Version of Record: https://www.sciencedirect.com/science/article/pii/S0967064518301115
Manuscript_90d41d9e8139cfa056cacebd7b50d146

Productivity and coastal fisheries biomass yields of the northeast coastal waters of the Bay of Bengal Large Marine Ecosystem

Michael J. Akester, International Center for Living Aquatic Resources Management ICLARM (WorldFish), Country Director, Myanmar

Abstract

Myanmar (Burma) is the second largest territory in Southeast Asia with a 2200 km coastline and continental shelf of 230,000 km^2. The Myanmar exclusive economic zone (EEZ) occupies 80% of the northeast coastal waters of the Bay of Bengal Large Marine Ecosystem (BoBLME); a 300 km stretch of the Bangladesh coastline completes the area. Four decades ago a combination of extensive mangrove forests, large continental shelf and fertile deposits from the rivers systems discharging into the Bay from two mega deltas (Ganges–Brahmaputra–Meghna and the Ayeyarwady) generated high productivity and valuable coastal fisheries. In terms of productivity, the end of the dry season (April) is the most productive, with 2590 ± 1560 mg C m^{-2} day^{-1} and high concentrations of chlorophyll a (3.14 ± 2.64 µg L^{-1}). In 2016, the Department of Fisheries (DoF Myanmar) reported marine fishery landings in Myanmar's waters of 2.9 million metric tons (mt), which would have accounted for 47% of the total BoBLME fish catch and 3% of global fisheries coming from 10% of the BoBLME maritime area of 6.2 million km^2. Sequential fisheries assessments by Fridtjof Nansen Fisheries Research vessels over four decades have shown that in 2015 a combination of factors has led to reduced yields of valuable fish species by 80% while low value, fast-recruiting fish species have increased. A 2011 Transboundary Diagnostic Analysis (TDA), delivered by the Global Environment Facility (GEF) co-funded FAO implemented BoBLME eight-country project, describes the causes for this dramatic reduction in biomass yields. A Strategic Action Programme (SAP) designed to mitigate the problems was endorsed in 2016 and will be implemented in 2019. The area's coastal fishing fleets are 95% artisanal. There is a combined total of 442 species of fish, prawn, shrimp and lobster in the area. The transboundary hilsa (*Tenualosa ilisha*) fishery is the most economically important in both Bangladesh and Myanmar. WorldFish and the DoF (Bangladesh and Myanmar) are currently operating hilsa conservation projects in both countries with the International Institute for Environment and Development (IIED) and USAID funded Enhanced Coastal Fisheries in Bangladesh (ECOFISH) projects. A 2018 FAO-WorldFish fisher folk vulnerability and social protection study has demonstrated the precarious nature of coastal fishers.

Key words: Myanmar, Bangladesh, Productivity, Coastal fisheries, Biomass yields, Hilsa, TDA-SAP, WorldFish, Social protection.

E-mail address: M.Akester@cgiar.org (M. J. Akester)

1. Introduction

This paper describes the current marine fisheries situation in the northeast sector of the Bay of Bengal, ninety percent of which corresponds to Myanmar's EEZ and ten percent to Bangladesh. With the exception of the research carried out by the fisheries research vessel Fridtjof Nansen, the Myanmar sector is largely data deficient due to political reasons. With the onset of a move towards democracy in 2012 and elections in 2015, fisheries research by the Myanmar Department of Fisheries (DoF) and development partners, including the Myanmar Fisheries Federation (MFF) under the Myanmar Fisheries Partnership (MFP), is starting to demonstrate a serious state of decline in the marine fisheries sector. The objectives of this study are to outline the importance of marine fisheries in Myanmar, describe the complexities and challenges of improving management and to highlight ongoing work linked to the forthcoming implementation of an eight-country Strategic Action Program (SAP) designed to mitigate the problems identified during the Transboundary Diagnostic Analysis (TDA) 2009-2012 (GEF-FAO 2012).

2. The geography of the area

Myanmar is the second largest country in Southeast Asia (676,000 km^2) after Indonesia (1,904,569 km^2). It has a coastline of approximately 2200 km from the Naaf River, border with Bangladesh in the north, to Kawthaung at the mouth of Kyan River, border with Thailand in the south (Fig.1). Myanmar's coastal area includes the Ayeyarwady mega delta, which discharges partially into the Gulf of Mottama and through a number of deltaic channels into the northern area of the Andaman Sea. Myanmar's continental shelf covers an area of around 230,000 km^{2}and is divided into three main geographical areas (UN, 2008): 1) a narrow northern area off the Rakhine coast; 2) a broad central area between the Ayeyarwaddy Delta, juxtaposed with the Andaman Sea and 3) the southern Tanintharyi Division adjacent to the Andaman Sea (Figs. 1. and 3). All three areas receive heavy sediment loads from the major rivers in the Bay of Bengal namely the Ganges–Brahmaputra in the north, Ayeyarwady and Thanlwin Rivers in the Delta area, while the Gulf of Mottama receives a combination of all these sediments together with flows from the Salween, Sittaung and Yangon Rivers. As a result, a 45,000 km^2 mud-zone has developed with important biodiversity in the northern area of the Andaman Sea (Ramaswamy and Rao, 2014).

The 300 km stretch of coastline in Bangladesh has similar conditions to those of the northern area of the continental shelf described above.

The surface water in the northeast Bay of Bengal area has a relatively low salinity in the monsoon season May-October: close to the Ayeyarwady Delta and Gulf of Mottama (20-25 ppt) and higher during the dry season at around 34 ppt in the areas 1 and 3 described above. Tidal elevation fluctuations in the Delta area are considerable at 6 m. It also has the largest seasonal sea level fluctuations (−40 cm to +54 cm) anywhere on the earth as a result of variations in the river discharges (Mohanty et al., 2008) and (Vinogradov and Ponte, 2011).

3. Climate

Myanmar and southeast Bangladesh have a monsoonal climate with the southwest monsoon from the Bay of Bengal and Indian Ocean bringing wet weather from May to October. There are two cyclone seasons, lasting around a month each from April to May and then again in October to November – at the start and end of the southwest monsoon period. The last category 4 cyclone to hit Myanmar was Cyclone Nargis in 2008 (Fig. 2). The damage sustained from the resultant storm surge was made worse by mangrove forest depletion as discussed below.

Apart from the immediate negative impacts caused by the destruction from high winds, storm surges, hypoxia in coastal areas (due to organic matter influx from the land by rainfall runoff), cyclones can also have a positive impact on fisheries as they trigger upwelling with nutrient flows to the photic layer and resulting phytoplankton blooms in open ocean areas.

4. Productivity of the continental shelf area

Myanmar's 230,000 km^2 of continental shelf is highly productive due to the upwelling from the nearby deep water ocean 16 to 20°N above the Ayeyarwady Delta, and 10 to 16°N, adjacent to the Andaman Sea where the shelf is at its widest due to the deposition of sediments from the river systems. While the waters are naturally productive, a combination of excessive fishing pressure, Illegal Unreported and Unregulated (IUU) fishing, increasing pollution and climate change are having negative effects on the coastal and offshore fisheries.

Productivity in the area varies seasonally with the highest levels recorded at the end of the dry season in April. These and chlorophyll-a levels have been recently assessed to be 2590 ± 1569 mg C m^{-2} day^{-1} with high concentrations of chlorophyll-a (3.14 ± 2.64 µg L^{-1}), (Thaw, Saw et al., 2017).

The 2015 Nansen study data, shown in Fig. 5, depicts a range of conditions at 5 m depth in Myanmar's coastal waters at the end of the dry season (April 2015, NORAD-FAO). Salinity levels are influenced by the freshwater flow from the delta. Temperature levels are high at around 30°C. Oxygen levels shown in Fig. 5 are low as full saturation of 30 ppt seawater at 30°C would be around 6 ppm. Most of the area has levels of 4 ppm with patches of high phytoplankton abundance being higher at 5 ppm (Fig.6). Fluorescence indicates the amount of phaeophytin in solution, a breakdown product of chlorophyll due to the ageing or grazing of phytoplankton populations. Low values of fluorescence (purple in Fig.5) indicate the presence of healthy phytoplankton cells, whereas high values are evidence of unfavorable growth conditions, low nutrients or high grazing pressure by pelagic fish species (Herbland, 1978).

The most accurate data collected in Myanmar waters over that last 4 decades has been provided by the Dr. Fridtjof Nansen Fisheries Research vessel surveys. Cruises during the pre- and post-southwest monsoon season in 2013 (November) and 2015 (April) showed that the abundance of fish during these periods to be quite different with greater abundance pre-monsoon (end of the dry season). This has been shown elsewhere in areas exposed to seasonal cyclonic wind impacts and high rainfall where pre-cyclone/hurricane fish abundance is higher than post monsoon (Miah et al., 2015). When the Nansen survey of 1980 is compared with those of 2013 and 2015 an 80% reduction of fish standing stocks is demonstrated.

Further evidence for the high productivity in coastal areas can be seen in Fig. 6 where the impact of the two mega-deltas can be seen at the northern and mid northeastern sectors of the Bay of Bengal.

Myanmar Department of Fisheries Statistics published in 2017 for the period 2015-16, report a total marine catch of almost 3 million metric tons (mt) (Table 1). This is 47% of the total BoBLME fish catch and 3% of global fisheries coming from 10% of the BoBLME maritime area of 6.2 million km^2. However, revised figures generated by the FAO in 2017 for the period up to 2014 suggest that the actual level in 2014 was less than half at around 1.1 million mt (Fig.7). This is 18% of the region's catch and 1% of global fisheries. While it is impossible to say what the most recent marine catch level is, due to a mix of statistical 'adjustments' by planners and the 'hidden-harvest' factor (unrecorded landings and transshipments), it is unlikely to be more than 1 million mt. This means that while fish production from the marine sector in Myanmar is still significant, the decline in marine capture fisheries is leading to a replacement from freshwater aquaculture with 34% now coming from this sub-sector – mostly in the form of freshwater carp culture (Figs.7 and 8).

