Stock Enhancement:
Strategic Approach for the Blue Swimmer Crab in SE Asia

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Stock enhancement:

Marine fisheries enhancement ("stock enhancement") is the use of hatchery-reared saltwater organisms to increase abundance and fishery yields in the wild. The practice began in the 1880's when fish hatcheries were first developed, but understanding of the ecology of wild stocks into which the hatchery-reared fish were released was very limited. That led to a varied history for stock enhancement. In the U.S.A., considerable effort between the 1880's until the early 1950's was made by Federal fisheries agencies to hatch and release many fish species. But in the later 1950's this effort was stopped for lack of evidence of its effectiveness. Modern methods of evaluating the effectiveness of stock enhancement are now available, and a code of responsible practices has been developed that can be used to guide effective application.

Marine enhancement programs are often seen as a rapid solution for various problems with managing fisheries resources. At best they may be an important component of a fisheries management regime. However, if enhancement programs are not implemented responsibly, they have the tendency to lull fishermen and fisheries managers into false confidence that may lead to inaction or delay in the development of a complete and effective management structure.

Although marine fisheries enhancement is not a "quick fix", it can be a useful tool for resource management when conditions warrant its use, and if the time and care needed are taken to develop an effective program. However, the allure of a quick fix has often prompted stakeholders to skip or ignore several elements required for enhancement programs to succeed, which leads to major failures of such efforts.

The field of marine fisheries enhancement contains many accounts of programs that failed because of a lack of planning or by not considering a quantitative approach. Most of the failures can be traced back to attempts to use enhancement when it wasn't warranted or to a failure to consider the principles necessary to develop and execute an effective enhancement program.

Successful stock enhancement requires determining the strategic goals of the effort, especially distinguishing two broad goals:

- "Put-and-Take Enhancement" that requires sustained subsidization of a fishery; versus
- "Spawning Stock Enhancement" of a fishery's reproductive potential that requires close coordination with improved fishery management.

There are many recent and on-going examples of each of these approaches to stock enhancement that are being advanced with varying success and failure. Considering the history and recent examples of both failure and success for stock enhancement, an effective program is best when it applies the standards and strategy of a "Responsible Approach to Stock Enhancement" (see below). This approach protects investors and insures that the effort will – as a minimum – contribute objective criteria for success (or failure), as well as provide valuable new information about the biology, life cycle, ecology and fishery of the target species.

<u>Why Consider Stock Enhancement for Blue Swimming Crab?</u>
Crab stocks from Asia have been severely depleted because of decades of intense fishing coupled with the lack of management of the fishery. Since the onset of the NFI Crab Council's support to in-country supplier organizations to implement Fishery Improvement Projects (FIPs), the industry has shown keen interest in applying stock enhancement as a way to increase landings. This is due in part to viewing enhancement as a faster way to increase yields from the crab fisheries rather than through reforms in the fishery that will take more time to implement.

Increasing crab populations through enhancement is an attractive idea. First, it seems logical that growing and releasing millions of small crabs will increase the number of crabs for harvest. And secondly, there is a lack of experience in the developing world with modern fisheries management. There are just not many examples of effective fisheries management, and the institutional infrastructure to implement and maintain an effective management regime is often lacking. Given that the goal of having sustainable crab fisheries through effective management is long-term, enhancement is looked at to provide a quick solution to declining stocks.

The blue swimming crab does have characteristics that are important to considering it for enhancement. It has tremendous reproductive potential, with females capable of producing millions of eggs. The hatchery technology for rearing swimming crabs to various potential release sizes is well known, both for blue swimming crab in Asia and for the similar "blue crab" in the U.S.A. Blue swimming crabs, from the megalopa stage on, are armed with claws that coupled with a sturdy shell may be important to survival in the wild. And blue swimming crabs grow rapidly to the size that they recruit into the fishery, perhaps in as little time as six months in some environments. On the other hand, high fecundity is a demographic trait of species with high juvenile mortality, which is a feature of larval stages in Portunid crabs. And growth in crabs requires molting of their protective shells, which introduces a series of highly vulnerable episodes that must be mitigated in a hatchery and field.

