Best Practices for Science-based Management of Swimming Crab Fisheries: Application to Indonesia's Blue Swimming Crab Fisheries

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Summary

The *Portunus pelagicus* (blue swimming crab) fishery is of major economic significance in Indonesia. It is the country's third most important export fishery product after tuna and shrimp, contributing $308,827,461(USD) to the national GDP, and employing about 90,000 fishermen and 185,000 pickers.[1] Unfortunately, Catch Per Unit Effort (CPUE) and observed maximum length have declined in recent years. These declines do not only suggest economic losses but also indicate a decline in stock status.

Several indicators of stock and fishery status, based on independent data streams to corroborate results, along with reference points, will be necessary to improve management by transitioning to science-based management. The Lampung BSC Management Plan articulates Spawning Potential Ratio (SPR) as an indicator of stock status. This paper reviews case studies to compare SPR reference points used to manage *Portunus pelagicus* and other crab species across the world with a focus on spawning potential ratio.

We found that while few crab fisheries do so currently, there appears to be a trend toward using SPR as a stock status indicator. However, there is a paucity of empirical information on how different SPR reference points may affect fishery performance. In the cases examined, SPR reference points are extrapolated from studies of finfish in temperate waters and adjusted using expert judgement (mainly by adjusting target levels downward, allowing higher exploitation rates, to account for the generally high productivity of crabs relative to temperate finfish). We summarize other indicators and reference values in use by other Coral Triangle crab fisheries along with available fishery performance information to serve as a guide for choosing indicators and reference points for the Indonesia BSC fishery and similar crab fisheries.

Generally, target levels of SPR 30% to 40% are internationally accepted based on finfish studies. A target of SPR 20% is accepted for BSC because BSC is thought to be more resilient to fishing

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[1]Center for Fisheries Research and Development, Ministry of Marine Affairs and Fisheries (2016) Stock Assessment of the Blue Swimming Crab (Portunus pelagicus) for Sustainable Management in Java Sea in 2016. Accessed at https://www.apri.or.id/wp-content/uploads/2016/11/2016-BSC-STOCK-ASSESSMENT-KKP-APRI-REPORT.pdf

pressure and more productive than most finfish species. However, empirical evidence from both the US blue crab and the Sri Lankan BSC fisheries suggest that SPR 30% may be a better target reference point for crab fisheries under data-poor situations.

We recommend the adoption of SPR30% as a target reference point for the Lampung BSC fishery, with an interim rebuilding target of SPR25% and a limit reference point of SPR10%. Studies indicate that Lampung BSC is currently exhibiting SPR levels of 18%, and that controlling Lampung BSC harvest such that mean carapace length increases to 115mm would result in SPR 22%.[2] Slightly less fishing mortality or other measures resulting in SPR 25% would be expected to result in larger average body size, achieving goals associated with higher meat yield and value. Indices that relate stock status and recruitment success to environmental variables, such as those used by Australia's Cockburn Sound crab fishery, may be especially important to consider when assessing and managing BSC fisheries in the context of climate change.

The following four harvest control strategies could be effective in achieving SPR targets in BSC fisheries: (1) gear restrictions to rebuild the size structure of BSC populations (i.e., requiring traps to have an escape gap with a dimension of 115mmX 35mm and nets to have a mesh size of at least 115 mm); (2) spatial restrictions such as prohibiting fishing in certain areas to protect juveniles and/or mature females; (3) temporal restrictions such as prohibiting harvest during the peak spawning season; and 4) measures that generate market incentives for fishing larger crabs. Currently, there are no incentives for wholesalers engaged in the export market to target larger crabs as most of the crab meat products can be made with smaller size crabs. Fishery stakeholders should come together to explore a market structure that promotes a mutually beneficial sustainable fishery.

Introduction

Biological characteristics of BSC

Blue swimming crabs are brachyuran crabs that belong to the Portunidae family. They are characterized by a flat disc shape with hind legs and nine spikes along their carapace. Males are usually bright blue while females are duller green/brown. The BSC is inherently resilient to fishing pressure as a result of high fecundity and high growth rate. In Indonesian waters, BSC reproduction is continuous throughout the year with two seasonal peaks, one from April to June and another from October to November.[3] Fifty percent of the juveniles reach sexual

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[2] Zairion, Z. et al. (2015). Sexual Maturity, Reproductive Pattern and Spawning Female Population of the Blue Swimming Crab, Portunus pelagicus (Brachyura: Portunidae) in East Lampung Coastal Waters, Indonesia. Indian Journal of Science and Technology. 8. 596. 10.17485/ijst/2015/v8i6/69368.

[3] Batoy, C.B. et al. (1987). Breeding season, sexual maturity and fecundity of the blue crab, Portunus pelagicus (L.) in selected coastal waters in Leyte and vicinity, Philippines. Accessed at https://agris.fao.org/agris-search/search.do?recordID=PH8811173

maturity at 91.0–102.9-mm CW (approx. 12months) and the breeding female population lies within the 103–170.9-mm CW size range (while spawning and breeding occurs at the age of sexual maturity, most of the ovigerous females are between103 and 170.9-mm CW.)[4] Although BSC is inherently resilient to fishing pressure, a few biological characteristic makes it susceptible to overfishing. They are relatively easy to catch since they can be caught within 50m of water column, and variations in temperature substantially influence recruitment success.[5] If not carefully managed, high levels of fishing mortality can negatively impact the health of the population, reduce yields, and reduce meat yield per crab as a result of decreased average size.

History of the fishery

The Indonesian BSC has a long history of exploitation. Prior to the decline of the U.S. Chesapeake Bay blue crab (*Callinectes sapidus*) in the 1990s, Indonesian BSC was only caught in small amounts for local consumption. Production dramatically increased in response to reduced supply of *C. sapidus*. By 2017, production totaled 15,867.017 tonnes with the U.S. market account for 71% of the total BSC export and revenue of $308,827,461[6]. The exponential growth in production coupled with a gap in management resulted in a decline in stock status in recent years.

BSC are caught throughout Indonesia with a variety of gear types. Fishing gears include bottom set gillnet, dip nets, traps, and mini-trawl. The choice of gear changes through time as the size composition changes as a result of fishing. The bottom set gill net targets larger size crabs at the depth of 20-50 m of the water column. As larger size classes are depleted, the dominant gear switches to dip-netting with lanterns to target smaller crabs at a shallower depth, then collapsible traps followed by mini-trawl to target even smaller crabs at a shallower depth. In recent years, the use of nets has declined and traps and trawl have become the dominant fishing gears. Fishing grounds range from the northern coastal waters of Java to South Sulawesi, throughout the Malaca Strait, and into Eastern Sumatra. The BSC are then sold to processors to prepare them for export. In Indonesia, crabs are mainly boiled and pasteurized for canned products, therefore, smaller crabs are also targeted.