5. Anthropogenic activities and their effects on productivity and marine fish yields

Mangrove forest destruction in Myanmar has been catastrophically high. The removal of the protective mangrove forest exposes the coastline to storm surges generated by either cyclones or tsunamis – both of which are common in the area. Coastal fisheries are damaged due to the loss of spawning and nursery areas within the mangroves.

Over 5% of Myanmar's mangrove forest cover was lost during the period 2000 to 2012 (Richards and Friess, 2016). While this occurred to varying degrees along the entire 2200 km of the coastline, the main losses were along the Rakhine coast (dark oval, Fig.9). The mangrove forest was initially removed to gain areas for rice production. The subsequent salinization of the soils encouraged shrimp farming. Due to the poor planning of the shrimp aquaculture production systems, disease destroyed the shrimp aquaculture industry, which has yet to recover.

The original area of mangrove forest in Myanmar was 320,106 ha in the early 20th century, about 275,000 ha in 2001, and probably consisting of only two-thirds of the cover of 2001 by 2013 according to a GIS assessment by ArcCona. The strong decline in mangrove cover adds to the factors contributing to coastal fish abundance decline (Sasekumar et al., 1992). Myanmar hosts 24 species of mangrove trees of which Rhizophora, Sonneratia, Avicennia, Bruguiera and Xylocarpus spp. are dominant. A list of common brackish water animals associated with mangroves and mangrove waterways, (including 39 species of fish, 11 species of shrimp, 8 species of crab, one Thalassina (mud lobster), 2 oysters, 2 mussels, 1 cockle, 9 gastropods and one Xiphosura (Horseshoe Crab)), was compiled by Htay Aung (1982) in (Zöckler et al., 2013).

In addition to mangrove forest reduction seagrass beds have also been damaged by a range of illegal fishing practices and land-based pollution (Green and Short, 2003).

Air pollution caused by the burning of rice stubble coupled with 'slash and burn' agriculture and industrial pollution has created a seasonal (post-southwest monsoon) brown haze pollution cloud as shown by NASA's Terra satellite in November 2011 (Fig.9). The '*Asian brown cloud*' over the Bay of Bengal has a negative impact on primary productivity at sea level due to the reduction of the photosynthetically active radiation (PAR) (0.4-0.7 μ) (Pandve, 2008).

The reduction in PAR solar energy caused by the *Asian Brown Cloud* has a negative impact on mangrove, seagrass and coral reef productivity in addition to phytoplankton production in coastal areas. The reduced primary productivity, coupled with fishing in excess of the recommended Maximum Sustainable Yield (the case in the northeastern area of the BoBLME) could have an impact on Ocean Tipping Points (Selkoe, 2017; Kelly et al., 2015). "Tipping points occur when small shifts in human pressures or environmental conditions bring about large, sometimes abrupt changes in a system – whether in a human society, a physical system, an ecosystem, or our planet's climate" (http://oceantippingpoints.org/portal/what-are-tipping-points).

The World Bank-funded State of the Basin Assessment (SOBA) studied the Ayeyarwady Basin under six packages implemented by different groups. The overall objective was to provide a scientific-baseline of the socio-cultural, hydroecological and economic systems of the Ayeyarwady and to fill in specific information gaps identified by the stakeholders and will be the foundation for future basin master plan activities. Although this study focuses on the river basin, i.e. inland areas, the status of the basin will have an impact on coastal fisheries. WorldFish and Fauna & Flora International (FFI) implemented Work Package 4: Biodiversity and Fisheries. Findings from FFI showed that in terms of inland areas, "the overall trend in biodiversity is declining across all taxa, mainly illustrated by the absence or loss of a species or species groups". The WorldFish work showed that there are clear signs of fisheries production decline in the delta and that fish resources are threatened by destructive practices (electrofishing, poisoning, habitat destruction). In addition, "Catch per species data are not compiled at the national level, and overall trends among individual species (e.g., hilsa and other high value species) are not available from landing statistics (e.g. top 10 species are known from export statistics, not from landings [Aye et al., 2006])".

The 2017 State of the Basin Assessment (SOBA) included a series of six work packages under the Ayeyarwady Integrated River Basin Management (AIRBM) project. SOBA's objective was to *"deliver a scientific baseline of the socio-cultural, hydro-ecological and economic systems of the Ayeyarwady and fill specific information gaps, identified by stakeholders, to be the foundation for future basin master plan activities*". Of the six work packages, Fauna and Flora International (FFI) and WorldFish covered Biodiversity and Fisheries respectively. The latter highlights a reassessment in 2017 of fisheries catch statistics from the 2003-2014 period (Fig. 7).

In 2011, a GEF and multi-donor Bay of Bengal Large Marine Ecosystem (BoBLME) project, implemented by the FAO, published a Transboundary Diagnostic Analysis (TDA) describing the LME's productivity and the reasons behind the decline in marine fisheries (GEF-FAO BoBLME project http://www.boblme.org/transboundary_diagnostic_analysis.html). These included mangrove destruction; atmospheric, land and sea pollution; open access to fishing grounds; government targets for increased fish catches; increasing demand for fish and fishmeal for (direct and indirect human consumption); overfishing and illegal unreported and unregulated (IUU) fishing. The main observation being that there is clear evidence of overexploitation of living marine resources. The core issues include:

- A decline in the overall availability of fish resources
- Changes in species composition of catches
- High proportion of juvenile fish in the catch
- Changes in marine biodiversity, especially through loss of vulnerable and endangered species

Illegal and destructive fishing practices are high on the list of contributing factors. On 5 June 2016, the Port State Measures Agreement (PSMA), the world's first international treaty designed specifically to tackle illegal, unreported and unregulated fishing, came into effect. Myanmar acceded to the treaty on 22 November, 2010; Bangladesh has yet to do so (FAO

http://www.fao.org/fileadmin/user_upload/legal/docs/037s-e.pdf).

Overexploitation leading to the reduction of biodiversity in this biodiverse area could lead to an ecosystem tipping point as described above. Selkoe et al. (2017) developed a set of seven principles to guide effective management in ecosystems with tipping points. "These principles are based on observations that tipping points: (1) are possible everywhere, (2) are associated with intense and/or multifaceted human use, (3) may be preceded by changes in early-warning indicators, (4) may redistribute benefits among stakeholders, (5) affect the relative costs of action and inaction, (6) suggest biologically informed management targets, and (7) often require an adaptive response to monitoring. Early action to preserve system resilience is likely more practical, affordable, and effective than late action to halt or reverse a tipping point" (Selkoe et al., 2017).

In addition, Integrated Ecosystem Assessments (IEA) (Fig. 13) will be a useful tool to use during the implementation of the forthcoming Strategic Action Program (SAP) for the BoBLME area - especially the northeastern sector referred to in this text - as there is a scarcity of information available for the region. The SAP is designed to put into effect a series of activities to mitigate the problems identified during the TDA process to ensure that:

- Fisheries and other marine living resources are restored and managed sustainably
- Degraded, vulnerable and critical marine habitats are restored, conserved and maintained
- Coastal and marine pollution and water quality are controlled to meet agreed standards for human and ecosystem health
- Social and economic constraints are addressed, leading to increased resilience and empowerment of coastal people

A value chain analysis and competitiveness strategy for the marine capture fisheries sector in Myanmar carried out by the International Labor Organization (ILO, 2015) refers to the rich biodiversity in Myanmar waters with more than 442 species of fish, prawn, shrimp and lobster in the EEZ. Out of 442 species recorded, 80 species are considered commercially important. These include sixty-three species of fish, five species of prawn and shrimp, two species of lobster, three species of shark, three species of ray, and one species of squid. Some of the most commercially important species of demersal and pelagic fish in Myanmar are the sea catfish (*Nemapteryx caelata*), trevally/scad (*Alepes melanoptera*), snapper (*Lutjanus bengalensis*), goatfish (*Parupeneus indicus*), sea eel/pike conger (*Muraenesox cinereus*), black bream (*Acanthopagrus berda)*, threadfin (*Leptomelanosoma indicum*), grunt (*Batrachoididae*), croaker/drum (*Johnius dussumieri*), mackerel (*Rastrelliger kanagurta*), grouper (*Epinephelus fasciatus*), pomfret (*Trachinotus blochii*), lizard fish (*Saurida tumbil*), and small-head hair tail (*Eupleurogrammus muticus*) together with a range of other pelagic fish Herring shad (*Alepes vari*) and Anchovy (*Stolephorus* *indicus*). Hilsa shad (*Tenualosa ilisha*) is the most economically important marine capture fishery product. It is the top marine export and popular in the local markets.

WorldFish and partners are working in the northeast Bay of Bengal (both Bangladesh and Myanmar) to protect the transboundary hilsa fisheries. The first project: the USDAID funded Enhanced Coastal Fisheries Bangladesh (ECOFISH^{BD}) has been in operation since 2014 and is being implemented by nine strategic partners (WorldFish, Bangladesh). The project is studying the hilsa distribution patterns, migration routes and breeding sites in Bangladesh in addition to setting up social protection systems for fisher folk when they are unable to fish during the closed season.

In Bangladesh, it is illegal to catch, carry or sell juvenile hilsa (jatka) from November 1 to June 30 or catch female hilsa during the breeding season, usually September and October. This ban was introduced by the government in 2011 to protect fragile stocks of hilsa, the country's national fish. Results have been encouraging as landing volumes are increasing while close season fishing bans are being maintained by 279 hilsa conservation groups formed in 81 villages since 2015. The project aims to have enabled 20,000 households to be involved in conserving hilsa by 2019. Access to micro-credit has helped fisher folk establish alternative livelihoods like vegetable production and livestock rearing during the hilsa close season.

In Myanmar, WorldFish is carrying out similar work on a Darwin Initiative-funded project designed by the International Institute for Environment and Development (IIED). The research started in 2017 and is currently carrying out a baseline survey of fisher folk active in the hilsa fishery. In 2018, eight hundred households participated in Focused Group Discussions (FDG) and Key Informant Interviews (KII) carried out by the Network Activities Group (NAG). At the same time, scientists from Yangon University undertook gonadosomatic index (GSI) studies on hilsa populations in the Ayeyarwady Delta. Associated work funded by the Australian Centre for International Agricultural Research (ACIAR) is looking at the cost effectiveness of installing fish passes on the river systems in Myanmar to allow hilsa to pass tidal barrages on the Ayeyarwady River channels. One of the key aims is to ensure the hilsa are able to migrate to their spawning grounds upstream and the juveniles can return to the sea. Otolith studies look at changes in the otolith chemistry used as spawning indicators, as reproduction triggers variations in otolith metal chemistry (Zn/Ca ratios in female fish), which could be used as retrospective spawning indicators (Sturrock et al., 2015).