Although enhancement is not typically part of a FIP, if done correctly enhancement could play a role in the restoration of crab fisheries. It is the purpose of this white paper to indicate the ways in which enhancement for the blue swimming crab may be used to improve stocks and the fishery, and to review the modern approach to enhancement built around a code of responsible practice. This code of practice can and should be used to identify legitimate opportunities for enhancement, plan an enhancement program around those opportunities, and choose methods that can be used to measure the effectiveness of the enhancement effort.

What Options Exist for Stock Enhancement?

Stock enhancement has often been used as a generic term referring to all forms of hatchery-based fisheries replenishment or enhancement. Researchers have classified the intent of stocking cultured organisms in aquatic ecosystems into various basic objectives. Together, they considered six basic types, listed here from the most production-oriented to the most conservation-oriented:

1. *Sea ranching* – recurring release of cultured juveniles into unenclosed marine and estuarine environments for harvest at a larger size in "put, grow, and take" operations. The intent here is to maximize production for commercial or recreational fisheries. Note that the released animals are not expected to contribute to spawning biomass, although this can occur when harvest size exceeds size at first maturity or when not all the released animals are harvested.

2. *Stock enhancement* – recurring release of cultured juveniles into wild population(s) to augment the natural supply of juveniles and optimize harvests by overcoming recruitment limitation in the face of intensive exploitation and/or habitat degradation. Stock enhancements can increase abundance and fisheries yield, supporting greater total catch than could be sustained by the wild stock alone. Stock enhancement also could be applied during periods when natural stock recruitment is minimal or episodically fails; although this requires a standby production system that can be activated when needed. However, such increases may be offset, at least in part, by negative ecological, genetic, or harvesting impacts on the wild stock component. Stock enhancements tend to attract greater numbers of fishers, which can offset expected increase in each individual's catch-per-unit-effort, unless the fishing effort is controlled.

3. *Restocking* – time-limited and selectively applied release of cultured juveniles into wild population(s) to restore severely depleted spawning biomass to a level where it can once again provide regular, substantial yields. Restocking requires that the release number to be substantial relative to the abundance of the

remaining wild stock, and that ecological and genetic integration of wild and cultured stocks be closely tracked, combined with very restricted harvesting.

4. *Enhancing Habitat Restoration* – involves supplying hatchery produced juveniles into areas that are being restored or managed in various ways. An example of this approach is the on-going effort for oyster reef rebuilding in Chesapeake Bay USA. More relevant examples exist for Portunid crabs in SE Asia where juvenile crabs have been supplied to mangrove restoration areas in small scale coastal sites of the Philippines and in larger mangrove silviculture restoration of the Mekong delta in Vietnam. If combined with habitat structure (such as dikes), this approach to enhancement could allow more control of the harvest and who benefits from its investment than a broad enhancement. Similarly, enhancing areas of restricted access (bays, estuaries) could have economic benefits. These approaches would require coordination with governmental land control or with traditional controls of, say, fishery cooperatives.

5. *Supplementation* – moderate releases of cultured organisms into very small and declining populations, with the aim of reducing extinction risk and conserving genetic diversity. Supplementation serves primarily conservation aims and specifically addresses sustainability issues and genetic threats in small and declining populations.

6. *Reintroduction* – involves temporary releases with the aim of re-establishing a locally extinct population. Continued releases should not occur, as they could interfere with natural selection in the newly established population. Fishing should also be restricted to allow the population to increase in abundance rapidly.

What Enhancement Options Might Work for the Blue Swimming Crab?
Looking at the various options for using enhancement with blue swimming crab, numbers 5 and 6 pertain to populations that have severely declined to the point of nearing extinction, or to locally extinct populations. The first four options may apply to the blue swimming crab. Numbers 2 and 3 have been tested successfully on a small scale for blue crabs in Chesapeake Bay. Number 4 has been applied to other Portunid crab species in SE Asia, especially in Vietnam. However, these are species (*Scylla* spp.) that are adapted to mangrove ecosystems, whereas the blue swimmer (*P. pelagicus*) is adapted to more open ecosystems such as sea grasses. Other valuable Portunid fishery species, such as "gazami" (*P. trituberculatus)*, could also be considered for this approach. Stock enhancement of gazami was conducted for more than 25 years as a "Put-and-Take" process of annually releasing 20 to 45 million hatchery-produced juvenile crabs in Japan. That large and long-term effort was summarized recently by Hamasaki et al. (2011), which we review below before returning to consider the blue swimmer crab in Southeast Asia.

