skills are not useful unless enough data are available to support at least a baseline stock assessment.

Unmanned Aerial Vehicles (UAVs) are unmanned aircraft that can perform a wide variety of functions using instrument packages carried onboard the aircraft. Some fisheries applications of UAV-based sensing include chlorophyll-*a*, and sea surface temperature measurements, as well as video surveillance of maritime activity. The aircraft are often time controlled by a ground controller (a pilot), but the vehicles may also have some autonomous ability to operate on their own. The vehicles range from very expensive multi-million dollar vehicles capable of flying long-range (> 2000 km), high altitude (20,000 m), and high endurance (48-hour) missions to smaller less expensive but more limited operational capabilities (e.g., < 10km range, 300 m altitude, < 2 hr endurance).

Strengths

- Being "unmanned", allows for long endurance flight missions (e.g., 24-48 hours for the more expensive UAVs), which is especially relevant for ongoing, repetitive observation missions (long and monotonous) as well as missions being conducted in potentially dangerous environments.
- Because they fly lower to the ground, they can generate imagery of higher spatial resolution, are not "blocked" by cloud cover, and can provide more real-time data than oceanographic remote sensing.

Weaknesses

- Smaller, cheaper UAVs will be limited by payload capacity (limiting the types of sensors it can carry).

Opportunities

- Even with the great costs associated with high-end UAVs, governments may still find it financially feasible to acquire such a system if they determine that they will be able to use it across a broad range of government functions, from defense to law enforcement, to scientific research.
- Currently, there is significant international and commercial interest to invest in and expand the roles and capabilities of UAVs and their associated sensors.

Threats

- Require skilled operators to be able to effectively and safely handle their operations.
- Legal and regulatory issues concerning the operation of UAVs in the same "civil" airspace as traditional aircrafts remains unresolved (e.g., political and/or regulatory realities may restrict a government from being able to operate a UAV for civilian purposes, or in domestic airspace).

Vessel light detecting using satellites. Low-light imaging satellite sensors are able to detect lights from boats, primarily fishing boats using lights to attract catch. Two systems collect low-light imaging data with the capability to detect boats: The U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) and the NASA/NOAA Suomi NPP Visible Infrared Imaging Radiometer Suite (VIIRS). The former (DMSP) has a 20+ year record. On the other hand, data collected from the latter (VIIRS) only go back to 2012 but have far better spatial resolution than DMSP and are radiance calibrated. The NOAA National Geophysical Data Center (NGDC) receives the data and operates the long term archive, and government agencies in Korea, Japan, Thailand and Peru, are already using these data for fishing boat detection.

Strengths

- The sensors, launch and collection costs are paid by other organizations.
- In some cases, it is possible to detect individual boat clusters.

Weaknesses

- Each satellite only collects data once per night; and VIIRS data delivery to NGDC delayed by 6-8 hours (i.e., data are not real-time).
- Not all fishing boats use light to attract catch; furthermore, boats may evade detection by turning off their lights for satellite overpasses.
- Clouds can obscure lights from fishing boats or blur them; however, thermal bands can be used to at least confirm areas where clouds are present.
- Spatial resolution is relatively coarse, 742 meters for VIIRS. Thus it is not possible to directly measure the size of boats.

Opportunities

- NGDC already has a robust DMSP and VIIRS processing infrastructure serving many customers.
- NGDC has established a prototype automatic lit fishing boat detection system for Indonesia. The software works well on low moon nights, but needs additional algorithm development to reduce false detections on nights with high lunar illuminance. The prototype is available at: http://www.ngdc.noaa.gov/eog/viirs/download_indo_boat.html
- NGDC-developed boat detection and reporting software could be installed at VIIRS ground stations. If this is implemented, the time from satellite overpass to data product delivery could be reduced to the 1-hour range. Indonesia's government has indicated interest in this and already has a ground station on Sulawesi.
- It may be possible to do capacity building by helping government operated ground.
- stations (e.g., Indonesia has one on Sulawesi) to source the VIIRS data.

Threats

- Fish catch can only be inferred; validation of the fishing activity would require cooperation by fishermen or intervention by enforcement agencies.