In the face of rising concern regarding declining BSC stock status, several governmental and non-governmental organizations are working on improving the sustainability of the fishery. The Asosiasi Pengelolaan Rajungan Indonesia (APRI), a blue swimming crab processor association representing more than 90% of the industry initiated a Fishery Improvement Project (FIP) with the Sustainable Fishery Partnership. Current management measures include a minimum

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[4] Zairion, Z. et al. (2015). Sexual Maturity, Reproductive Pattern and Spawning Female Population of the Blue Swimming Crab, Portunus pelagicus (Brachyura: Portunidae) in East Lampung Coastal Waters, Indonesia. Indian Journal of Science and Technology. 8. 596. 10.17485/ijst/2015/v8i6/69368.

[5] Zheng, J. and G.H. Kruse. (1999). Evaluation of harvest strategies for tanner crab stocks that exhibit periodic recruitment. J. Shell sh Res. 18:667–679.

carapace width restriction of 110 mm, and prohibitions on berried female catch and on trawling.

EDF helped create the Lampung BSC Management Committee and worked to support the development of a BSC fishery management plan for Lampung Province by this Committee. The plan includes several indicators along with reference points for each indicator that will drive implementation of management measures. One of these indicators is Spawning Potential Ratio (SPR). In the APRI FIP and the BSC Management Plan, the Target Reference Point (TRP) for SPR is set at $SPR_{30\%}$ and the Limit Reference Point (LRP) at SPR $_{20\%.}$ Research suggests that harvest control measures have so far not been effectively implemented. The 2016 stock assessment shows several testing sites in which SPR was above the LRP $SPR_{20\%}$ but failed to reach the TRP. In Lampung, the SPR was below LRP. Despite relatively high fishing mortality levels, the assessment suggests that the fishery targets mostly mature adults, reducing the risk of growth overfishing. The risk of recruitment overfishing is thought to be low due to the high fecundity of crabs. Nonetheless, compared to neighboring countries such as Sri Lanka, the average observed size is much smaller, suggesting that some degree of overfishing has occurred.[7]

The purpose of this paper is to find defensible biological reference point for the BSC fishery that would be expected to result in desirable conservation, yield, and profit outcomes.

Methods

To develop recommended target and limit reference points for the Lampung BSC fishery, we conducted a literature review to compare reference points that have been used to manage BSC fisheries. We found case studies for BSC and similar crab fisheries in Australia, Sri Lanka, Philippines, Thailand, Vietnam, and U.S. Sources of literature included multi-publisher databases, government libraries, NGO libraries, and scientific journals.

Indicators are categorized by the most common methods used to evaluate indicators: yield-per-recruit (also referred to as dynamic pool model, spawning-stock-biomass-per-recruit models), spawner-per-recruit models, and surplus production models. The implicit and explicit theoretical considerations of using these indicators, target, and limits are then summarized and analyzed.

Case studies in crab fishery management

Philippines, Thailand, and Vietnam

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[7] J. Prince et al. (2020) "Length based assessment of spawning potential ratio in data-poor fisheries for blue swimming crab (Portunus spp.) in Sri Lanka and Indonesia: Implications for sustainable management" Regional Studies in Marine Science 36 (2020) 101309

BSC stocks in Philippines, Thailand, and Vietnam appear to be overfished. In general, there is a lack of management, research, and enforcement in BSC stock management in these countries. The FIPs and FMPs are fairly new. Therefore, it is hard to assess their effectiveness.

Length-Based Spawning Potential Ratio (LBSPR) is used as an indicator in both the Philippines and Thailand, starting in 2015 and 2020 respectively. In the Philippines, the Target Reference Point (TRP) is SPR 30% and the Limit Reference Point (LRP) is SPR 20%. Several management measures are on the books in the Philippines, including a prohibition on catch of berried females, a minimum size limit of 102 mm, a mesh size limit, limits on fishing effort, and temporal closures. The Philippine BSC stock has not been formally assessed but it is thought to be overfished based on a preliminary PSA analysis. We were not able to find reference points for LBSPR or information on stock status or management measures for Thailand.

In Vietnam, Catch Per Unit Effort (CPUE) is used as an indicator. Recently, the minimum mesh sizes for BSC gillnets, traps, and Chinese traps were increased to 120 mm, 50 mm, and 43 mm respectively. We were not able to access the stock assessment, but the stock is thought to be overfished with some signs of increasing biomass based on a Seafood Watch Report.[8]

Gulf of Mannar/Palk Bay, Sri Lanka

The Sri Lankan BSC fishery (SLBSC), like the Indonesian BSC fishery, is located in tropical waters and experiences high fishing pressure. However, compared to Indonesia, it has a shorter exploitation history and uses different fishing gears. In Sri Lanka, BSC is caught mainly with polyfilament bottom set gillnets with a mesh size of 89-152 mm. The fishery started in 2001 and developed rapidly after the end of the 30-year-long civil conflict of 2009. In 2011, BSC became Sri Lanka's second most important crab fishery, with an export value of around USD 6 million. Forty percent was directly exported to the U.S. market. Fishing occurs mostly in Gulf of Mannar and Palk Bay (See Figure 2). They are sorted by size after a 10 to 12-hour long fishing trip and then exported fresh, frozen, or canned.

In 2013, Sri Lanka joined the BSC FIP and immediately started implementing LBSPR reference points. Target and limit reference points in Sri Lanka are adjusted based on the internationally accepted value (based mainly on finfish studies such as groundfish[9] and other small pelagic

[8]Monterey Bay Aquarium (2019). Seafood Watch Swimmer Crab Vietnam Report. Accessed at https://seafood.ocean.org/wp-content/uploads/2019/01/Copy-of-MBA_TSC_SeafoodWatch_Swimmer_Crab_Vietnam_Report.pdf

[9] Clark, W. G. 1991. Groundfish exploitation rates based on life history parameters. Canadian Journal of Fisheries and Aquatic Sciences, 48: 734–750.

species[10]) of $SPR_{30\%}$ to $SPR_{40\%}$.[11] In Sri Lanka, an upper TRP is set at SPR 40%, a lower TRP is set at SPR 30%, and a LRP (overfishing threshold) is set at SPR 20%. Typically, fishing at a level that will reduce spawning stock biomass per recruit (equivalent to lifetime egg production) to 20% of the unfished level ($F_{20\%}$) is suggested as the recruitment overfishing threshold for fishing mortality in well-known stocks with at least average resilience, while $F_{30\%}$ is suggested as a recruitment overfishing threshold for less well-known stocks or those believed to have low resilience.[12] A study on Alaskan ground fish proposed $F_{40\%}$ as threshold when resiliency (D) is low (calculated based on instantaneous fishing mortality, recruitment and biomass at the MSY level relative to their unfished levels, yield at various fishing mortality rates, biomass relative to their unfished level, recruitment relative to unfished level).[13]

In Sri Lanka, the overfishing threshold for BSC is lower than those from the finfish studies mentioned above. This means that BSC can be subjected to more fishing pressure before spawning potential is reduced to a level that triggers overfishing declaration. $SPR_{20\%}$ is generally accepted by experts for BSC since it is a highly productive species. Results of stock assessments indicate that despite the high fishing pressure (F/M ranges from 2.7 to 4), the catch continues to be dominated by larger size crabs. The mean estimated size at 50% maturity ($L_{50\%}$) is 104mm and $L_{95\%}$ is 124mm. These sizes are much larger than the $L_{50\%}$101mm and $L_{95\%}$103mm average sizes observed in Indonesia. Stock assessment shows that the fishery has achieved the lower TRP of SPR30% since 2015 and has achieved the upper TRP of SPR 40% since 2016.