Information from the Japanese work with gazami (*Portunus trituberculatus*)
Despite a large, long-term enhancement effort, analysis of the gazami fishery in Japan has not included large-scale tagging with micro-wire or "DNA fingerprinting".

Without that quantitative estimate of the contribution of hatchery crabs to the fishery, the efficacy of the Japanese effort has been questioned. Instead, Japanese analysis comes from two very small-scale micro-wire tagging studies and from correlations of crab catch with hatchery releases, as summarized below.

Hamasaki et al. (2011) summarizes the available information for the Japanese gazami effort, some of which we considered previously in our development of the Chesapeake blue crab hatchery and release research. However, our review of this paper indicates a number of confusing and apparently contradictory points. Here are the key points, as we see them:

- The Japanese program has been a "put-and-take" enhancement effort, because hatchery-produced juveniles released in spring grow quickly to fishable size by the end of summer and are caught by the fishery within 6-8 months, before they reproduce and contribute to the spawning stock.
- The scale of production nationally has been large, ranging from 18 million to 41 million juveniles released annually from 1983 to 2005. This production was accomplished as a combined effort of local, prefectural and national hatcheries. It has largely focused on gazami (*Portunus trituberculatus*), with some work on blue swimmer crab (*P. pelagicus*) and mud crab (*Scylla paramanomosain*).
- In 2007-2008, focused studies were conducted to test hatchery survival to C1 (i.e., larval survival to first crab) in mass production of gazami (14 hatcheries, 340 trials) and also included some other species – blue swimmer crab (4 hatcheries, 51 trials) and mud crabs (2 hatcheries, 17 trials). The data indicate that larval survival to C1 in hatcheries was similar for the 3 species. Many trials (20-30%) resulted in survival of less than 5% but occasionally improved to over 50%, and mean survival was 10-13%. Disease and nutrition were key problems in the hatcheries, but more than 60% of larval mortality occurred from unknown causes in hatcheries. The Japanese are focusing research on disease control and nutrition for larvae. During our 10-year R&D work on hatchery production of Chesapeake Bay juvenile blue crabs, we were able to achieve survival rates of 80% through the 8 zoeal stages (versus 4 zoeae in gazami) to megalopae, and 40% from hatch to C7 juveniles by developing protocols for mass production of C7 juveniles. We achieved these improved survival rates by optimizing larval rearing in biotic and abiotic conditions and using several approaches to reduce cannibalism at the nursey stage.
- Only small juveniles (stages C2-C7) were released because releasing larvae was judged to be ineffective. However, the vast majority of gazami releases were C2 stage juveniles (7-10 mm) because rearing to C4 stage (20 mm) resulted in juvenile survival in the hatchery dropping from 75% to 20%, which was unacceptable to Japanese hatcheries. However, no information was provided about efforts to reduce cannibalism (such as adding structure into hatcheries as our blue crab project did on small scale). Released mud crabs (*Scylla paramamosain*) were apparently larger in size (12-15mm); and one field experiment in small inlets that used micro-wire tagging for mud crabs 30-68 mm in size were able to detect 12.5% recapture rates
- Their analysis of crab catch as a correlation with hatchery releases is

confusing, because our examination of the data does not seem to support the authors assertions. Specifically:

