Overview of sea cucumber aquaculture and sea-ranching research in the South-East Asian region

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Abstract

South-East Asia has traditionally been the global centre of production of tropical sea cucumbers for Chinese markets. Early research into culture methods took place outside this region, notably in India, the Pacific region and China. However, recent investment in *Holothuria scabra* (sandfish) culture has led to some significant advances within this region. The Philippines and Vietnam have been at the forefront of recent efforts, with involvement from substantial national programs and local institutions as well as international donors and scientific organisations. Smaller programs are ongoing in Thailand, Malaysia and Indonesia. Recent advances and simplifications in hatchery techniques are a major step forward, having promoted the development of experimental-scale sea-ranching ventures, and given rise to a small, commercial pond-based culture industry in Vietnam. Technology developments in nursery systems are likely to provide opportunities for culture enterprises in a broader range of environments than is now possible. A major research thrust in the Philippines towards developing cooperative sea-ranching enterprises has demonstrated good potential, and institutional/legislative arrangements to ensure adequate property rights have been tested. Rotational culture with shrimp is proving successful in Vietnam, while the possibility of proximate co-culture of sandfish and shrimp has largely been ruled out. Small-scale experiments in the Philippines raise the possibility of co-culture in ponds with a number of finfish species. Current research directions are looking at diversifying technology to increase success in a range of coastal conditions, better understanding the social and biophysical conditions required for success, and finding ways of effectively scaling-out developed systems and technology.

Introduction

Globally, the husbandry of tropical sea cucumbers appears 'on the cusp' of success—we are starting to see the construction of commercial-scale hatcheries and farms and, at the other end of the spectrum, sustained forays into community-based culture and sea-ranching systems (e.g. see papers in these proceedings). However, most have yet to demonstrate commercial viability, and many stakeholders are interested to see the outcomes of current pilot ventures. This situation is a product of both the considerable advances that have occurred over the past decade in hatchery and grow-out technology, and the resistance of bottlenecks to unconstrained success. The widespread and growing interest in this commodity is indicative of strong market-based drivers to increase production of sea cucumber (Brown et al. 2010). This has a dual impact of increasing pressure on wild stocks already in crisis, yet also opening the door to opportunities for new coastal livelihoods based on sustainable approaches to

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culture and sea ranching. This symposium is therefore very timely, and allows researchers to take stock of current benchmarks for various stages of production, and gain a shared understanding of bottlenecks, constraints and critical areas for further research.

As the historical global centre of tropical sea cucumber harvest (e.g. Gamboa et al. 2004; Schwerdtner Máñez and Ferse 2010), countries throughout South-East Asia retain a keen interest in developments in culture and sustainable resource management, and, in many instances, sit at the forefront of industry and technology development. The precipitous decline in sea cucumber stocks throughout the region (Conand 2004; Bell et al. 2008) has had dire implications for coastal livelihoods in some areas. While not well documented (but see Shiell and Knott 2010; Wolkenhauer et al. 2010), it is likely that the wholesale removal of sea cucumbers has contributed to reduced resilience among coastal ecosystems.

Social impacts of this decline go beyond lost income. Traditionally, a significant part of the sea cucumber resource in South-east Asia has been obtained by 'gleaning' in the shallows (Choo 2008). Such fisheries provide a disproportionate social benefit, as they have no capital entry requirements (i.e. they are accessible to those without the means to invest) and are accessible to women and children. These highly vulnerable shallow resources are invariably, however, the first to disappear under conditions of uncontrolled harvesting. Harvesting deeper resources becomes more capital intensive (requiring a boat and diving gear) and is generally the exclusive domain of men. A more insidious effect of overharvesting is seen as sustained pressure drives fishers deeper in search of viable stocks; diving-related accidents leading to permanent disability or even death are all too common in villages where sea cucumber harvesting plays an important role in livelihoods. Clearly, the restoration of livelihoods based on near-shore sea cucumber harvest and improved governance of the resource have great potential to benefit coastal communities throughout the region.