In contrast, a MSY indicator developed by the Indian Council of Agricultural Research and the Central Marine Fisheries Research Institute suggested that overfishing is occurring in the SLBSC fishery and recommended more stringent management based on the use of a surplus production model using a Monte Carlo Method (CMSY) [14] Results show that the fishery exceeds the MSY of 7360t in Sri Lanka. F/F_{MSY} during 2017 was 0.726 and most of the year this value was above 1. The B/B_{MSY} in 2017 was 0.833 and from 2012 onwards it is below 1.[15] This analysis

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[10] Mace, P. M. and M. P. Sissenwine. 1993. How much spawning per recruit is enough? p. 101-118. In S. J. Smith, J. J. Hunt and D. Rivard [ed.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120.

[11] Prince, J. et al. (2014). Revisiting the concept of Beverton-Holt Life History Invariants with the aim of informing data-poor fisheries assessment. ICES Journal of Marine Science. 10.1093/icesjms/fsu011.

[12] Mace, P.M. et al. (1993). How much spawning per recruit is enough? In S.J. Smith, J.J. Hunt and D. Rivard [eds.] Risk evaluation and biological reference points for fisheries management. Canadian Special Publications in Fisheries and Aquatic Sciences 120:101-118.

[13]Clark, W.G. et al. (2002) F35% Revisited Ten Years Later. North American Journal of Fisheries Management 22:251–257, 2002

[14] Froese, R., Demirel, N., Coro, G., Kleisner, K.M. and Winker, H. (2017), Estimating fisheries reference points from catch and resilience. Fish Fish, 18: 506-526. doi:10.1111/faf.12190

[15]Jose, J. et al. (2019). Fishery Management Plan for Palk Bay Blue Swimming Crab. Accessed atwww.researchgate.net/publication/338549275_Fishery_Management_Plan_for_Palk_Bay_Blue_Swimming_Crab

indicates that the fishery may be experiencing fishing mortality close to Fmsy, and the declining catch trend since 2012 (Fig 9) suggests that overfishing may be occurring. However, the fact that the fishery has attained SPR target levels does not corroborate these findings.

The Sri Lanka BSC fishery uses several management measures including gear restrictions, minimum size limits, and fishing effort controls (only polyfilament bottom set crab nets with a mesh size of >=114mm are allowed) to achieve its LBSPR target levels. In addition, regulations prohibit plants from buying crabs that are <100g[16]. As a result, harvest ($SL_{50\%}$) ranges from 116-142mm which is substantially higher than selectivity of 74mm in Indonesia (See Figure 3). That being said, the regulation prohibiting the use of monofilament nets is not fully enforced.

The Sri Lankan BSC fishery appears to have performed relatively well compared to the BSC fisheries of neighboring countries such as Indonesia, China, Philippines, Vietnam, or India based on the limited data available for these fisheries. In these other BSC fisheries, small crabs (100g – 149g) and very small crabs (80g – 99g) dominate the catch. In Sri Lanka, medium and large crabs are still prevalent.

Cockburn Sound, Australia

The BSC fishery has been an important recreational and commercial fishery in western Australia since the 1990s. BSCs are caught with pots and sold in various forms in both domestic and export markets. Frozen crab, live/fresh/salted/brine crab, frozen crab meat, and other products containing crabmeat were imported to the United States from Australia.[17]

The ecological characteristics of the BSC stock in Cockburn Sound are different from those of its Indonesian counterpart. The BSC stock is located at 32°10'S, 115°43'E where the temperature range is near the thermal limit for BSC, making the stock more susceptible to environmental changes. High fishing mortality and habitat degradation can increase the probability of recruitment failure and reduced resilience to demographic and environmental stochasticity. [18] While Indonesian BSC spawns all year round, the Cockburn Sound BSC spawns only during the Austral spring/summer between October and January. The female crabs also experience higher mortality during the winter months from April to September. Moreover, genetic studies indicate the population to be self-recruiting, meaning that the population is unlikely to grow

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[16] J. Prince et al. (2020) "Length based assessment of spawning potential ratio in data-poor fisheries for blue swimming crab (Portunus spp.) in Sri Lanka and Indonesia: Implications for sustainable management" Regional Studies in Marine Science 36 (2020) 101309

[17] The Safina Center Seafood Analysts. (2015). Monterey Bay Aquarium Seafood Watch Blue Swimmer Crab Australia Report. Accessed at https://www.seafoodwatch.org/-/m/sfw/pdf/reports/c/mba_tsc_seafoodwatch_swimmer_crab_australia_report.pdf

[18] Kendrick, G.A., May M.J., Hegge B.J., Cambridge M.L., Hillman K., Wyllie A. & Lord, D.A. 2002. 'Changes in seagrass coverage in Cockburn Sound, Western Australia between 1967 and 1999'. Aquatic Botany 73: 75-87.

from recruitments from other populations.[19] This suggests the need for the fishery to adapt to varying recruitment success and conserve local spawning biomass.

The Cockburn Sound fishery once used total catch and CPUE as indicators, along with a minimum legal size of 130mm and limited entry to control fishing mortality and effort. However, these measures were not adequate to prevent the decline of the stock under unfavorable environmental conditions and sustained fishing mortality. The CPUE indicator failed to detect the decline in juvenile recruitment which was confirmed later. [20]

Currently, the stock is assessed with an index of juvenile and residual (after season) stock abundance, an egg production index, catch, and CPUE. The juvenile and residual index is used to predict the catch of the coming season. The length of the season is adjusted to provide buffer for next year (to provide for additional spawning stock). Fishery closure occurs when the juvenile and residual index is below the LRP 1.6 that corresponds with catch ≤150t based on the catch projection. The TRP for this index is set at 3.0, where the fishing season will remain open till the end of June. Between index levels of 1.6 and 3.0, the length of the season extends linearly (See Figure1). Yield-per-recruit models such as the juvenile abundance index do not usually take into account environmental conditions, as productivity is assumed to be equal at all times. The egg production index takes into account the water temperature before the onset of spawning to help further understand the contribution of residuals (individuals more than 1 year old) to the stock and provides justification for management (See Figure 3 c). The incorporation of indices that relate stock status to environmental conditions may be especially important in the context of climate change.

The BSC fishery in Cockburn Sound, Australia is on its way to a slow recovery. Production peaked at 362t in 1997/78 and declined drastically in the 2000s. After the fishery collapsed in 2006, it was closed for three years. The fishery is now partially opened with stringent harvest control rules and measures.

Chesapeake Bay, U.S.A.

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[19] Lipcius, R.N. and W.A. van Engel. 1990. Blue crab population dynamics in Chesapeake Bay: variation in abundance (York River, 1972-1988) and stock-recruit functions. Bull. Mar. Sci 46:180–194.