- Looking at nation-wide data provided separately by Hamasaki for annual releases from 1983-2015 and catch from 1956-2015, the plot appears to show a decline in catch correlating with declining hatchery releases. However, our plotting and analysis of these national data as a regression of catch versus release does not show a significant correlation at all.
- Hamasaki et al. (2011) broke down the data by large regions, but it is very difficult to assess the analysis because their graphs of catch are on separate axes from releases with confusing figure labels and legends. The Seto Inland Sea received the largest numbers of released juveniles and had the largest annual catches. In looking at plots in Hamasaki et al (2011) for catch versus juveniles released seem to show positive correlations for the Seto Inland Sea, East China Sea, Central Pacific and Northern Sea of Japan. But there is no apparent correlation for 3 other areas (North Pacific, South Pacific, Western Sea of Japan).
- Regression analysis of catch versus release in Hamasaki et al (2011) appears to show significantly positive correlations for several areas (as above). However, comparisons of the sample size for the data in the regressions does not appear to correspond to the data plotted. The N's listed for the regressions (N=4 to 8) are much smaller than the number of points in the plotted graphs for 1977-2006 (N=29); and therefore we suspect that data were selectively analyzed in some undetermined way.
- Despite this unclear analysis, the authors ascribe average contributions of hatchery release to 31% of the catch in the Seto Inland Sea, 30% in East China Sea, and 25% in the Central Pacific. It is not clear how this was calculated because the released crabs were not identified with micro-wire or DNA technologies. Similarly, it is not clear how the authors conclude that hatchery releases in the Seto Inland Sea increased landings by 33.6 g per release.
- Analysis of release-catch experimental studies for two small bays indicated a small positive relationship of about 2.4 g gained in catch per juvenile gazami released; but only a 1.5% contribution to the catch. However, by releasing into small bays, the tests were contained in a well-defined area; and importantly, these studies included micro-wire tagging of 3000-4000 juveniles that could be detected in the local fishery markets. However, in addition to releases of very few crabs, the number of released cohorts (N= 11 for gazami; N=4 to 12 for mud crabs) was small and catch was highly variable and only weakly significantly correlated for gazami in one bay. Because these studies used micro-wire tagging to show hatchery crabs actually reaching the seafood markets, we used these studies to help guide our research strategy for Chesapeake blue crabs.

Recommendation for Blue Swimmer Crab.
In the case of the blue swimmer crab, “Sea Ranching” and “Put-and-Take Enhancement” would require endless hatchery production on a large scale, especially if applied to larval releases, which disperse widely and which are sure to have poor survival and returns. Such an approach would be ill-advised and prohibitively costly on a scale that would be meaningful for the vast region of the SE Asia fishery. Instead, highly focused “Stock Enhancement” that is best described as “Restocking” is a more promising strategy. “Restocking” involves the release of hatchery-reared crabs into the wild in carefully selected locations where they will grow to reproductive size and increase the reproductive output of targeted segments of the fishery sock. The goal of restoring fishery production would focus on significantly increasing reproductive females; however, males might be harvested after mating and thus provide some direct augmentation to the fishery.

Rough cost analysis of crab enhancement? What scale of releases might make a difference? What’s the relative cost of releasing zoea, megalopa and juveniles?

A cost analysis for hatchery production of juvenile crabs in Southeast Asia is difficult, because the analysis depends a great deal on specific location, time and the scale of production; and the Council has not indicated anything about the scope of their interest. That said, the publication by Hamasaki et al. (2011) on Japanese gazami production gives some information. They indicate that the cost of released juveniles at the C2 stage (about 7-10 mm) is 5 yen (say 4.5 U.S. cents), but this is for production and release of 18 -40 million juveniles from many hatcheries per year. It does not include the cost of fishing. Increased scale of production reduces the cost per released crab; but production at the scale of the Japanese requires a large commitment of infrastructure and staff. Our small-scale production of Chesapeake blue crabs indicated a cost estimate of 25+cents for C7 (20mm) juveniles in the range of 50,000 -500,000 juveniles; but this is in an experimental research setting and we expect the cost to decrease with larger scale production.

The cost of releasing larvae would be quite low, because it does not require much effort. However, as we have repeatedly said, the value of the effort is a balance of cost and benefit. Releasing larval stages will result in no gain because of very high mortality and wide dispersal, so that no matter how low the cost, there will be no gain. This would be equivalent to throwing money into the sea. The cost of producing larger, more advanced life stages increases significantly, especially for cannibalistic portunid crabs; but the survivorship and chance of increasing production also increases greatly.