A recent study funded by the FAO and implemented by WorldFish and partners (WorldFish-FAO in press, 2018) looked at several fishing communities in the Ayeyarwady Delta. Two of these communities were in Labutta District in the extreme south of the Delta (Fig.15). Approximately half of the labour force are full-time fishers targeting a range of species including the anadromous hilsa (Fig. 16). Both villages have similar vulnerabilities relating to storms and floods resulting in loss of boats, fishing gear in addition to potable water scarcity and associated diarrhea problems. The 2008 cyclone Nargis devastated the villages: Ah Ya Taw lost 66% of its people and Yaw Twin Seik lost 75%. UNDP revolving funds supported some fishers post-Nargis, however most are dependent on traditional moneylenders and village fish collectors (cover the costs of fishing trips and receive the product at a low but guaranteed price). The problem with these low prices is that this will lead to increased fishing effort thereby risking the depletion of natural resources locally.

Recommendations from many sources in relation to the conservation of the hilsa stocks call for a reduction in fishing effort, enforcement of close seasons and mesh sizes, sanctuaries at spawning sites, spawning runs open (including fish passes at tidal barrages) and a national (multi-national) hilsa management plan. A recent SEAFDEC meeting (13-14 March 2018) recommended the use of thematic maps to indicate the species' migration and spawning areas in the Bay of Bengal (SEAFDEC, 2018).

6. Summary

The northeast sector of the Bay of Bengal is a naturally productive system historically generating a rich abundance of biodiverse fish stocks. Anthropogenic impacts on the area have led to an 80% decline in commercial fish stocks from the 1980ies to 2015 and an ecosystem affected by reduced primary productivity and increasing land-based pollution. A large and growing oxygen minimum zone (OMZ) (Bristow et al., 2017) in the center of the Bay of Bengal is currently not causing nutrient loss in the form of nitrogen (unlike other OMZs globally). However, Bristow et al. (2017) note that, if minimal traces of oxygen currently measurable in the OMZ are removed, nitrogen loss could accelerate. The latter could be instrumental in pushing areas of this Large Marine Ecosystem into a 'tipping point' with further disastrous impacts on productivity and biomass yields.

The future of fisheries in the area under reference depends on the commitment of the eight countries with an EEZ in the Bay of Bengal area and their combined impact on the area beyond national jurisdiction (ABNJ): Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka, and Thailand. The main threats come from IUU fishing and overfishing coupled with inadequate Monitoring Control and Surveillance (MCS) systems. Many of the commercial fish stocks in the area are migratory and thereby impacted by events of a transboundary nature, often linked to poor fisheries management capacity. A 2018 draft policy brief on Capacity Building as a Key Aspect of a New International Agreement on Marine Biodiversity Beyond National Jurisdiction (BBNJ), has been produced by a multi-institutional effort, led by the GEF/FAO/GOF (Global Ocean Forum 2018). This instrument is designed to "assist discussions at the Intergovernmental Conference on the development of an international legally binding instrument under The United Nations Convention on the Law of the Sea (UNCLOS) on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (BBNJ)" (Global Ocean Forum). Regarding comments earlier in this paper on anthropogenic impacts, often land-based, the broader ecosystem considerations for the northeast sector of the Bay of Bengal relate to the serious risk of regime shifts. The latter is likely to increase the current trend of biodiversity reduction and commercial species decline. An increase in cnidarian (jellyfish) populations, due to a reduction in predators (tuna and turtles) and increased zooplankton availability due to planktivorous fish population reductions, is also likely. The socio-economic impacts of these changes are already being seen in Myanmar where there is a shift towards increased freshwater fish production from aquaculture to satisfy increasing demand for fish at same time that marine fish landings are in decline. Benefits in the marine sector will come from ecosystem-based fisheries management coupled with the trend towards co-managed fisheries and associated no take areas.

Although the area is data deficient, there are currently a number of research projects in operation in the area including catch data collection in southern Rakhine State by the Wildlife Conservation Society (WCS, 2018). WCS also has data from fisher logbooks, trader invoices, length-weight surveys over the last two years and are preparing for publication. IUCN, FFI, WWF, EDF, IIED, WorldFish, bi-lateral and multi-lateral donors under the Myanmar Fisheries Partnership, led by the Department of Fisheries, are all working to address the absence of data in the northeast of the Bay of Bengal over the last half century.

Acknowledgements

The author would like to thank Dr. Kenneth Sherman and his team at the National Oceanic and Atmospheric Administration (NOAA) Northeast Fisheries Science Center, Narragansett Laboratory for the continued support to the wellbeing of the world's Large Marine Ecosystems and the millions of small-scale fisher folk who depend on these once highly productive fishing areas. In addition, we express our gratitude for the funding provided to WorldFish Myanmar by:

1) The Darwin Initiative for the research entitled: *'Carrots and sticks: incentives to conserve hilsa fish in Myanmar'*;

2) The FAO for the research project: *'A participatory vulnerability study to assess the state of social protection and poverty dimensions in the Myanmar fisheries sector'*; and

3) The Australian Centre for International Agricultural Research (ACIAR) for the project: FIS/2015/046 *'Improving fishery management in support of better governance of Myanmar's inland and delta fisheries'*, which also looks at leased areas for hilsa fishing.

References

Baran, E. et al., (2017) Fisheries in the Ayeyarwady Basin. Ayeyarwady State of the Basin Assessment (SOBA) Report 4.1. National Water, Resources Committee (NWRC), Myanmar. http://airbm.org/downloads/SOBA/SOBA%204.1%20Fisheries%20report_2017_F.pdf Accessed 14 August 2018.

Bristow, L. et al., (2017) N2 production rates limited by nitrite availability in the Bay of Bengal oxygen minimum zone. Nature Geoscience. https://doi.org/10.1038/NGEO2847

FAO Agreement on port state measures to prevent, deter and eliminate illegal, unreported and unregulated fishing. http://www.fao.org/fileadmin/user_upload/legal/docs/037s-e.pdf Accessed 14 August 2018.

GEF-FAO BoBLME project (2012) http://www.boblme.org/transboundary_diagnostic_analysis.html Accessed 14 August 2018.

Global Ocean Forum (2018) https://globaloceanforum.com/2018/04/16/policy-brief-on-capacity-building-as-a-key-aspect-of-a-new-international-agreement-on-marine-biodiversity-beyond-national-jurisdiction-bbnj/ Accessed 14 August 2018.

Green, E.P & Short, F., (2003). *World Atlas of Seagrasses*. UNEP-WCMC, Cambridge, UK and University of California Press, Berkeley.

Herbland A., (1978). The soluble fluorescence in the open sea: Distribution and ecological significance in the equatorial Atlantic Ocean, Journal of Experimental Marine Biology and Ecology, Elsevier.

Hermes R., (2010). Bay of Bengal Large Marine Ecosystem: Project Overview, "Community-based Integrated Coastal Management: Best Practices and Lessons Learned", IUCN Ecosystems and Livelihoods Group, Colombo, Sri Lanka, 28-29 July 2010

Thaw, Saw et al., (2017) Seasonal dynamics influencing coastal primary production and phytoplankton communities along the southern Myanmar coast. Journal of Oceanography. 73. DOI: 10.1007/s10872-016-0408-7

ILO, (2015) Value chain analysis and competitiveness strategy: marine capture fisheries: Myeik and Yangon, Myanmar / International Labour Organization, ILO Liaison Officer for Myanmar. - Yangon: ISBN: 9789221300311; 9789221300328 (web pdf) https://www.ilo.org/wcmsp5/groups/public/---ed_emp/---emp_ent/documents/publication/wcms_446510.pdf Accessed 14 August 2018.

Islam, M.M., et al., (2018). Social Considerations of Large River Sanctuaries: A Case Study from the Hilsa Shad Fishery in Bangladesh. Sustainability 2018, 10, 1254.

Kelly R. P., et al., (2015). How Not to Fall Off a Cliff, or, Using Tipping Points to Improve Environmental Management, 41 Ecology L. Q. 843

Aye., et al., (2006). Inland Fishing Gear and Method in Southeast Asia: Myanmar. Southeast Asia Fisheries Development Centre, Training Development, Thailand, 184 pp. (11) Socioeconomics and Livelihood Values of Setse and Kyaikkhami Coastal Areas in the Thanlwin River Mouth.

http://www.seafdec.org/download/inland-fishing-gear-and-methods-in-southeast-asia-myanmar/ Accessed 14 August 2018.

S. R., Kiran, (2017). General Circulation and Principal Wave Modes in Andaman Sea from Observations, Indian Journal of Science and Technology 10(24). Available at SSRN: https://ssrn.com/abstract=3002048

Levin PS, Möllmann C. (2015). Marine ecosystem regime shifts: challenges and opportunities for ecosystem-based management. Phil. Trans. R. Soc. B 370: 20130275. http://dx.doi.org/10.1098/rstb.2013.0275

Miah MNU, Shamsuzzaman MM, Harun-Al-Rashid A, Barman PP (2015) Present Status of Coastal Fisheries in Sitakunda Coast with Special Reference on Climate Change and Fish Catch. J Aquac Res Development 6: 362. doi:10.4172/2155-9546.1000362 https://www.omicsonline.org/open-access/present-status-of-coastal-fisheries-in-sitakunda-coast-with-special-reference-on-climate-change-and-fish-catch-2155-9546-1000362.pdf Accessed 14 August 2018.

Mohanty P.K., et al., (2008) Sediment Dispersion in the Bay of Bengal. In: Mohanty P.K. (eds) Monitoring and Modelling Lakes and Coastal Environments. Springer, Dordrecht.