[20] de Lestang, S., L.M. Bellchambers, N. Caputi, A.W. Thomson, M.B. Pember, D.J. Johnston, and D.C. Harris. 2010. Stock-Recruitment-Environment Relationship in a *Portunus pelagicus* Fishery in Western Australia. In: G.H. Kruse, G.L. Eckert, R.J. Foy, R.N. Lipcius, B. Sainte-Marie, D.L. Stram, and D. Woodby (eds.), Biology and Management of Exploited Crab Populations under Climate Change. Alaska Sea Grant, University of Alaska Fairbanks. doi: 10.4027/bmecpcc.2010.06.

The Chesapeake Bay blue crab (*Callinectes sapidus*) fishery has gone through ups and downs. After the stock declined due to overexploitation in the 1990s, continuously improved science-based reference points had a positive impact on stock status.

Three benchmark reference points have been used in this fishery. Currently, exploitation rate from a yield-per-recruit analysis and female abundance are used as indicators. The TRP is set at exploitation rate (U) 0.255 (when 25% of the female crabs are harvested annually) that will result in 215 million age+1 female crabs, while the LRP is at U =0.5*NMSY that will result in 70 million age+1 female blue crabs.

The original reference point between 2001-2006 was based on an exploitation rate developed from a yield-per-recruit analysis[21]. The LRP was set at the fishing mortality that maintains 10% of the virgin spawning potential ($F_{10\%}$) and TRP at $F_{20\%}$.[22] However, these reference points based on exploitation strategy seemed to be insufficiently connected to the management objective -- maintaining a stock abundance of 200 million age+1 crabs baywide – perhaps due the effects of environmental variation on crab abundance. Managers expressed concern about exploitation-rate-based indicators that they felt diverted attention from sustaining desirable crab abundance levels.

A revision of the 2005 reference point was made in 2008 by adding empirical crab abundance estimates to help evaluate stock status. Revisions were as follows:

LRP: F10%, U 53%, 86 million age+1 crabs
TRP: F20%, U 46%, 200 million age+1 crabs

Control of exploitation rate and of female crab mortality had different effects on stock status. Despite a drop in exploitation rate as a result of the revised reference points, stock abundance did not increase. Despite a dramatic 37% decrease in exploitation rate from the peak in 1999, crab abundance remained far below the interim target of 200 million crabs. In contrast, measures that reduced mortality of female crabs introduced in 2009 doubled the abundance to 235.1 million crabs with a modest drop of 2% in exploitation rate compared to 2008.

As a response, the current reference point adopted in 2011 reflects two major changes: 1) the integration of abundance estimates and female specific exploitation rate as reference points; and 2) the adoption of female-specific reference points. Integrated reference points were set to

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21 Miller, T. J., S. J. D. Martell, D. B. Bunnell, G. Davis, L. A. Fegley, A. F. Sharov, C. F. Bonzek, D. A. Hewitt, J. M. Hoenig, and R. N. Lipcius. 2005. Stock Assessment of Blue Crab in Chesapeake Bay: 2005. Final Report Ref: [UMCES]CBL 05-077. UMCES Tech. Ser. No. TS-487-05-CBL., University of Maryland Center for Environmental Science Chesapeake Biological Laboratory, Solomons, MD.

22 Bunnell, David & Miller, Thomas. (2005). An individual-based modeling approach to spawning-potential per-recruit models: An application to blue crab (Callinectes sapidus) in Chesapeake Bay. Canadian Journal of Fisheries and Aquatic Sciences - CAN J FISHERIES AQUAT SCI. 62. 2560-2572. 10.1139/f05-153.

align with management objectives. Female-specific reference points were adopted because abundance estimates were sensitive to the sex ratio of exploitation based on model projections. With these considerations, the current reference points are:

TRP: Exploitation rate (U) 0.255, which corresponds to 215 million age+1 female crabs
LRP: U =0.5*N_{MSY}, which corresponds to 70 million age+1 female blue crabs and 400 to 600 million crabs annually

A precautionary buffer on allowable exploitation rate (75% of Umsy) was applied to comport with National Standard 1 of the federal Magnuson Stevens Act. After the revision of the harvest control rules, the historic data were reassessed. Results showed that the stock was technically overfished from 2001-2003 when overall abundance was used instead of female-specific abundance as reference points. Female exploitation rate has also changed as the result of revision. Over the entire sex-specific time series available (1994- 2009), the harvest of crabs taken from the Chesapeake Bay was 62.8% female. Now it has dropped to around 25%.

The most recent 2016 stock assessment shows that crab abundance has rebounded from low levels observed between 1998-2004 (See Figure 8)[23] Adherence to reference points based on yield-per-recruit analysis and female abundance estimates seems to have rebuilt the Chesapeake Bay stock. Nonetheless, the stock assessment also cautioned that the use of female-specific reference points could impair recruitment, due to limited sperm levels.[24]

Conclusions and Recommendations

Few crab fisheries are managed using SPR as an indicator, hence there is a paucity of empirical information on how different SPR reference points may affect fishery performance. We summarize other indicators and reference values in use by other Coral Triangle crab fisheries along with available fishery performance information to serve as a guide for choosing indicators and reference points for the Indonesia BSC fishery and other similar crab fisheries.

The Sri Lankan BSC fishery experience suggests that management driven by a LBSPR indicator can serve as a useful starting point for science-based management.

Table 1: indicators, reference points, analytical methods, and stock status

Country	Indicators	Reference points	Method	Stock status

[23]Chesapeake Bay Stock Assessment Committee. (2016). 2016 Chesapeake Bay Blue Crab Advisory Report. Accessed at https://www.chesapeakebay.net/documents/CBSAC_2016_Report_6-30-16_FINAL.pdf
[24] UMCES. (2011). 2011 Stock assessment for blue crab in Chesapeake Bay. Accesed at https://hjort.cbl.umces.edu/crabs/docs/Assessment_document_final_approved.pdf

Australia	Juvenile abundance index+ egg production index+ catch projection model	LRP:1.6 (=1.5t of catch) TRP:3.0	Yield-per-recruit+ egg-production index+ surplus production	In recovery
Sri Lanka	LB-SPR	LRP: SPR 20% Upper TRP: SPR 40% Lower TRP: SPR 30%	Yield-per-recruit using SPR as proxy	Abundant
Philippines	Reference point in progress (pilot program in LB-SPR)	LRP: SPR20% TRP: SPR30%		Overfished
Indonesia	LB-SPR	LRP:SPR 20% TRP: SPR30%	Yield-per-recruit using SPR as proxy	Overfished
Thailand	LB-SPR (Started in 2020, unable to access FMP)			Overfished
Vietnam	MSY		Biomass model	Overfished
Chesapeake Bay, U.S.A.	Exploitation rate + age 1+ female abundance estimates	LRP: U $=0.5*N_{MSY}$, (which corresponds to 70 million age+1 female blue crabs) TRP: (U) 0.255, which corresponds to 215 million age+1 female crabs	Yield per recruit	Abundant(winter dredge survey abundance estimate)

Generally, target levels of SPR 30% to 40% are internationally accepted based on finfish studies. A target of SPR 20% is accepted for BSC because BSC is thought to be more resilient to fishing pressure and more productive than most finfish species. However, empirical evidence from both the US blue crab and the Sri Lankan BSC fisheries suggest that SPR 30% may be a better target reference point for crab fisheries under data-poor situations.