The key research question is to determine the cost-benefit equation for the most appropriate stage and size at release, and to proceed incrementally to test for effects and value of increasing scale. Moreover, a crucial aspect of this is to determine the behavior of the size/stage at release, especially if there is a key switch in behavior from widely dispersing to more sedentary behavior. For both blue crabs and gazami, this switch is at about 20 mm – C7 for blue crabs and C4 or C5 for gazami. The Japanese proceeded to release at C2, because they decided that the cost of rearing through 2 or 3 more juvenile molts was too expensive for their hatcheries. Consequently, in our judgement, they lost a great deal of the production value of their releases, and it is difficult to see a strongly positive increase in their catches (see below). The behavior of juvenile blue swimmer crabs is not well-documented and would be a key research priority for the proposed project.

The hatchery releases of juveniles in Japan declined markedly from a peak of 41 million in 1997 to the lowest level in 2005. According to Hamasaki, this progressive decline resulted in large part from reduced government spending on hatcheries during economic difficulties, indicating to us that benefits were not balancing costs.

Steps to Test Hatchery Production and Releases for Spawning Stock Enhancement. In addition to developing hatchery production capabilities, several key elements would be essential for success in a Restocking Strategy.

(1) Impose effective minimum size at harvest. The fishery – at least in the enhancement area – would need to effectively impose a minimum harvest size larger than maturation and first reproduction. In combination with prohibiting harvest of berried females, this size restriction is needed to ensure that hatchery produced crabs actually contribute to recruitment and enhancement of the stock.

(2) Establish best size/stage of release. A second key aspect of a Restocking Strategy is the need to identify the appropriate life stage for release. Release of large numbers of larvae (zoea or megalopae) is likely to be fruitless due to their high rate of mortality and wide dispersal. Rather, most successful stock enhancement programs release a juvenile stage that (A) bypasses earlier stages with highest levels of mortality; and (B) exhibits a shift to more sedentary behavior for feeding and growth to maturity. The most effective life stage needs to be determined experimentally, and a stock enhancement research program also needs to consider the cost of hatchery rearing early life stages to the point of release. In blue crabs (*Callinectes sapidus*) in the USA and some other Portunid species fished extensively in Asia (*Portunus trituberculatus*), research has determined that certain early juvenile stages move into nursery habitats where they stop dispersing to feed and grow (approximately 20 mm carapace width – C7 juvenile instar in *C. sapidus*; C4-5 in *P. trituberculatus*).

(3) Determine "enhanceable sites". It is crucial to identify sites and/or times where the fishery stock is, in fact, "recruitment limited". Adding juveniles to a site will be completely ineffective if the stock production is actually limited by other factors, say, food availability, refuge habitat, predators, or disease. Experimental identification of "enhanceable sites" is vitally important for success. Moreover, although the scale of enhancing the full geographic scope of blue swimming crab fisheries would be a daunting challenge, there may be strategic localized sites that are key "source populations" for regional fisheries. This consideration follows from widely accepted ecological theory of "meta-population dynamics", whereby populations are composed of both "source" and "sink" sub-elements. If these component areas could be identified, then a stock enhancement strategy

could avoid attempting to enhance “sinks” and selectively target “source” areas. This concept is also an important feature of “Marine Protected Areas (MPAs)” in conservation strategies. Distinguishing these areas requires research to determine the scale of dispersal of the life stage released during enhancement. It also requires a release strategy that identifies optimal sites for growth and survival of the hatchery products. This research approach was applied to hatchery-reared blue crabs released into small bays in Chesapeake Bay, where production of adult crabs was increased 2-10 fold over natural production and 2-times the production of pond-cultured crabs in China, and without the cost of feeding pond-reared crabs. Importantly, the quantitative evidence of greatly increased production proved that these sites were in fact “recruitment limited”, and thus good locations for the enhancement approach. Further, the resulting adult crabs were slated to augment the reproductive stock, although males would supplement the fishery after mating.