In addition to sea ranching or enhancing/restocking wild stocks, sea cucumber culture can play a critical role in restoring resilient livelihoods among coastal aquaculture farmers. Shrimp production dominates this sector in much of South-East Asia. The disease-related serial boom-and-bust cycle that has characterised shrimp production globally (Dierberg and Kiattisimkul 1996) is strongly evident in this region. Such cycles leave casualties, and prominent among them are small-scale producers who typically have limited reserve capital and struggle to recover from losing entire crops to disease (Mills et al. 2011). Sea cucumbers show substantial promise as a sustainable alternative species that can be grown instead of, or with, shrimp, and should provide a more tenable risk profile. Currently, up to 12 farmers are involved in sandfish pond farming in Vietnam.

Recent developments in sea ranching and pond farming in the South-East Asian region are explored here, concentrating on *Holothuria scabra* (sandfish), as this is the focus of current development efforts. The paper does not seek to provide a comprehensive review of all activities in the region, but rather is a 'selective highlights' package that may be somewhat biased towards the lead author's experience. It is intentionally biased towards research that does not appear elsewhere in this volume; much of the current research being undertaken in the region is covered in some depth by others in this symposium. The paper is organised by ontogenic staging rather than geography, considering hatchery, nursery, growing-out and postharvest issues separately.

Hatchery and nursery production

Simplified hatchery systems

The earliest reports of hatchery research on sea cucumbers date back as far as the 1930s (see Yellow Seas Fisheries Research Institute 1991). Today, the culture of temperate species (notably *Apostichopus japonicus*) is in full-swing in China and Japan (Chen 2004), but commercial-scale hatchery production of tropical species is only now becoming a possibility. Considerable research effort in India (James et al. 1994) and the Pacific region (Battaglene et al. 1999) laid the foundations for culture of *H. scabra* on a commercial scale. These techniques were further refined through the work of the WorldFish Center and partners in New Caledonia, and published in a comprehensive hatchery manual for *H. scabra* (Agudo 2006). Recent advances have seen these techniques further refined, simplified and customised for low-investment systems suitable for developing countries (Duy 2010, 2012; Gamboa et al. 2012). Among key modifications and simplifications that have improved success rates are:

- a reduction in requirements for live feed production, to a point where a single species (*Chaetoceros muelleri*) can be used

- low-density culture of larvae (around 0.3 larvae/mL)
- the use of settlement plates coated with a dried algal (*Spirulina*) paste rather than previous techniques of natural conditioning of plates with benthic diatoms.

These techniques reduce the complexity of culture systems and the incidence of infestations by parasites or copepods, and have led to substantially increased survival rates. Experience from Vietnam and the Philippines suggests that a current 'benchmark' for survival from egg to 5-mm juveniles is around 2.5%. Experience from the increasing number of pilot-scale hatcheries developed in various locations indicates that, almost invariably, 'off-the-shelf' hatchery systems will not be adequate, and a degree of customising is required (e.g. Gamboa et al. 2012) to achieve acceptable production.

A 'state-of-the-art' hatchery system has recently been constructed at the Southeast Asian Fisheries Development Center – Aquaculture Department[a] (SEAFDEC–AQD) in the Philippines (Figure 1), and several training courses on hatchery techniques have now been conducted. The facility is set to play an important role in further training and the provision of juveniles for further sea-ranching and pond-culture trials in the Philippines.