The use of SPR 30% as a target appears to have enabled the Sri Lankan BSC fishery to maintain high yields and high average size. The U.S. BSC fishery fished between SPR 10% and SPR 20% between 2001-2006, however, these reference points alone were not able to protect the stock under consecutive years of poor environmental condition and sustained fishing pressure. Conversely, female specific exploitation rate combined with empirical abundance estimates led to a significant increase in stock abundance due to the decrease in female catch. Both U.S. and Australia proved the usefulness of multiple indicators and the development of female specific protection measures to protect spawning stock.

The Way Forward

The case studies demonstrated that appropriate reference points combined with effective management measures can significantly improve BSC stock status. Conversely, if not carefully managed, despite being inherently resilient, the BSC fishery can become economically unprofitable. To improve Indonesian BSC stock status both in terms of abundance and crab size so the fishery can profit in the years to come, we recommend the following:

Short term

In the short term, we recommend **adoption of an upper SPR target of SPR30% for the Lampung BSC fishery, and starting adaptive management using a target of SPR 25%, with a limit at 10%.** A Lampung-specific study indicates that controlling BSC harvest such that mean carapace length increases to 115mm (from current levels of 74mm) would result in SPR 22%.[25] Slightly less fishing mortality or other management measures resulting in SPR 25% would be expected to result in larger average body size, achieving goals associated with higher meat yield and value.

We suggest that the following four harvest control strategies could be effective in rebuilding the Lampung BSC fishery: 1) gear restrictions (i.e., only traps with escape gap with a dimension of 115mmX 35mm and nets with a mesh size of 115 mm should be allowed); 2) spatial restrictions such as prohibiting fishing in nearshore areas where juvenile crabs aggregate; 3) temporal restrictions such as prohibiting harvest during the peak spawning season; and 4) measures that generate market incentives for fishing larger crabs. Currently, there are no incentives for wholesalers in the export market such as U.S. to target larger crabs as most of the

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[25] https://www.researchgate.net/publication/281266637_Sexual_Maturity_Reproductive_Pattern_and_Spawning_Female_Population_of_the_Blue_Swimming_Crab_Portunus_pelagicus_Brachyura_Portunidae_in_East_Lampung_Coastal_Waters_Indonesia

crab meat products can be made with smaller size crabs. Fishery stakeholders should come together to explore a market structure that promotes a mutually beneficial sustainable fishery.

Long term

Case studies showcased the usefulness of catch projection models and additional indicators other than SPR to inform management decisions. Managers can use catch projection models to adjust the length of the fishing season to provide additional protection for the spawning stock and ensure fishery profit for the coming year. Currently available data (i.e. length at age maturity, asymptotic length, F/M, and growth rate) are not adequate to parameterize such models for the Lampung BSC fishery. There is a gap in fishery-independent data and sufficient data time series to provide accurate estimates. We recommend conducting fishery-dependent and independent surveys to help estimate total catches and abundance, increase understanding of exploitation rate and stock structure, and provide insight into how environmental stochasticity affects the productivity of BSC stock**.** In addition to stock assessment data, economic data (e.g. profitability of fishery) and social data (e.g. employment) can also help define management objectives. As the data availability and quality improve, management entities can leverage these data to optimize the performance of gear restrictions, spatial and temporal restrictions, or other management measures.

As shown in the table below (Table 1), both Australia and U.S.A. have seen improvements in stock status by using a combination of yield-per-recruit models and surplus production models as indicators. However, many southeast Asian (SEA) countries do not have the capacity to take a similar approach. In these contexts, it is advisable to use a combination of indicators to reduce uncertainty about stock status and provide scientific justification for taking management measures.

Figures

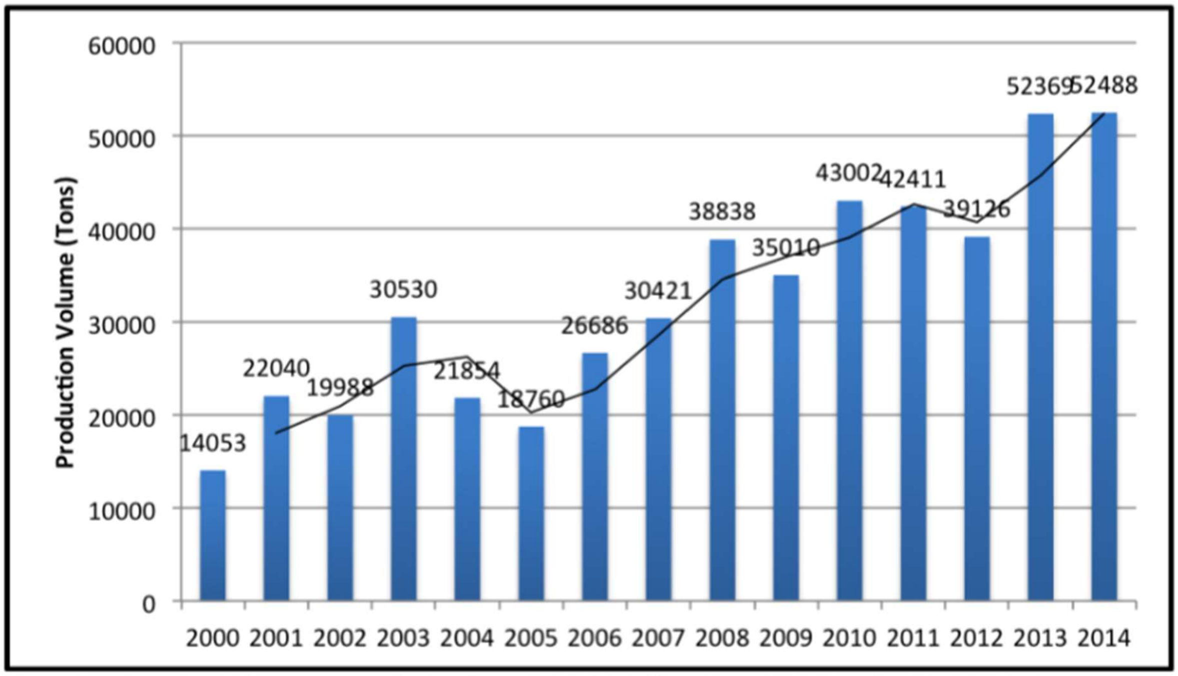

Figure1. Indonesia BSC capture. Data from MMAF and DGCF(2015) showed an exponential growth in production since the 1990s.