NORAD - FAO PROJECT GCP/INT/003/NOR CRUISE REPORTS "DR. FRIDTJOF NANSEN" EAF-N/2013/9 http://www.boblme.org/documentRepository/Nansen%20ecosystem%20survey%20Myanmar%2013%20November%20-%2017%20December%202013.pdf Accessed 14 August 2018.

Pandve HT., (2008) The Asian brown cloud. Indian Journal of Occupational and Environmental Medicine;12:93-5. http://www.ijoem.com/text.asp?2008/12/2/93/43269 Accessed 14 August 2018.

Ramaswamy V. and P. S. Rao (2014), Geological Society, London, Memoirs, 41, 231-240, 2014, https://doi.org/10.1144/M41.17 Chapter 17 The Myanmar continental shelf.

Richards D. R. and Friess D.A., (2016). Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. Proceedings of the National Academy of Sciences of the United States of America. 2016;113 (2):344-349. https://doi.org/10.1073/pnas.1510272113

Sasekumar, A.; Chong, V.C.; Leh, M.U. & D'Cruz, R. (1992), Mangroves as a habitat for fish and prawns. Hydrobiologia, 247, 195-207. https://link.springer.com/chapter/10.1007/978-94-017-3288-8_21 Accessed 14 August 2018.

SEAFDEC-Sweden Project convened the "Technical Experts Meeting on Management of Transboundary Species for Northern Andaman Sea" on 13-14 March 2018 in Bangkok, Thailand http://www.seafdec.org/cooperation-for-the-management-of-transboundary-species-in-the-northern-andaman-sea-myeik-archipelago/ Accessed 14 August 2018.

Selkoe K.A., (2017). Ocean Tipping Points (OTP), Photosynthetically Active Radiation (PAR) Average Annual Maximum Anomaly, 2002-2013 – Hawaii.

http://www.pacioos.hawaii.edu/metadata/hi_otp_all_par_anom_freq.html Accessed 14 August 2018.

Selkoe K.A. et al., (2017). Principles for managing marine ecosystems prone to tipping points https://doi.org/10.1890/EHS14-0024.1

Sturrock, A. et al., (2015). Quantifying physiological influences on otolith microchemistry. Methods in Ecology and Evolution. https://doi.org/10.1111/2041-210X.12381

UN, 2008 Continental Shelf Submission of the Union of Myanmar December 2008 http://www.un.org/depts/los/clcs_new/submissions_files/mmr08/mmr_es.pdf Accessed 14 August 2018.

Vinogradov, S.V., and R.M. Ponte, (2011): Low-frequency variability in coastal sea level from tide gauges and altimetry. Journal of Geophysical Research, 116, C07006, https://doi.org/10.1029/2011JC007034

Wildlife Conservation Society (WCS), (2018). https://myanmar.wcs.org/ Accessed 14 August 2018.

WorldFish – FAO (2018) in press. Participatory Rural Appraisal and Vulnerability Study of Ayeyarwady Delta fishing communities and social protection opportunities.

WorldFish Bangladesh https://www.worldfishcenter.org/pages/protecting-hilsa-bd/ Accessed 14 August 2018.

Zöckler, C. Delany, S. & Barber, J. (2013). Scoping Paper: Sustainable Coastal Zone Management in Myanmar. ArcCona Ecological Consultants, Cambridge, UK.

http://www.lighthouse-foundation.org/fileadmin/LHF/PDF/Myanmar_-_Scoping_Paper_Myanmar_Coastal_Zone_Management_211113_96dpi.pdf Accessed 14 August 2018.

Figures

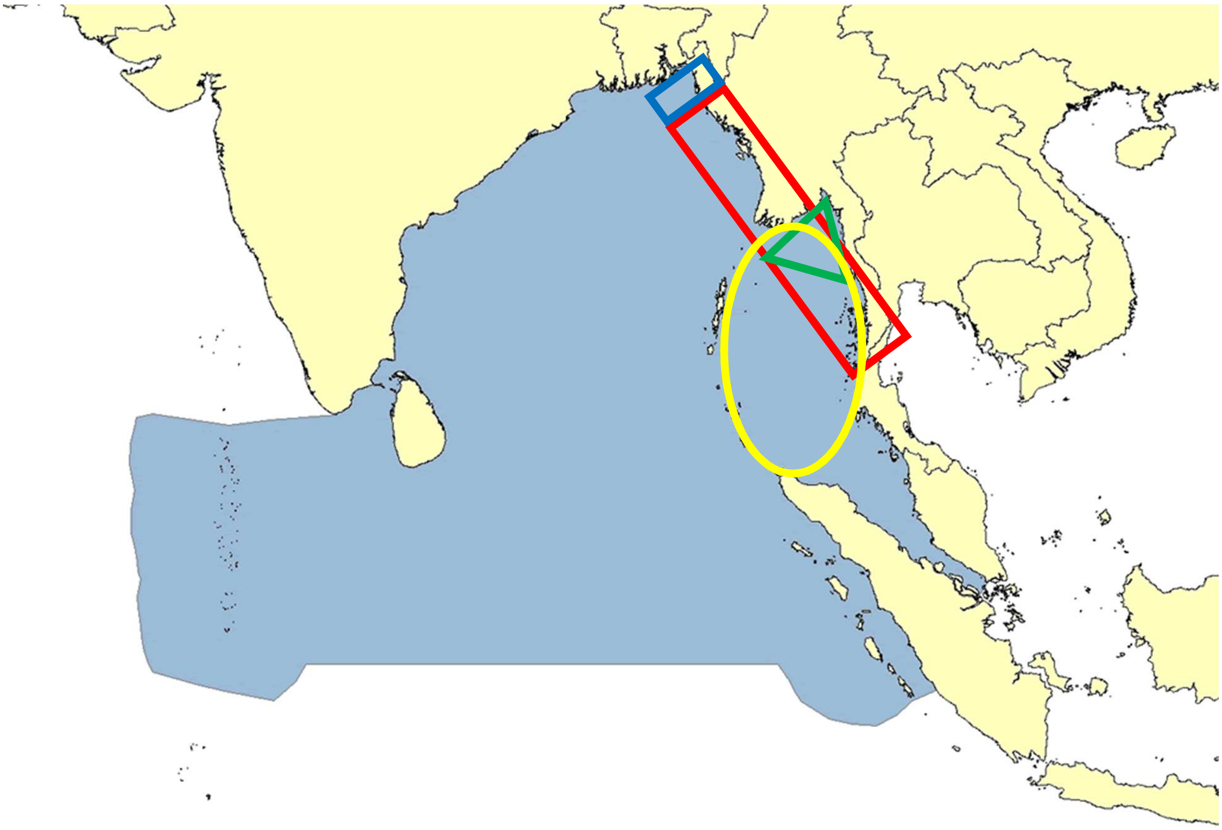
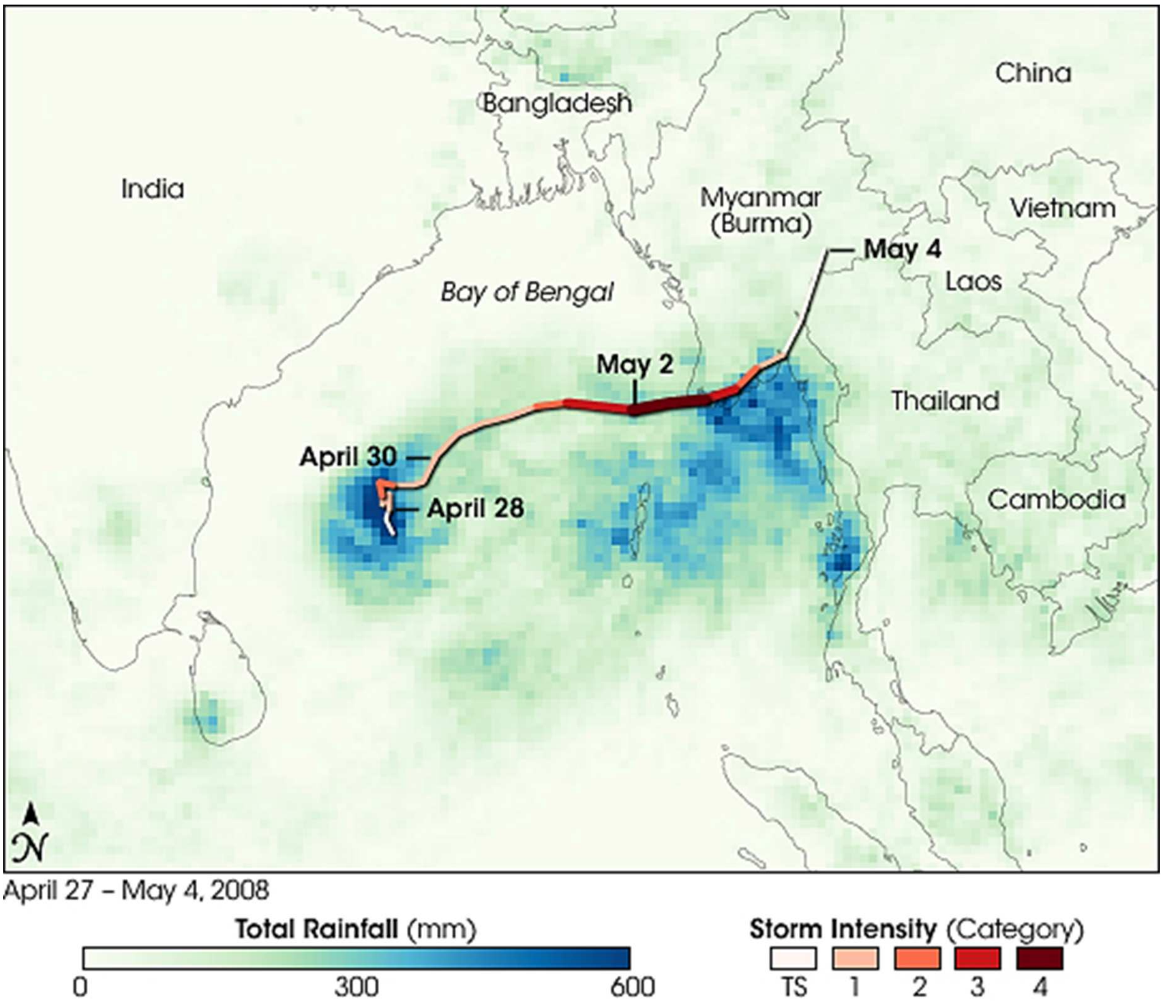
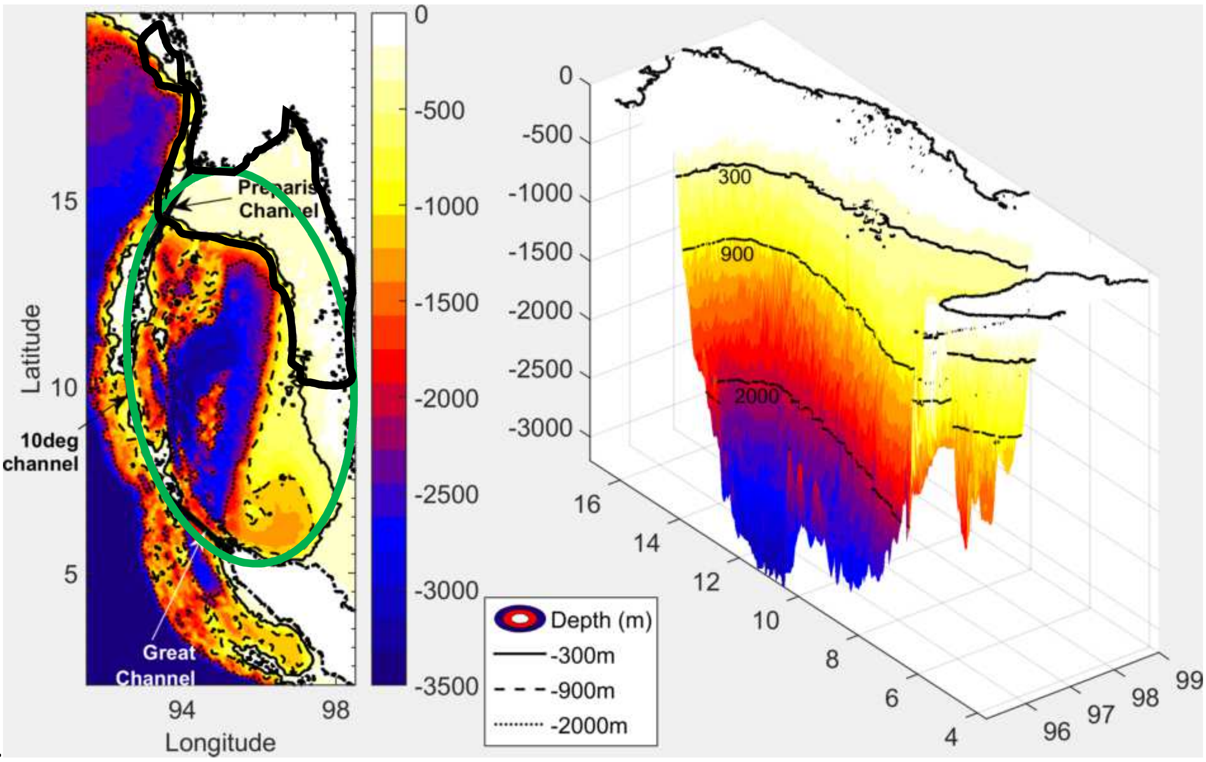