Nursery systems

Typically, some 35 days after settling, at a length of around 5 mm, sandfish juveniles are moved from settlement tanks to a nursery system. While hatchery-based raceway systems have proven successful at an experimental scale, it is difficult to see how such systems could be workable at a commercial scale—the costs of the tank area and the water supply required are high. A range of nursery systems has been trialled in Vietnam and the Philippines under Australian Centre for International and Agricultural Research (ACIAR) and national funding. Fine-mesh nets (referred to as 'hapas') are now routinely used (Pitt and Duy 2004) and have been extremely successful in ponds in Vietnam (Figure 2, left), resulting in high survival and growth rates. Juvenile sandfish in hapas feed on algal fouling that grows on the hapa mesh. In the Philippines it has proven difficult to find ponds with adequate seawater exchange rates to maintain the salinities required for nursery stages. In response, effort has been directed at developing floating hapa systems that can be deployed in sheltered marine embayments (Figure 2, right). These systems have great potential for community sea-ranching operations—they allow the transport of juveniles from hatcheries at an early stage, resulting in low mortality; and engage communities in the production cycle at the earliest opportunity, maximising potential financial benefits (Juinio-Meñez et al. 2012a).

Hapa-based nursery systems are commonly used until juveniles reach a weight of 2–5 g. In previous pilot trials of both sea ranching (Juinio-Meñez et al. 2012a) and pond culture (e.g. Pitt and Duy 2004), and in commercial culture in Vietnam until recently, juveniles have been released to their grow-out environment at this size. An 'advanced nursery' stage has now been introduced in Vietnam. Ponds with an optimal seawater supply and muddy-sand, organically rich sediment are seeded with 2–5-g juveniles from hapas at a high density of up to 50,000 juveniles/ha (compared with 10,000 juveniles/ha for grow-out). These are grown to up to 50 g and farmers have the choice of purchasing either small juveniles or advanced juveniles for around twice the price. There are two major drivers behind the development of this system. First, the typical grow-out time from a 2–5-g juvenile to a 350–400-g saleable product in central Vietnam is around 12 months. However, in many ponds there remains some risk associated with growing sandfish through the wet season—pond stratification and low salinities may cause reduced growth rates or mortalities if not well handled (see 'Pond culture' below). By seeding ponds with advanced juveniles, the grow-out period can be reduced to 7–9 months, so that the wet season can be avoided. Second, the survival rate of larger juveniles is invariably greater following release (Purcell and Simutoga 2008), partially offsetting the additional cost of larger juveniles. This advanced nursery system allows for the ponds with the best seawater supply to be used productively for advanced nursery culture throughout the wet season, with a larger number of lower quality ponds used for grow-out in the dry season.

Grow-out

Pond culture

Pond culture of sandfish is an attractive proposition for several reasons. The high but often transient profitability of shrimp culture, combined with the

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Figure 1. Purpose-built sea cucumber hatchery at the Southeast Asian Fisheries Development Center – Aquaculture Department, Iloilo, the Philippines (Photos: J. Zarate)

Figure 2. Nursery hapas in a pond at the Research Institute for Aquaculture No. 3 National Seed Production Center, Vietnam (left); and floating hapas in an enclosed marine embayment established by the University of the Philippines Marine Science Institute (right) (Photos: D. Mills (left) and C. Hair (right))

extreme risk profile associated with this activity, have resulted in a situation where smallholders have tended to lose out to large corporate interests with the financial backing to recover from stock crashes. Intensification of culture methods has also led to severe fouling in ponds, resulting in anoxic sediments and the ultimate abandonment of ponds. Sea cucumbers potentially represent a lower-risk investment for smallholders. As a species that is low on the food chain, they provide better environmental outcomes than shrimp farming, and do not require feeding if stocked in ponds previously used for shrimp culture.