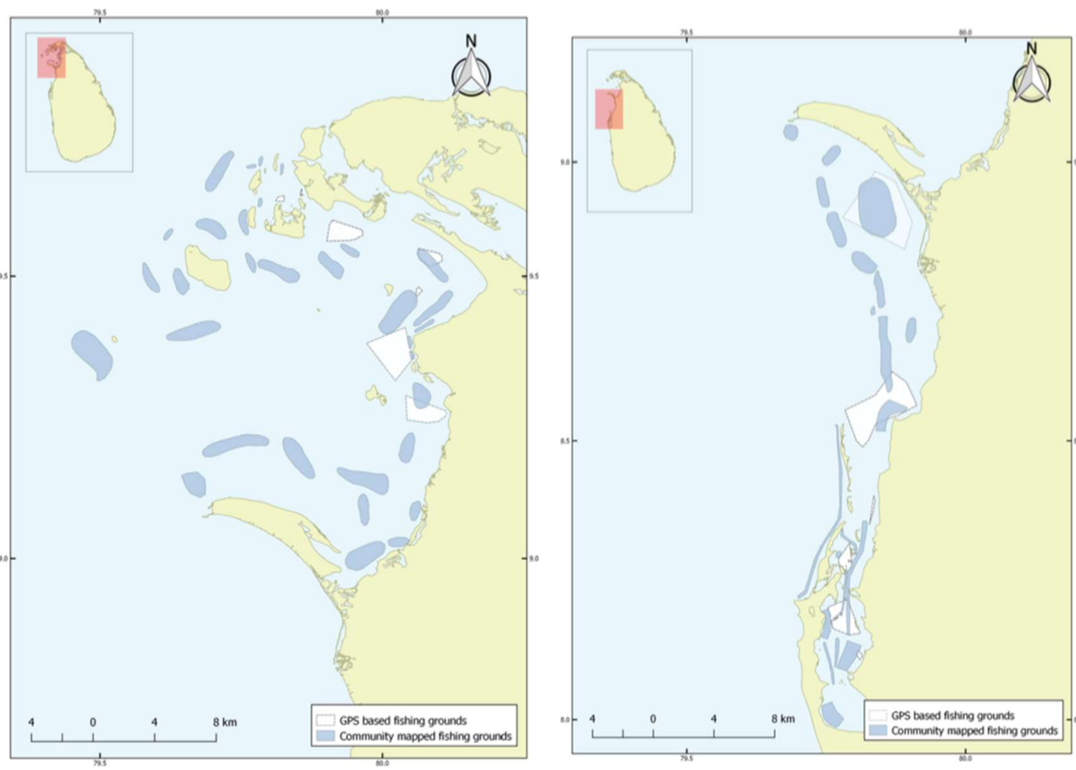

Figure 2. Sri Lanka: Palk Bay fishing grounds (Left), Gulf of Mannar fishing grounds(Right)

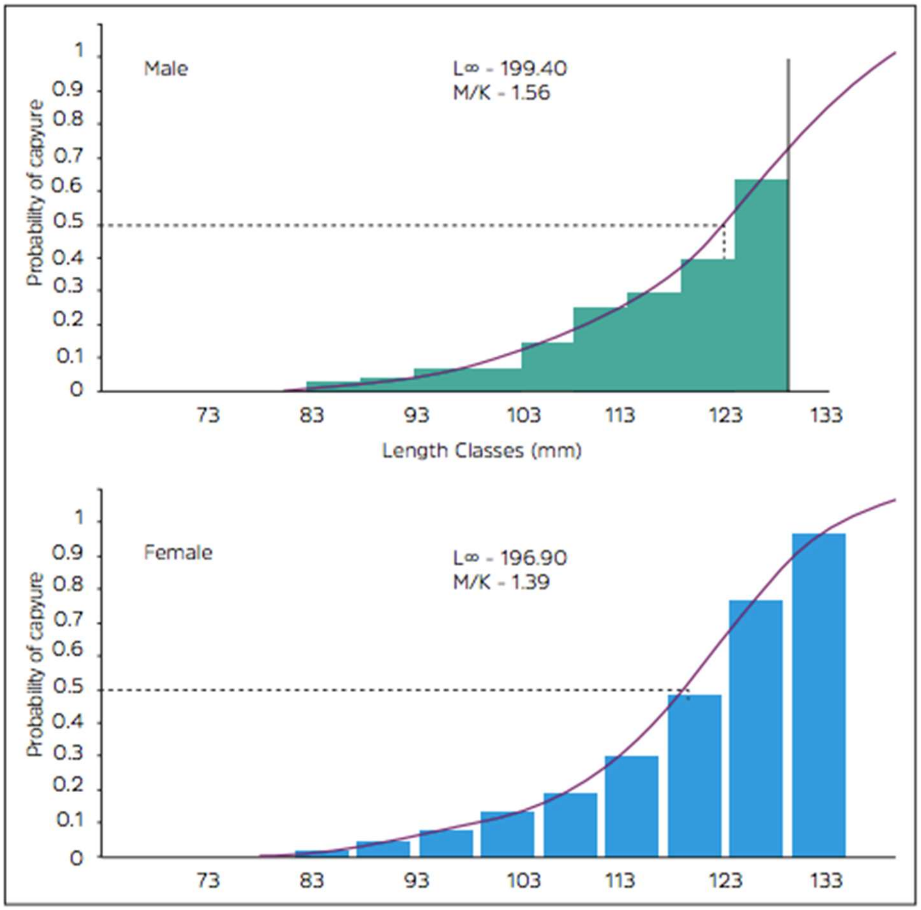

Figure 63- Probability of capture in male and female *Portunus pelagicus* (BSC)

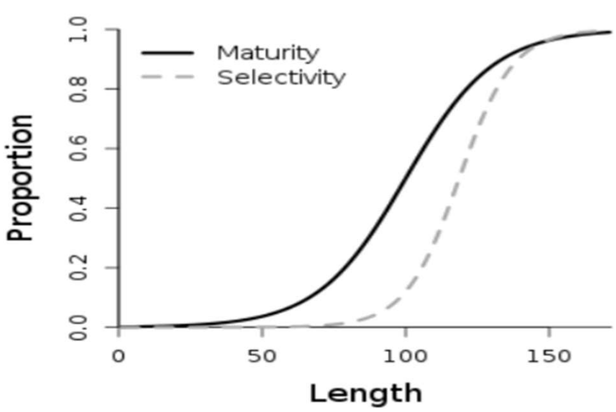

Figure 2. Sri Lanka (top) and Indonesia (bottom): Both fisheries show knife edge selectivity while Pamekasan, Indonesia has a much steeper curve (male and female combined).