Fig. 1. The northeast coastal waters of the Bay of Bengal Large Marine Ecosystem correspond to the 2200 km of the Myanmar (Burma) coastline – area long and short rectangles (Hermes, 2010). The area in Bangladesh waters are depicted in the small rectangle. The Gulf of Mottama is shown as a triangle and the Andaman Sea boundary is outlined in the light oval.



Fig, 2. Track of Cyclone Nargis, May 2008. Image credit: NASA/Jesse Allen, using data provided by the TRMM science team.



.

Fig. 3. The Andaman Sea basin (light oval) showing shallow Myanmar coastal waters to a maximum of 300 m south of the Ayeyarwady Delta (area demarcated by dark continuous line), (Kiran, 2017).

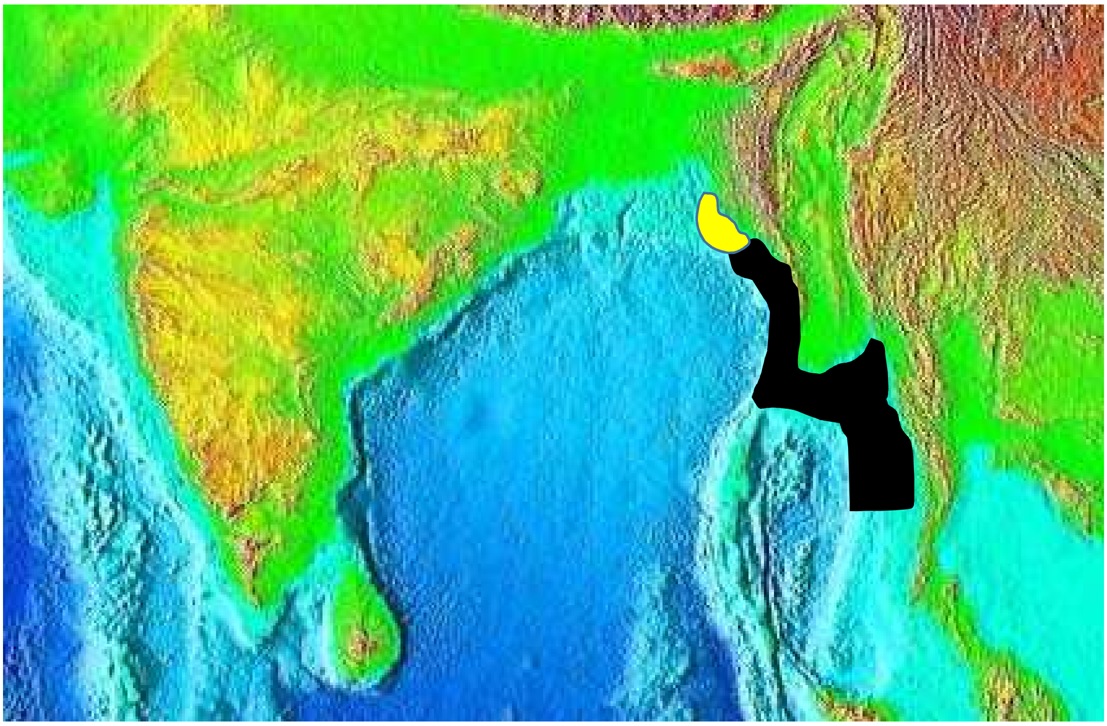


Fig. 4. Dark area highlight indicating that in the Bay of Bengal most of the continental shelf area is within the 200-nautical mile EEZ corresponding to Myanmar. A smaller area corresponds to Bangladesh (light area) Image source http://www.ngdc.noaa.gov/mgg/image/2minrelief.html

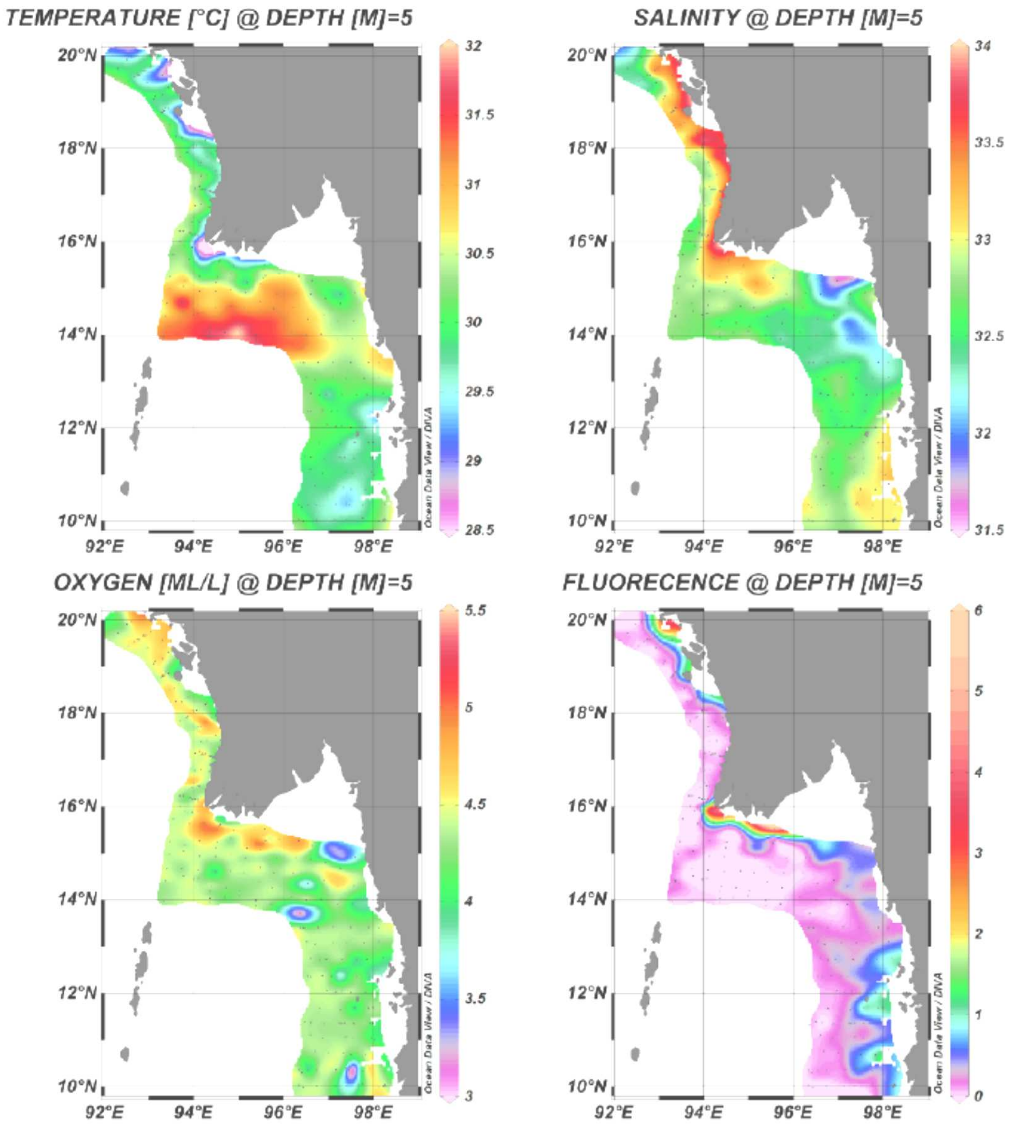


Fig. 5. Dry season horizontal near-surface (5 m depth) distributions of temperature, salinity, oxygen and fluorescence for the whole Myanmar coastal area. Figure from the NORAD-FAO Project GCP/INT/003/NOR: Cruise reports 'Dr. Fridtjof Nansen' EAF – N/2015/4.