(4) “Tag” all hatchery-produced crabs. A successful Restocking Strategy for fishery enhancement requires that hatchery-produced individuals be “tagged” so that they can be distinguished from “wild” individuals. This is essential to quantify contribution of hatchery releases to the stock and/or catch. On small scales, tagging has been accomplished using micro-wire tagging and/or elastomer injections (Northwest Marine Technology). However, modern genomic technology now allows for “DNA fingerprinting” of hatchery individuals on a large scale. DNA fingerprinting also has an important advantage of allowing us to ensure that hatchery releases do not alter the genetic make-up of the wild stock. As Leber points out in a recent publication:

*“A symptom of [*many enhancement efforts*] is the relentless concern among stakeholders and hatchery managers about the numerical magnitude of fish released, rather than on the effective contribution of the hatchery program to fisheries management goals. The thinking behind this approach apparently is “grow and release lots of hatchery fish and of course they’ll survive and add to the catch” without realizing the need to optimize release strategies or that the impact from stocking could in fact be a negative one on wild stocks if certain precautions are not taken.”*

(5) Apply genomic technologies. As we did for the blue crab in the Chesapeake Bay, we proposed to develop mitochondrial and microsatellite DNA analysis technologies for blue swimmer crab. This was not done for gazami in Japan, and prevents rigorous assessment of enhancement contribution to the fishery. We will use these technologies to measure genetic diversity, both as a tool for tracking the contribution by hatchery juveniles and as a direct measure the genetic diversity of the wild stocks. Based on our work with blue crabs in North America, genetic diversity of the population is probably extremely high. To maximize diversity of juveniles released, we will select brood stock for hatchery production from widely varied individuals and never re-use females for multiple broods or use F1 generations. This will help assure that enhancement does not adversely impact genetic diversity of the wild stock. It is also worth remembering

that an on-going intensive fishery also can have significant impacts on the genetic diversity of the stock. Managing for enhancement of the reproductive stock using genomic tools can insure that diversity is also managed.

“Restocking” is the most logical and realistic option for blue swimming crab in Southeast Asia. It is quite likely that areas exist where fishing pressure has reduced crab populations to a level where reproduction is limited. Restocking into this area could restore the spawning biomass to a level where it can contribute to recruitment, both in this area and in the wider sea. The restocking effort would require the release of hatchery-grown crabs in numbers that would substantially increase the crab abundance in the selected area relative to the remaining wild stock. Restocking would be most effective if harvests from the area are restricted. Once the crab population in the chosen area is restored to the desired level, the restocking program can be ended, or it could be shifted to other times and locations where recruitment limitation was evident. Given that hatchery methods for raising juvenile Portunid crabs are well known for several species, a crucial requirement in this approach would be to determine sites that are in fact “recruitment limited” and are scaled appropriately to pilot tests of enhancement. This determination would require establishing a hatchery for *P. pelagicus* that could produce juvenile crabs to experimentally test proposed field release sites. Importantly, it would also require developing an effective way of marking hatchery produced crabs to distinguish them from wild crabs. We propose to develop and use DNA “fingerprint” technology to identify the hatchery produced crabs post-release.

As a model to guide this effort, we refer to a restocking program for the “blue crab” in the Chesapeake Bay USA (Hines, Zohar and others, see references below). After developing efficient blue crab hatchery technologies, this program showed that stock enhancement of hatchery-reared juveniles released into appropriate sites resulted in 100-300% increase in mature blue crabs. Further, a key aspect of this research showed how hatchery crabs could be tagged/ marked to measure crab enhancement in the field – through existing micro-wire technology for small-scale releases of 10,000-50,000 juveniles, or through genomic tagging (DNA fingerprints) for larger batches of juveniles. Although this Chesapeake program was not implemented for lack of funding, we propose that this approach could be applied to blue swimming crab. Given that the purpose of restocking is to establish a spawning population of crabs, it is important to ensure that the genetics of the released animals is very similar to the wild stocks.