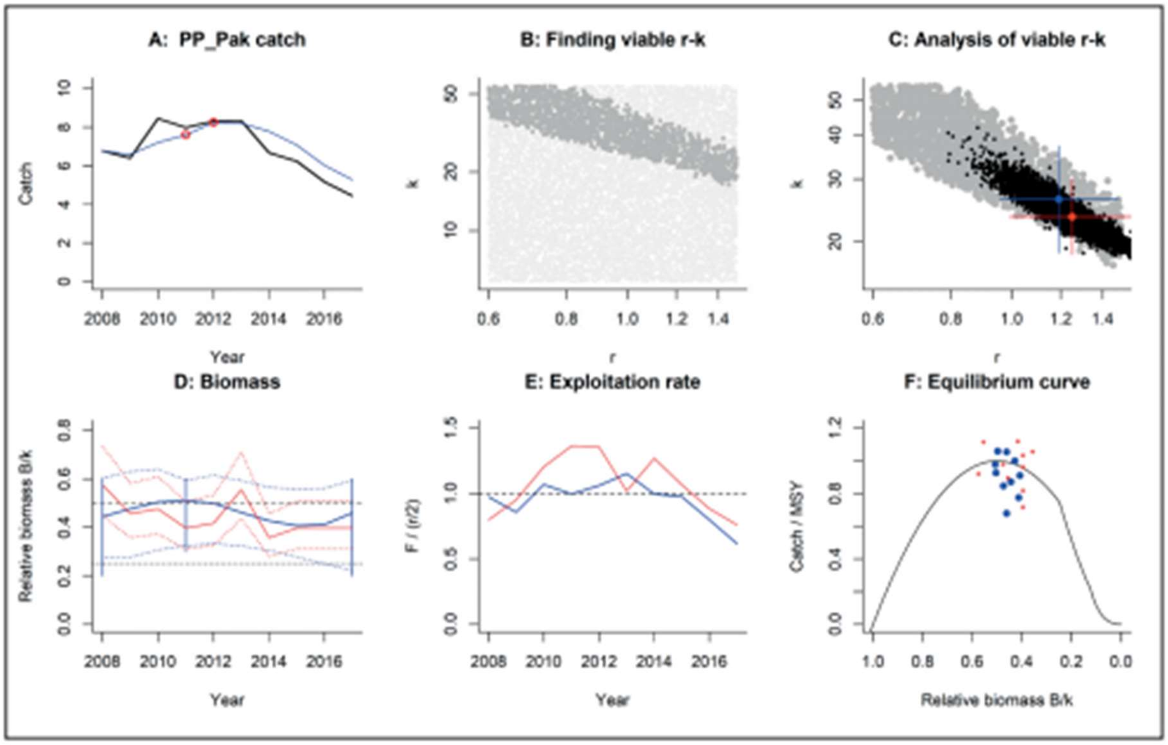

Figure 68- Results of CMSY analysis for *Portunus pelagicus* (BSC) landings in Palk Bay during 2007-17

Figure 3.Sri Lanka: CMSY analysis shows the Catch/MSY lingers around its maximum most of the years

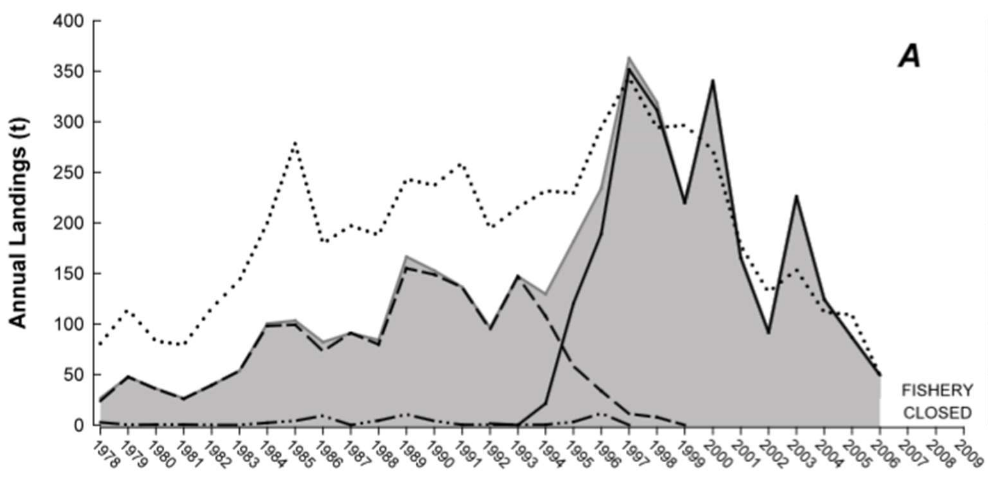

Figure 4 Cockburn Sound, Australia: BSC catch increased substantially in the 1990s, declined in the 2000s and ultimately led to fishery closure from 2006-2009. Total catch (■); gill nets (- - - - -); crab traps (——); other (– ·· –) and effort (········).

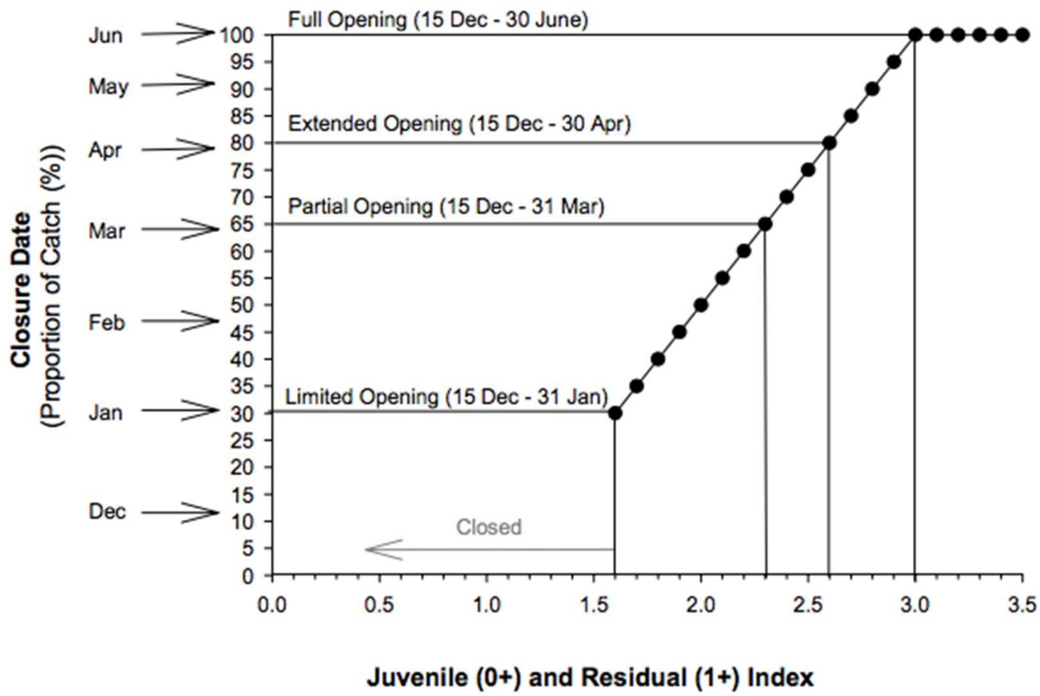

Figure 5 Cockburn Sound, Australia: The framework adjusts the length of the commercial season according to a juvenile and residual index derived from monthly trawl surveys and commercial monitoring.[26]