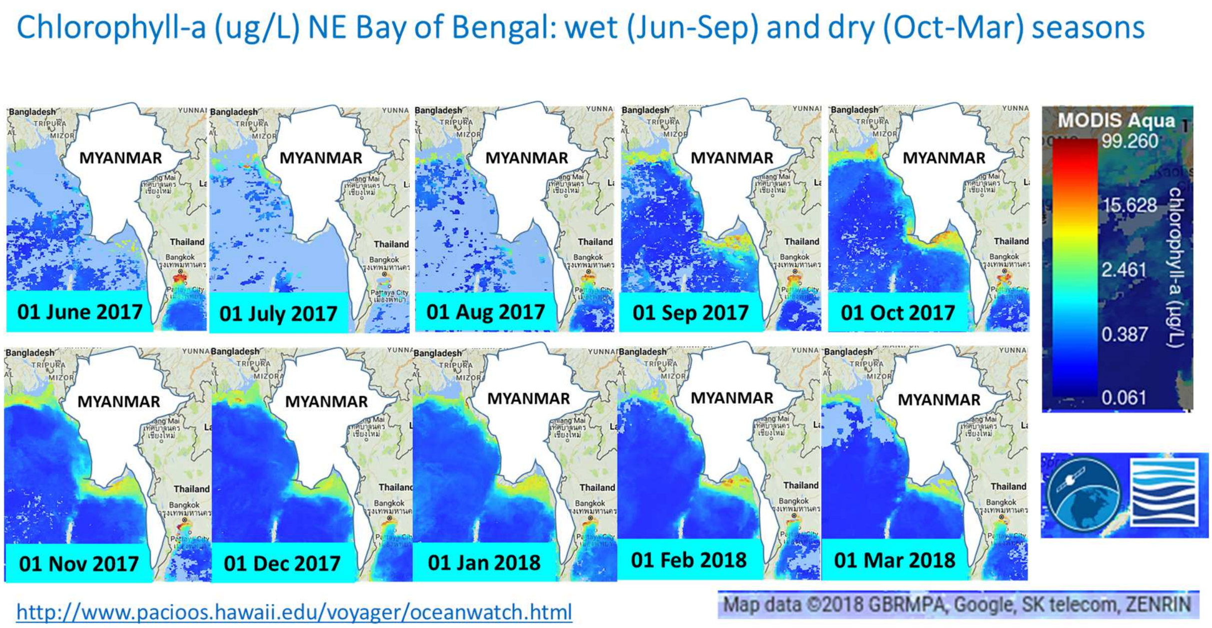


Fig. 6. PACIOOS 'Oceanwatch' satellite data showing chlorophyll-a levels (light areas on dark ocean background) from the wet to the dry season.

Table 1. Myanmar Department of Fisheries statistics published in 2017 [thousand metric ton]

Year	Total	Aquaculture	Leasable Fisheries	Open Fisheries	Marine Fisheries
2014-2015	5316.95	999.63	315.36	1147.76	2854.20
2015-2016	5591.83	1014.42	338.69	1241.98	2996.74

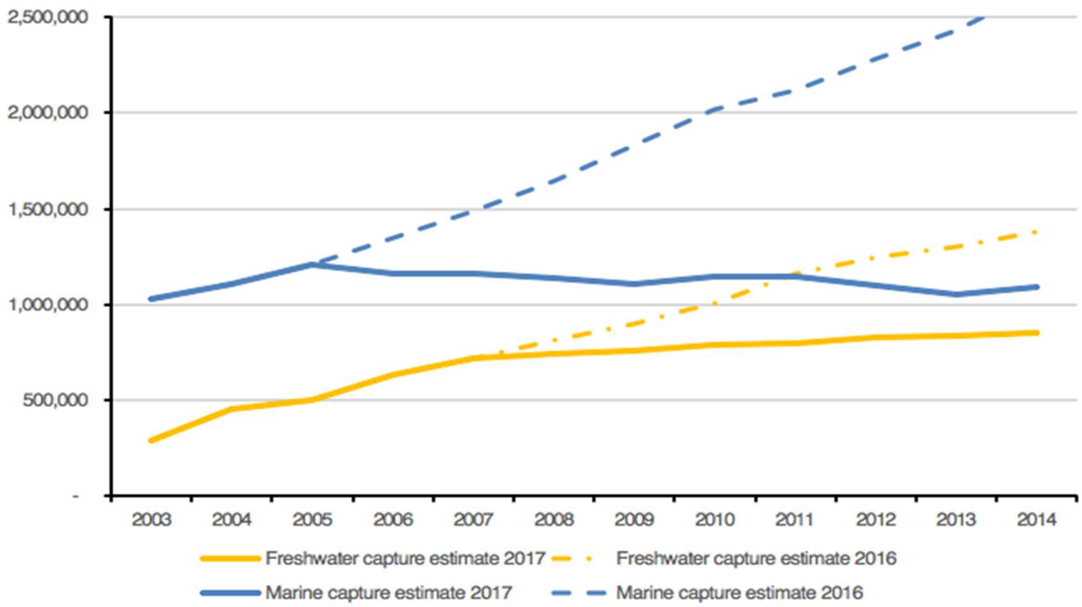


Fig. 7: Reassessment in 2017 of catch statistics from the 2003-2014 period (FAO FIGIS data in November 2016 (dotted lines) and September 2017 (plain lines). Source: National Water Resources Committee (NWRC), Ayeyarwady State of the Basin Assessment (SOBA) report - 4 'Fisheries in the Ayeyarwady Basin' prepared by Eric Baran et al. (2017).

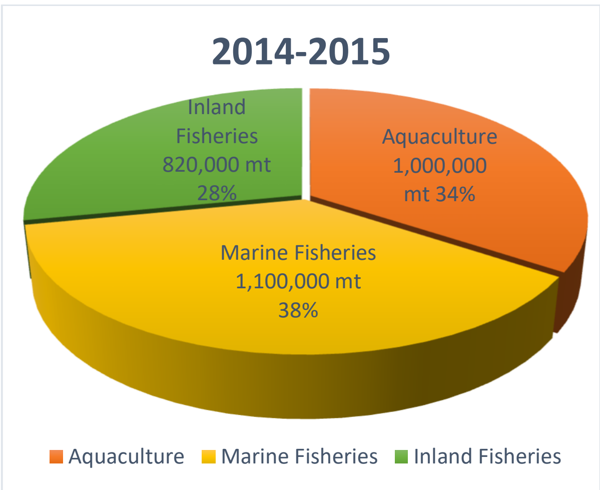


Fig. 8. Adjusted Myanmar DoF fish production figures for the period 2014-2015 showing the production from marine fisheries and the importance of both freshwater fisheries and aquaculture.

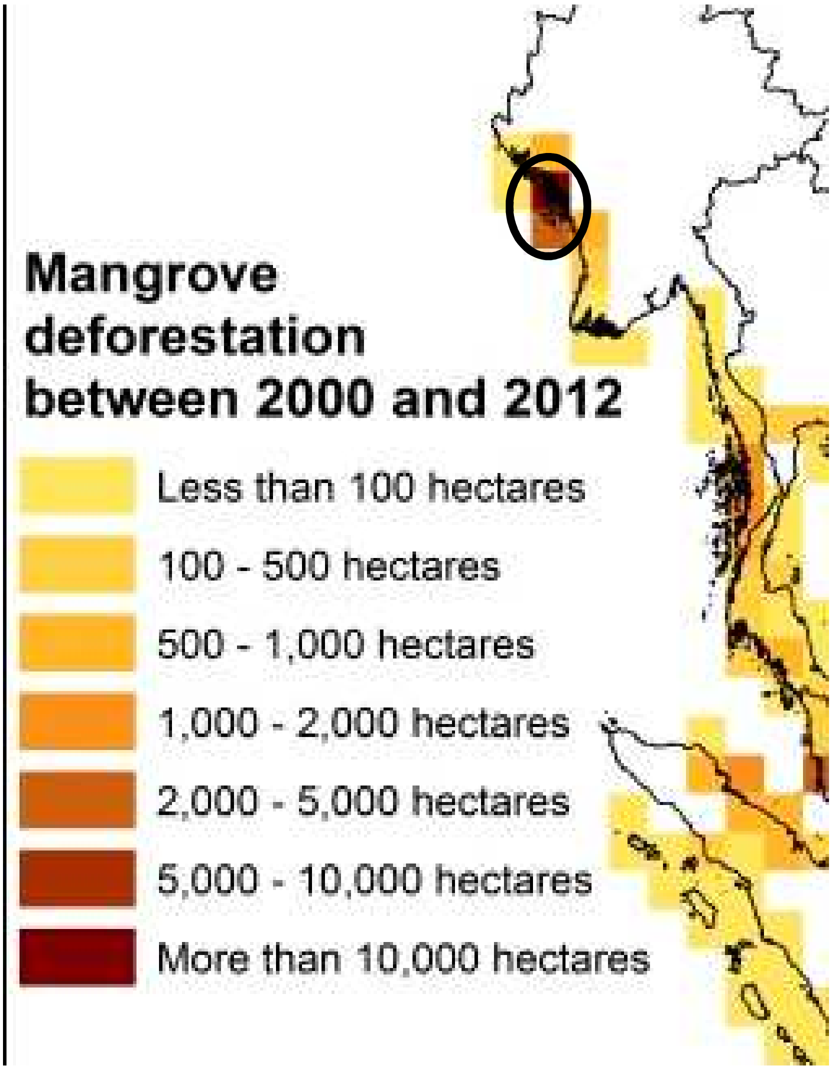


Fig. 9. Mangrove destruction along the coast of Myanmar over the period 2000 to 2012. The dark oval indicates the area of central Rakhine state where a combination of rice and subsequently shrimp farming removed more that 5% of the mangrove cover.