There are, however, biophysical issues that ultimately restrict the number of shrimp ponds suitable for sandfish culture. Most critically, the vast majority of ponds were established for growing *Penaeus monodon* (tiger shrimp); to maximise yield of this species, brackish water is required. As a result, ponds were generally located with good access to a freshwater source, and it may be difficult to maintain the salinities required to optimise sea cucumber growth. *Holothuria scabra*, while somewhat tolerant of reduced salinity (Pitt et al. 2001; Mills et al. 2008), grows best in marine conditions

(30–34 ppt as a general rule). In many culture trials, sudden salinity drops due to storm action and tropical downpours have resulted in high mortality (Pitt et al. 2001; Lavitra et al. 2009; and personal experience of two of the authors—N. Duy, Vietnam; C. Raison, Thailand). Notably, these issues have largely been circumvented in Vietnam, where several farmers are producing *H. scabra* in commercial quantities. Mills et al. (2008) assessed survival and growth of sandfish through the wet season by direct monitoring of commercial ponds and through farmer interviews. Although growth rates declined rapidly, survival of sandfish enclosed in nine pens within three operating commercial ponds was 100% through the 2007–08 wet season, which included nine consecutive days of exceptionally heavy rains. Interviews with farmers revealed that, while most lost sandfish due to freshwater ingress during their first year of production, simple management protocols such as ensuring regular tidal water changes or, in some instances, using paddlewheels to 'de-stratify'[b] pond water resulted in very high survival rates. It should be noted, however, that ponds used for sandfish culture in central Vietnam have very good canal systems, and tidal regimes mean that substantial water changes are possible on most tides. Ponds with similar characteristics have proven difficult to find in other countries.

Without a doubt, one of the greatest restrictions on profitable pond-based sea cucumber culture is density limitation of growth rates. Past research (Battaglene et al. 1999) suggests that growth rates decline when densities exceed 225 g/m^2, while empirical evidence from Vietnam suggests that a density of around 1 animal/m^2 in coastal ponds (without adding feed) provides an optimal balance between growth rates and total production for a target harvest size of 300–400 g (Pitt and Duy 2004).

Recent experiments at the Shrimp Genetic Improvement Center in Thailand (C.M. Raison, unpublished data) looked at the relationship between stocking density, feed rates, growth and survival. An orthogonal experiment compared growth and survival over 36 days among treatments comprising two densities of early juvenile sandfish (average individual weight 1.74 g at densities of about 50 and 85 g/m^2), and five feeding rates (0.05–0.25 g/treatment/day of commercial shrimp starter feed). Preliminary results indicate a strong positive relationship between feed rate and growth rate, and a weaker negative relationship between stocking density and growth rate. While by far the highest growth rates were seen among animals held at low density with high feed rates (average 234% weight gain per individual, compared with 39% for high density, low feed rate), the greatest overall gain in biomass was seen in the treatment with high density of sandfish and moderately high feeding rate. It was also clear from results that overfeeding can be an issue—survival was reduced at the highest feed rates. Where ponds already have rich organic sediments, the addition of feed may cause higher mortality rates. In addition, where nutrient conditions indicate that higher production rates might be achieved through feeding, these need to be offset against additional labour and feed costs. Results also show that organic loading in sediments can be too high for sandfish survival, so there is a limit to the effectiveness of sandfish for bioremediation in these situations.

Co-culture: Pond-based co-culture systems involving sea cucumbers are conceptually very attractive. A pond containing only sea cucumbers for the duration of a grow-out cycle 'wastes' the space available in the water column, while the pond sediment bioremediation potential of sandfish has the potential to improve pond conditions for co-cultured species. Similarly, sea cucumbers grown under sea farms are seen as having the potential to alleviate fouling problems, while enriched deposits from faeces and food waste may increase the growth rates of sea cucumbers (Slater et al. 2009). Unsurprisingly, interest in co-culture in ponds has centered on shrimp, as most coastal ponds have been constructed for shrimp culture, and shrimp are a high-value commodity. Unfortunately, this match gives way on the reality of agonistic interactions, and sea cucumbers invariably come off second best. Trials with *Penaeus monodon* (tiger shrimp; Pitt et al. 2004) and *Litopenaeus stylirostris* (Pacific blue shrimp; Purcell et al. 2006; Bell et al. 2007) showed some initial promise; however, larger scale trials proved unsuccessful.