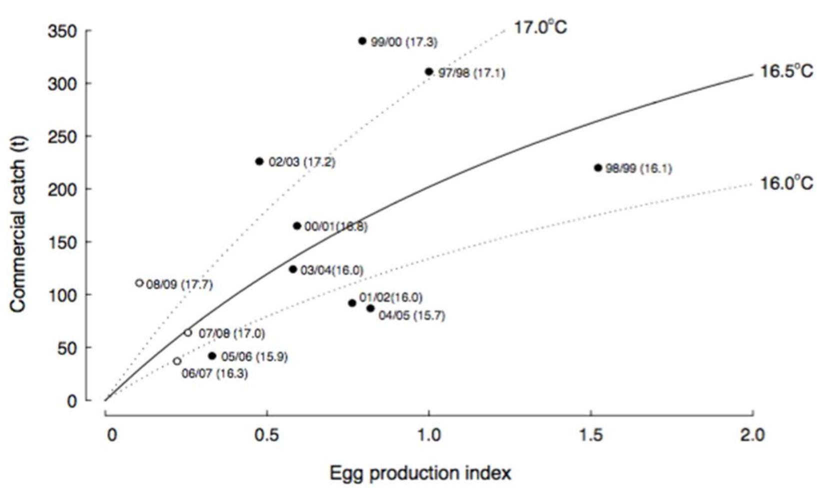

Figure 6. Cockburn sound, Australia: Beverton and Holt stock-recruitment relationship between commercial catch and egg production (preceding season) at three different water temperature. Higher temperature is favorable for higher catch with the same egg production index.

[26] http://www.fish.wa.gov.au/Documents/research_reports/frr219.pdf

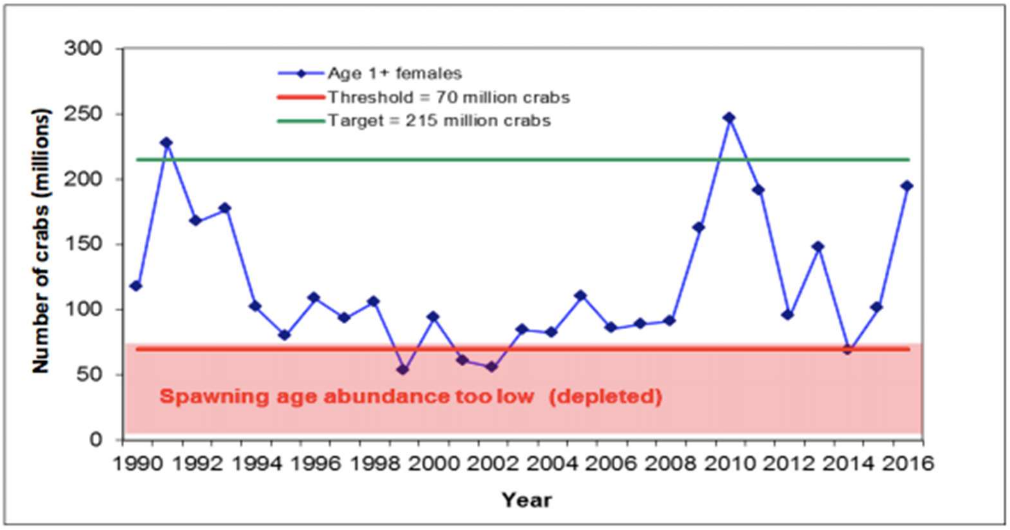

Figure 7. Chesapeake Bay, U.S.:winter dredge survey estimates of abundance of female blue crabs age one year and older

Table- 8. Estimated monthly catches of *Portunus pelagicus* (tonnes) at Palk Bay & Gulf of Mannar during 1972-1974.

Year	1972		1973		1974	
Gear	Gillnet	Trawl Net	Gillnet	Trawl Net	Gillnet	Trawl Net
Jan	20.37	3.74	17.08	11.11	9.87	19.18
Feb	22.50	2.92	14.56	8.38	11.35	7.64
Mar	12.90	2.89	19.36	5.18	14.90	8.34
Apr	12.62	3.25	19.02	6.77	18.73	12.10
May	11.79	2.25	19.18	3.64	15.75	7.82
Jun	13.76	2.69	14.18	3.27	15.58	9.43
Jul	13.01	3.31	14.73	4.24	9.69	6.96
Aug	15.58	2.68	13.06	7.62	13.81	3.86
Sep	12.45	2.87	17.34	8.25	11.68	5.47
Oct	11.34	2.22	14.37	10.66	11.39	9.55
Nov	11.21	2.97	11.66	4.74	12.19	12.07
Dec	10.05	2.84	12.47	6.49	10.14	9.97
Total	167.58	34.63	187.01	80.34	155.07	112.39

Source: Ameer Hamsa (1978)

Figure 8

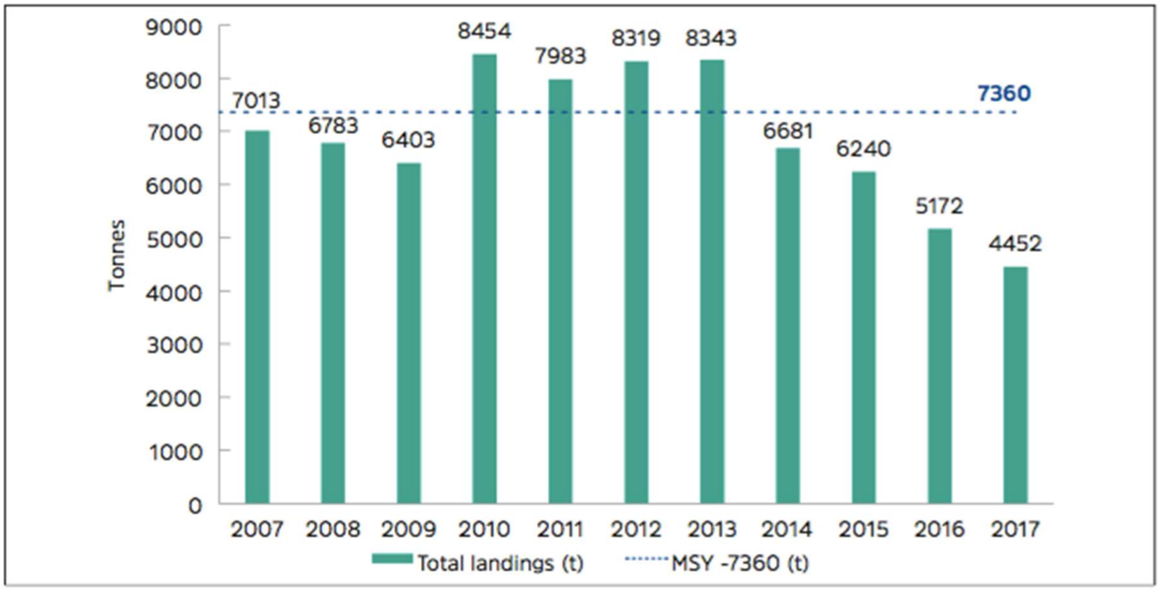

Figure 67- Total *Portunus pelagicus* (BSC) landings in Palk Bay during 2007-17 and MSY level

Figure 9