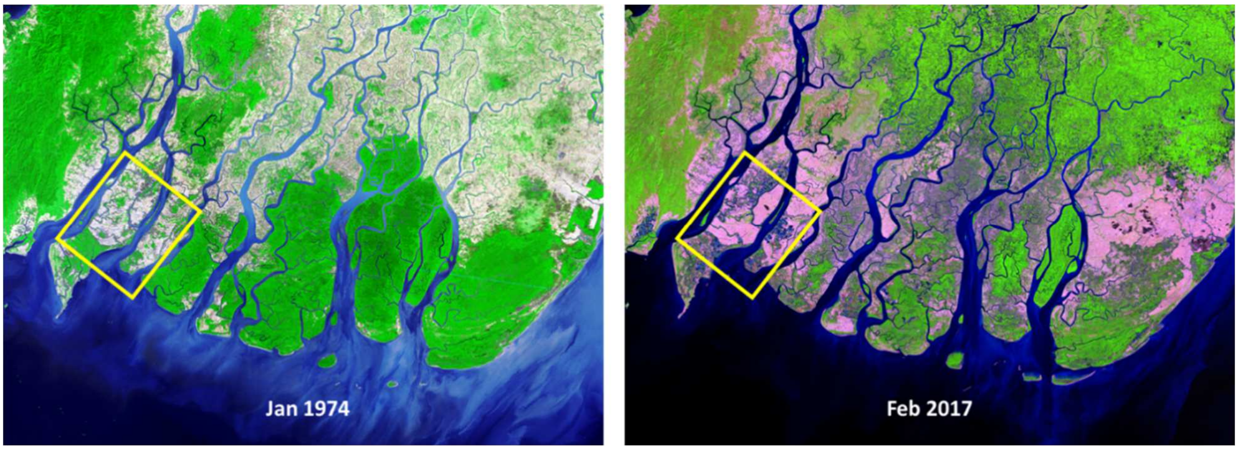


Fig 10. Mangrove forest destruction over a 43-year period in the lower Ayeyarwady Delta (Source USGS Landsat). The light rectangle shows the area of detail in Fig. 10 – Labutta Township.

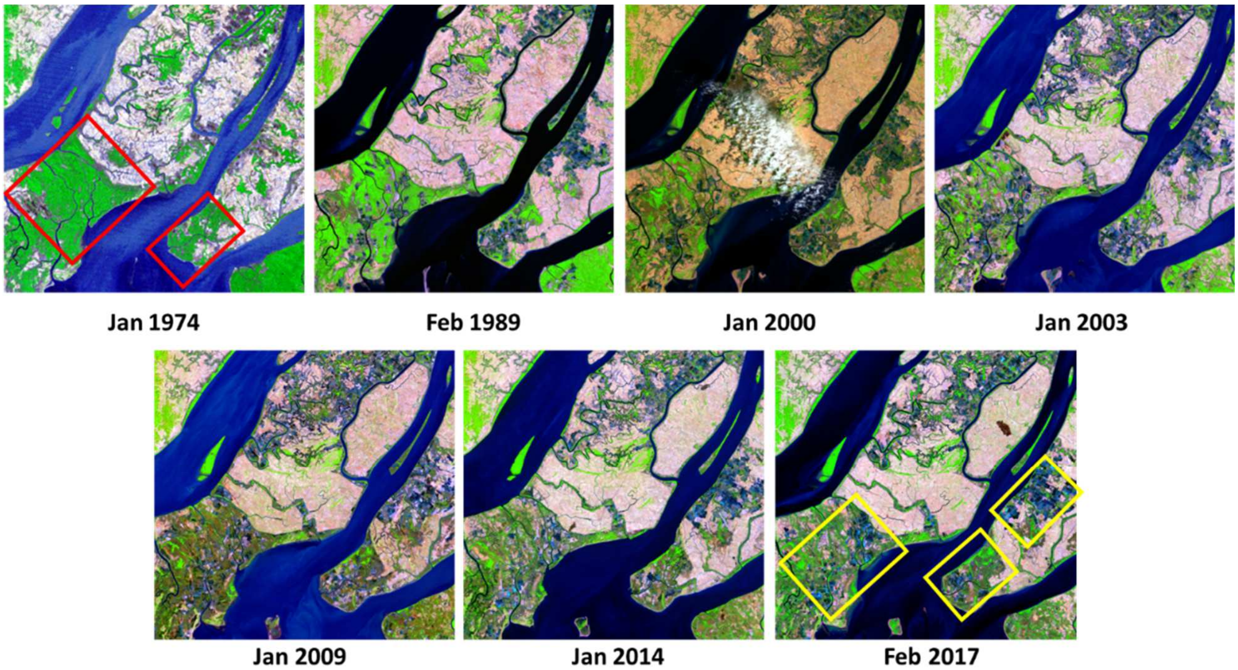


Fig. 11. Mangrove forest removal over a 43-year period and shrimp pond increase (light rectangles) in Labutta Township Ayeyarwady Division. Source USGS https://earthshots.usgs.gov/earthshots/node/67#ad-image-4-4

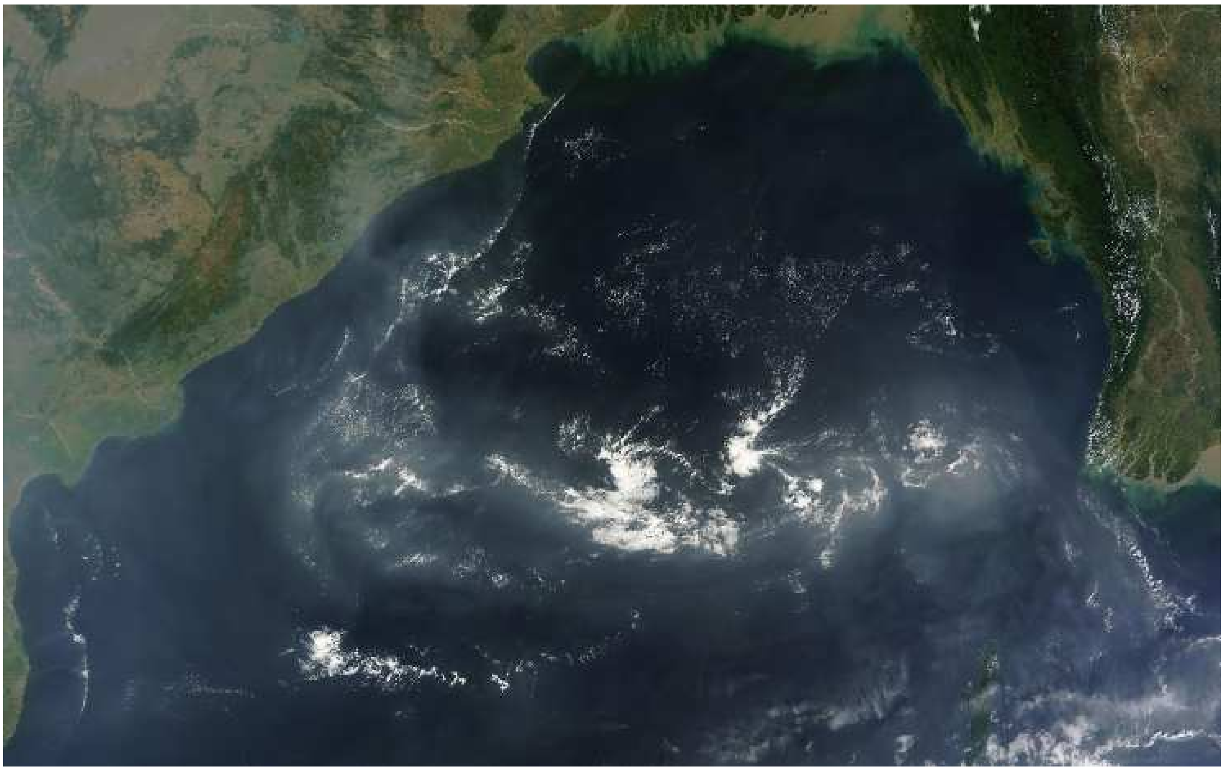


Fig. 12. The Asian brown cloud over the Bay of Bengal from India to Myanmar. NASA image courtesy LANCE/EOSDIS MODIS Rapid Response Team at NASA GSFC.