Whether stock enhancement or restocking is pursued, it is important to understand that survival and recruitment to the fishery following hatchery releases is a complex issue. It requires much greater understanding about the fishery, hatchery crab performance and biological and ecological factors in the wild than simply asserting that "the catch is down and releasing large numbers of fish (or crabs) will bring it back up”. It is also very clear that hatchery-based stock enhancement or restocking can only be effective as part of a broader program that also manages the fishery and protects spawning stocks and nursery grounds.

What Role Can Enhancement Play in Fisheries Improvement Programs?

Enhancement is not recognized as a core element of FIPs by any of the leading organizations that produce fisheries sustainability standards, perform fisheries certifications or rate fisheries as sustainable. Many of the leading NGOs in this field are much more concerned about the possible negative effects of enhancement than about the possible contribution enhancement might make to fishery. These possible negative effects include weakening the genetic integrity of wild stocks and increasing disease risk. Some of the current debate about hatchery enhancement of salmon has brought these issues into focus. If we are to use enhancement to augment populations of blue swimming crab, we'll have to carefully consider the possible negative effects or face difficult challenges from the environmental NGO community.

Enhancement, if successful, may be part of an overall management strategy for blue swimming crab. The Crab Council, based on examples of effective fisheries management of other crustacean species, believes that in the long run management of blue swimming crab fisheries will be primarily based on establishing and enforcing a minimum harvest size that allows for reproduction and on protecting berried females. In a workshop held in Bangkok during November 2015, it was reported that harvest of buried females and crabs as small as 85-90 mm carapace width were being sold into the processing plants. Minimum size at reproduction is believed to be approximately 127 mm, so that limiting harvesting to sizes above 130-135 mm would be an essential and effective first step in recovery of the fishery. Several fishery scientists pointed to a potentially effective way that the FIP could achieve these goals, even in the absence of governmental regulation or enforcement. Specifically, processors must cease accepting and paying for under-sized crabs and buried females. The workshop scientists hypothesized that fishermen will quickly adjust their gear (e.g., increase net mesh size) to avoid smaller crabs.

So How Can We Proceed with Enhancement?

The field of marine fisheries enhancement has progressed significantly in the last two decades. Science in this area is rapidly growing, both because of the debate about the effectiveness of enhancement and the need for quantitative evaluation, and because of advances in aquaculture, genetics, tagging and fisheries modeling. A clear process for developing, evaluating and using enhancement has emerged, and this effort has been led by Leber, Blankenship and others. This process, taken from recent papers by Dr. Leber and adapted here for blue swimming crab, is known as the "responsible approach to marine fisheries enhancement". This approach has the following stages, which were successfully adapted in the above mentioned, most comprehensive stock enhancement ever for a crab species, the blue crab in the Chesapeake Bay. It is important to the NFI Crab Council and to future Council funding for enhancement programs that this process and these guidelines be followed.

Stage I: Appraisal and Goal Setting	
1	Understand the potential role of enhancement within the fishery system

2	Engage with fishery stakeholders to develop a rigorous and accountable decision making process
3	Select a target stock and area for enhancement to take place
4	Conduct a stock assessment to show that the target stock is recruitment overfished
5	Quantitatively assess potential contributions of enhancement to fisheries management goals
6	Asses the social and economic benefits, and costs of the enhancement

Stage II: Research and Pilot Studies	
1	Choose an enhancement system suitable for the fishery and management objectives
2	Use genetic resource and health management protocols to avoid negative effects on wild populations
3	Ensure that the released crabs can be identified
4	Use an empirical process to determine an optimal release strategy

Stage III: Implementation and Management	
1	Define enhancement goals and the methods that will be used to measure success
2	Develop and implement effective governance including a management plan
3	Assess enhancement effectiveness including a cost-benefit analysis
4	Assess and manage ecological impacts
5	Use adaptive management

What methods are available for tackling enhancement?