Recent trials in Vietnam by Mills and Duy (unpublished data) on *Litopenaeus vannamei* (white leg shrimp) perhaps ended the shrimp proximate co-culture ideal. This trial was set up under parameters

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[b] Stratification occurs when low salinity water sits on top of higher salinity water in the ponds, isolating the higher salinity water from the atmosphere. This may lead to reduced oxygen levels in the saline water, and a so-called 'lens effect' caused by the upper layer of less saline water. This is said to result in increased temperature in the saline water, which further increases oxygen demand and compounds depletion.

that should have greatly favoured sea cucumbers. In previous trials, postsettlement juvenile sandfish were tested with shrimp post-larvae. In the recent trials in Vietnam, larger juveniles (approx. 50 g) from 'advanced nursery' systems were tested with shrimp post-larvae, giving the sandfish a 'head start'. This system would have the advantage that both shrimp and sandfish would reach market size at around the same time, simplifying the harvest process. Small-scale tank trials again showed some promise—if shrimp were stocked at fairly low density (15 post-larvae/m^2), survival and growth of sandfish were acceptable (although lower than controls). Interestingly, survival of shrimp was higher in all treatments with sandfish than in the shrimp-only controls. These trials were scaled up in 15 × 500 m^2 ponds. The primary objective of the trial was to compare productivity and financial return from co-culture systems with that of rotational culture systems. The results were clear-cut—while growth rates were initially fastest in the co-culture treatments, after 6 weeks in ponds the shrimp had reached a size where they could prey on the sandfish, and total mortality of sandfish in co-culture ponds followed shortly thereafter. It seems that either temporal or physical separation of shrimp and sea cucumbers is required for successful production of both species in a single pond. The former (rotational culture) is already practised by a number of producers in Vietnam, and our trials have shown high sandfish growth rates in ponds recently used for shrimp culture (Mills and Duy, unpublished data). Physical separation of shrimp and sandfish grown at the same time in ponds has yet to receive attention. This is a potentially fertile area for research that has yet to be tackled at any level.

Co-culture with finfish is also a possibility. Farmers in Vietnam have successfully grown sandfish with sea bass (*Lates calcarifer* or barramundi); however, the market for this species in Vietnam is not strong, and this combination has not persisted in the industry. Recent trials at the SEAFDEC–AQD in the Philippines have highlighted several finfish species that may be compatible with sandfish. Species for the trials were selected based on commercial importance within South-East Asia. Species selected were milkfish (*Chanos chanos*), sea bass (*Lates calcarifer*), rabbitfish (*Siganus guttatus*), grouper (*Epinephelus coioides*), pompano (*Trachinotus blochii*) and mangrove red snapper (*Lutjanus argentimaculatus*). Initial trials involved tank-testing the compatibility of juvenile fish with juvenile sea cucumbers. Results were most positive for pompano, milkfish and sea bass—in all cases survival was close to 100%, although the growth rate of the sandfish was notably low (Figure 3). Rabbitfish and grouper were not compatible with sandfish. Current activities see trials with these more successful species being scaled up in experimental pond environments.

Sea ranching

Sea ranching is essentially a 'put and take' activity, where cultured juveniles are released into an area of natural habitat and harvested when they reach a commercially optimal size. Compared with pond culture, inputs are nominally lower, as the processes between release and harvest are largely left to nature. The trade-off here is that, as the level of care that can be offered to sandfish throughout the growth process is reduced, survival will be considerably lower than that seen in pond culture. In addition, property rights