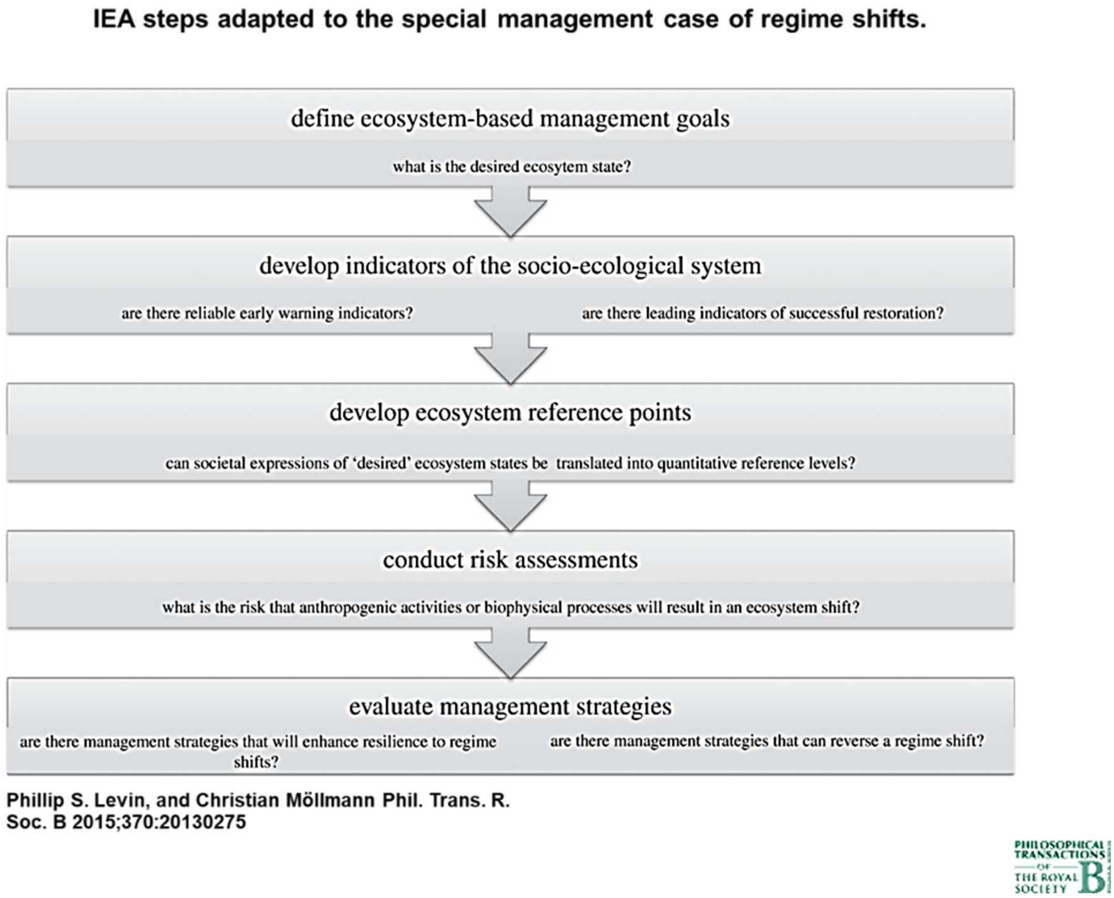


Fig. 13. Using the IEA process to organize a framework for incorporating regime shift theory and observations into management practice (Levin and Möllman, 2014**).**

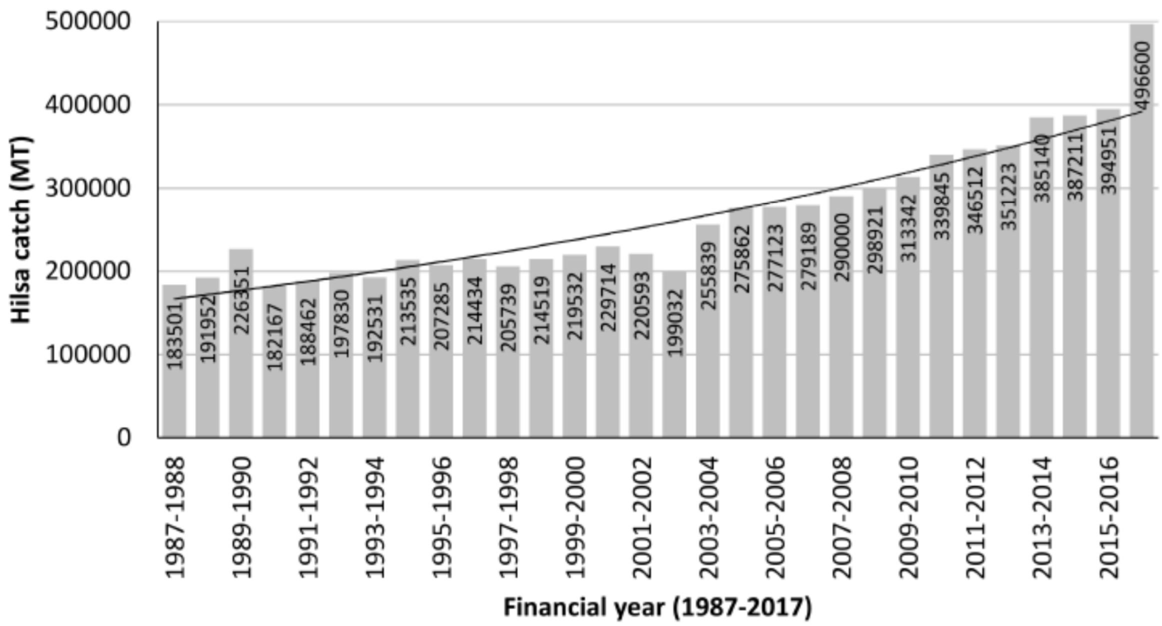


Fig 14. Increasing trend of hilsa production after hilsa management action plan introduced in 2003. (Islam M.M., et al., 2018).

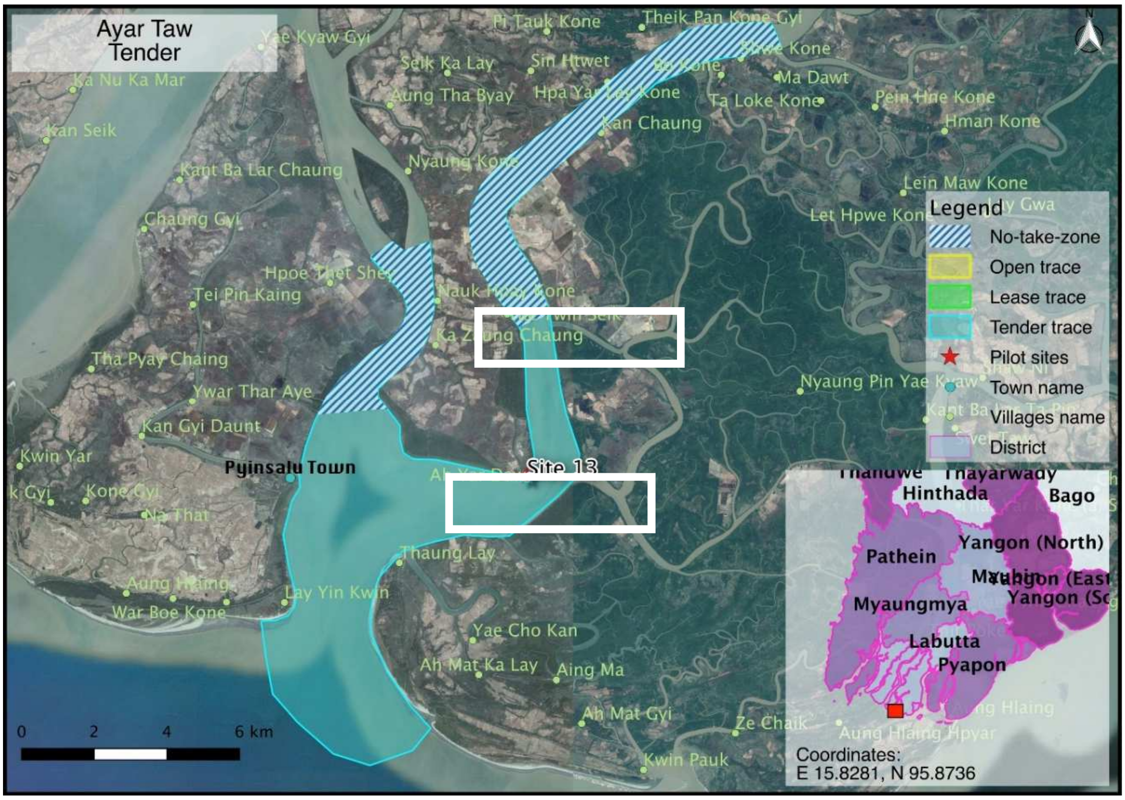


Fig. 15. Ah Ya Taw and Yae Dwin Seik villages (light rectangles) in the Labutta District in the Ayeyarwady Region.

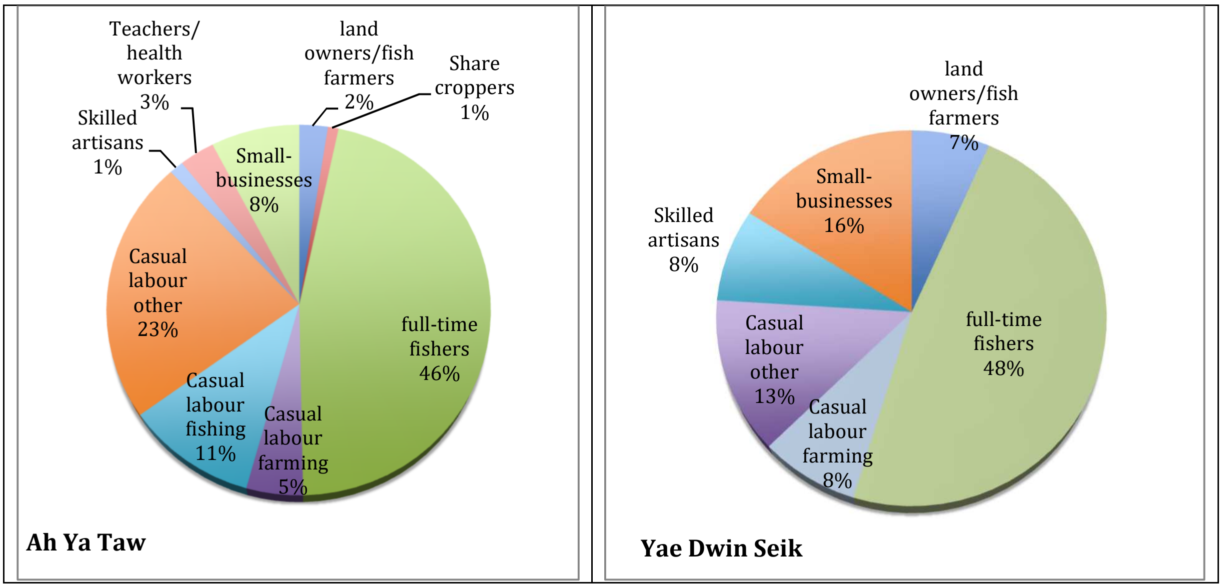


Fig. 16. Ah Ya Taw and Yae Dwin Seik villages labour distribution January 2018. Source FAO WorldFish