Given the process for implementing enhancement outlined above, there has been considerable progress in thinking and in technology development that can be helpful. Most important has been the development of quantitative tools for measuring the success of enhancement programs. Methods for hatchery rearing of Portunid crabs have been widely established in the USA, China, Japan, Vietnam, and Philippines. Tagging crabs as small as 10mm with coded wire tags has been shown to be feasible, and crabs smaller than that can be tracked using genomics (we will have to develop the DNA fingerprints specific for the blue swimming crab). These tagging techniques are necessary to determine optimum release strategies, including size at release, location of release, time of day of release, season of release, optimal release habitats etc., as well as to monitor the fate of the hatchery crabs post-release.

However, dispersal behavior and optimal nursery habitats for the blue swimmer crab are not well understood. Research would be needed to test the feasibility, optimization and economics of hatchery releases, including the optimal size/life-stage for release. Specifically, an experimental hatchery would be needed to produce enough tagged juveniles that can be released in controlled quantitative field experiments to determine an effective release strategy. If successful, then that model strategy could be scaled up. Importantly, the sites of release should be coordinated with, and linked to, improved fishery management, potentially with parallel field experiments to test the efficacy of increasing minimum catch size to 130 mm.

The former SEAFDEC aquaculture facility at Iloilo in the Philippines is a potential site for this feasibility study in partnership with the Aquaculture Research Center of the Institute of Marine Environmental Technology of the University of Maryland in Baltimore, Maryland, and the Smithsonian Environmental Research Center in Edgewater, Maryland. A goal would be to work with Philippine scientists, students and the local fishery to re-establish an experimental hatchery and appropriate field sites for the project. Researchers in the USA would help provide scientific support to train Philippine researchers and fishery managers with sponsorship by the Crab Council. This project could serve as a model for training and exported to other areas in Southeast Asia.

The Bottom Line

The Crab Council understands the keen interest that many of the producer associations have in enhancement. However, the Council believes that the main emphasis of the FIPs needs to be on the core elements of fisheries sustainability as presented in the Marine Stewardship Council standards. The Council has indicated that it is willing to support enhancement programs; but those programs need to align with the "responsible approach to marine fisheries enhancement", as well being based on lessons learned and success of the blue crab enhancement program in the Chesapeake Bay.

We all hope that hatchery-based enhancement of blue swimming crab populations can be successful and play a role in improving populations and supporting a productive and economically viable fishery. We have the hatchery and enhancement experts and tools to determine optimum release strategies, and the tools to measure overall success and economic viability and we know how to address potential negative effects.

Acknowledgments & References

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Much of this discussion is based on the 2013 paper by Dr. Ken Leber from the Mote Marine Laboratory in the U.S.A. (Marine fisheries enhancement, coming of age in the new millennium, P. Christou et al. (eds.) *Sustainable Food Production*, Springer Science + Business Media, New York, 2013). We encourage those interested in pursuing enhancement of blue swimming crab to read the complete paper (we can

provide a copy), and to seek out Dr. Leber and his associates for guidance. A good website to pursue stock enhancement is run by the Science Consortium for Ocean Replenishment (SCORE). The web address is:
http://www.stockenhancement.org/about/responsible_approach.html

In addition, an overview of stock enhancement research on blue crabs in Chesapeake Bay, led by the authors of the current document, may be found in two papers:

Zohar, Y., A.H. Hines, O. Zmora, E.G. Johnson, R.N., Lipcius, R.D. Seitz, D.B. Eggleston, A.R. Place, E. Schott, J.D. Stubblefield, and J.S. Chung. 2008. The Chesapeake Bay blue crab (*Callinectes sapidus*): A multidisciplinary approach to responsible stock enhancement. Reviews in Fisheries Science 16:25-35.

Hines, A.H., E.G. Johnson, A.C. Young, R. Aguilar, M.A. Kramer, M. Goodison, O. Zmora, and Y. Zohar. 2008. Release strategies for estuarine species with complex migratory life cycles: Stock enhancement of Chesapeake blue crabs, *Callinectes sapidus*. Reviews in Fisheries Science 16:175-185.

The summary paper for put-and-take stock enhancement in Japan is:

Hamasaki, K., Y. Obata, S. Dan, S. Kitada (2011). A review of see production and stock enhancement for commercially important portunid crabs in Japan. Aquacult Int.19:217-235.