Vessel Monitoring System (VMS) is a GPS satellite-based positioning system whereby vessels, usually fishing vessels, are outfitted with transmitting units that report on the vessel's position, time at position, course, and speed. This information is collected by communications satellites (e.g., Immarsat, Iridium, Argos) and reported only to those who are authorized to receive the information, such as governmental enforcement organizations. Most Regional Fisheries Management Organizations (RFMOs) as well as many States have already mandated VMS use on larger commercial fishing vessels, and in some cases, data-sharing arrangements between countries have been established (e.g., EU and the South Pacific Forum Fisheries Agency). VMS is currently one of the most widespread cooperative surveillance systems (i.e., systems that require participation or compliance by the vessel owner or crew) used in fisheries management. Depending on the hardware systems in use, messages may also be transmitted through the VMS systems. VMS units cost approximately US$1000-4000 each.

Strengths

- Compared to other electronic systems that are still being tested/developed (e.g., electronic monitoring), VMS is simple, autonomous, and automatic with no need for image analysis and little/no need for operator intervention.
- In contrast to other vessel tracking systems (e.g., AIS), VMS is already being used to track many fishing vessels.

Weaknesses

- In contrast to electronic monitoring systems, VMS can only provide indicators of possible prohibited activity; thus, specific fishing activities can only be verified by corroborating evidence (e.g., direct observation) (e.g. enforcement patrols or shipboard observations).
- VMS is a cooperative system (i.e., VMS cannot monitor non-participating vessels); furthermore, units can be disabled or tampered with.
- Compared to AIS, the reporting rate of VMS is typically once every hour; increasing this rate would require several hundred dollars of additional annual operating costs per vessel.

Opportunities

- Better integration of data between VMS and other vessel tracking systems (e.g., AIS) would allow for global tracking of most types of cooperative vessels (i.e., vessels that agree to use these systems) as well as better detection of anomalous activity (e.g., through geo-fencing, whereby zones or boundaries are created which when crossed result in alerts being issued).
- The use of VMS technology may help a country demonstrate it is exercising due diligence in helping to combat illegal, unregulated, and unreported (IUU) fishing, at least as pertaining to part of its national fleet.
- The Thailand Department of Fisheries has 100 fishing boats equipped with VMS. The Indonesia Ministry of Marine Affairs and Fisheries has 1000 boats equipped with VMS. It may be possible to better evaluate the potential benefits of VMS based on these assets.

Threats

- Unlike in AIS where there is an existing international legal framework for data sharing and standardization, there is currently no binding global agreements regarding the use of VMS.

Appendix B. S&T Survey Questions

Pre-catch information needs:

1. Choose one from the list below. Which of these S&T innovations, if implemented in the next 5 years, will have the greatest impact on PRE-CATCH information needs for trans-boundary (i.e., trans-national) marine fisheries throughout the ASEAN (Association of Southeast Asian Nations) and Coral Triangle countries?

Choices: Active acoustics, AUVs, Climate and ocean change predictions, DFAD detection, Integrated ecosystem and socio-economic models, NGS technologies, Oceanographic remote sensing data, Passive acoustics, Population genetics analyses, Seascape ecology, Smartphone and crowd-sourcing apps, Stock assessment analyses, UAVs

2. Complete the following sentence: In meeting pre-catch information needs for ASEAN and Coral Triangle trans-boundary marine fisheries, the main advantage of my chosen S&T over other available S&T is:

3. Complete the following sentence: In meeting pre-catch information needs for ASEAN and Coral Triangle trans-boundary marine fisheries, the main barrier to successfully implementing my chosen S&T is:

4. Are there any S&T innovations that were not pre-identified in the list above that you would have selected as your top choice? If so, please identify this S&T below and describe ONE main advantage and ONE main barrier to its implementation in the space below.

Point-of-catch information needs:

1. Choose one from the list below. Which of these S&T innovations, if implemented in the next 5 years, will have the greatest impact on POINT-OF-CATCH information needs for trans-boundary (i.e., trans-national) marine fisheries throughout the ASEAN (Association of Southeast Asian Nations) and Coral Triangle countries?

Choices: Active acoustics, AIS, AUVs, DFAD detection, Electronic monitoring, Electronic reporting, Forensic labs, Integrated ecosystem and socio-economic models, OTH radar, Passive acoustics, Seafood safety and quality testing, Smartphone and crowd-sourcing apps, UAVs, Vessel light detecting using satellites, VMS

2. Complete the following sentence: In meeting point-of-catch information needs for ASEAN and Coral Triangle trans-boundary marine fisheries, the main advantage of my chosen S&T over other available S&T is:

3. Complete the following sentence: In meeting point-of-catch information needs for ASEAN and Coral Triangle trans-boundary marine fisheries, the main barrier to successfully implementing my chosen S&T is:

4. Are there any S&T innovations that were not pre-identified in the list above that you would have selected as your top choice? If so, please identify this S&T below and describe ONE main advantage and ONE main barrier to its implementation in the space below.

Point-of-processing/packaging information needs:

1. Choose one from the list below. Which of these S&T innovations, if implemented in the next 5 years, will have the greatest impact on POINT-OF-PROCESSING/PACKAGING information needs for trans-boundary (i.e., trans-national) marine fisheries throughout the ASEAN (Association of Southeast Asian Nations) and Coral Triangle countries?

Choices: Electronic monitoring, Electronic reporting, Forensic labs, Integrated ecosystem and socio-economic models, Seafood safety and quality testing, Smartphone and crowd-sourcing apps

2. Complete the following sentence: In meeting point-of-processing/packaging information needs for ASEAN and Coral Triangle trans-boundary marine fisheries, the main advantage of my chosen S&T over other available S&T is:

3. Complete the following sentence: In meeting point-of-processing/packaging information needs for ASEAN and Coral Triangle trans-boundary marine fisheries, the main barrier to successfully implementing my chosen S&T is:

4. Are there any S&T innovations that were not pre-identified in the list above that you would have selected as your top choice? If so, please identify this S&T below and describe ONE main advantage and ONE main barrier to its implementation in the space below.

Point-of-purchase/consumption information needs:

1. Choose one from the list below. Which of these S&T innovations, if implemented in the next 5 years, will have the greatest impact on POINT-OF-PURCHASE/CONSUMPTION information needs for trans-boundary (i.e., trans-national) marine fisheries throughout the ASEAN (Association of Southeast Asian Nations) and Coral Triangle countries?

Choices: Electronic monitoring, Electronic reporting, Forensic labs, Integrated ecosystem and socio-economic models, Seafood safety and quality testing, Smartphone and crowd-sourcing apps

2. Complete the following sentence: In meeting point-of-purchase/consumption information needs for ASEAN and Coral Triangle trans-boundary marine fisheries, the main advantage of my chosen S&T over other available S&T is:

3. Complete the following sentence: In meeting point-of-purchase/consumption information needs for ASEAN and Coral Triangle trans-boundary marine fisheries, the main barrier to successfully implementing my chosen S&T is:

4. Are there any S&T innovations that were not pre-identified in the list above that you would have selected as your top choice? If so, please identify this S&T below and describe ONE main advantage and ONE main barrier to its implementation in the space below.

Seafood supply chain integration:

1. Choose one from the list below. Which of these S&T innovations, if implemented in the next 5 years, will have the best ability to link together information throughout the SEAFOOD SUPPLY CHAIN for trans-boundary (i.e., trans-national) marine fisheries throughout the ASEAN (Association of Southeast Asian Nations) and Coral Triangle countries?

Choices: Active acoustics, AIS, AUVs, Climate and ocean change predictions, DFAD detection, Electronic monitoring, Electronic reporting, Forensic labs, ntegrated ecosystem and socio-economic models, NGS technologies, Oceanographic remote sensing data, OTH radar, Passive acoustics, Population genetics analyses, Seafood safety and quality testing, Seascape ecology, Smartphone and crowd-sourcing apps, Stock assessment analyses, UAVs, VMS, vessel light detection using satellites

2. Complete the following sentence: In linking together information throughout the seafood supply chain for ASEAN and Coral Triangle trans-boundary marine fisheries, the main advantage of my chosen S&T over other available S&T is:

3. Complete the following sentence: In linking together information throughout seafood supply chain for ASEAN and Coral Triangle trans-boundary marine fisheries, the main barrier to successfully implementing my chosen S&T is:

4. Are there any S&T innovations that were not pre-identified in the list above that you would have selected as your top choice? If so, please identify this S&T below and describe ONE main advantage and ONE main barrier to its implementation in the space below.

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* See list of “Acronyms and Abbreviations”