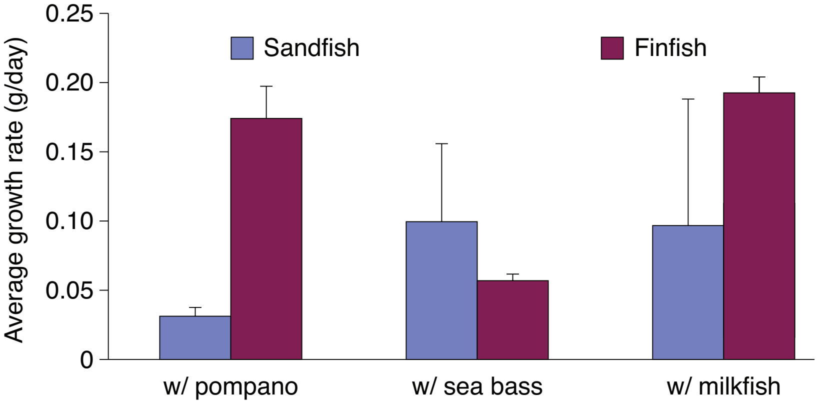

Figure 3. Average growth rates of sandfish and finfish species held in co-culture

issues are less straightforward and the social dimension of culture systems becomes as critical as the biophysical dimensions. Researchers in the Philippines (see Juinio-Meñez et al. 2012b) have been at the forefront of developing strategies for community engagement and equitable property rights, as well as developing, adopting or adapting techniques necessary to build viable sea-ranching systems (Figure 4). Specific challenges for sea-ranching systems include minimising poaching, sustaining engagement, matching environmental and social requirements, and managing severe weather events

Minimising poaching: The high value of sandfish has meant that protecting sea-ranch areas has proven difficult. Permanently manned guardhouses have been established at pilot sites in the Philippines (Figure 4) to overcome this issue. Clearly, this represents a considerable investment on the part of the group owners. However, sea ranching is being promoted as a supplemental income for small-scale fishers, and discussions with participants reveal that the opportunity cost of being one of several sea-ranch owners involved in site guarding is not high. The platform becomes a social meeting point, and fishers can just as well sit on the platform and mend nets or build gear as they could onshore.

Sustaining engagement: The time from establishing a sea ranch to the first fiscal returns in the Philippines will likely be at least 12 months and possibly closer to 18 months. Once the first batches of released sandfish have reached harvest size, regular harvests will be possible; however, the lack of any

Figure 4. Sea ranching in the Philippines: mature animals from the ranch (left), the guardhouse to counteract poaching (top right) and the leader of the sea-ranching group illustrating the principles of the ranch design. All photos from the Victory sea ranch, northern Luzon, the Philippines (Photos: D. Mills and C. Hair)

return on time or money invested during the early stages has been an issue. Pressure from participants to harvest at smaller sizes needs to be resisted in order to optimise returns from the sea ranch.

Matching environmental and social requirements: Both the engagement of strong and respected local institutions and the presence of appropriate habitat are essential preconditions for successful sea-ranching operations. Imposed on this, appropriate mechanisms for site governance must be developed. In the Philippines we have encountered a lot of enthusiasm to engage in sea-ranching activities, but a lot of energy and goodwill can be wasted if the appropriate conditions are not present. Managing expectations is a crucial part of establishing sea-ranching systems.

Managing severe weather events*:* Of the countries engaged in active research, the Philippines is particularly prone to the impact of typhoons and flooding. The shallow inshore areas generally used for sea ranching are susceptible to physical damage and acute salinity drops from these events. In addition to damage to ranching infrastructure and possible mortality of stock, at a pilot site in the Philippines it appears that stripping of rich organic surface layers from the sediment resulted in substantial negative growth of standing stock (A. Juinio-Meñez, pers. comm.).

Restocking / stock enhancement

The biological case for active restocking of overexploited sea cucumber populations is a strong one (Bell et al. 2008). Due to the low dispersal ability and the need to be close to mates for successful reproduction, recovery from heavy overfishing will be protracted ('allee effect'), if indeed at all possible (Friedman et al. 2011). Restocking provides a plausible route back to viable populations where no other may exist. The social case is just as strong—the potential for well-organised communities to create sustainable, supplemental livelihoods through restocking or stock enhancement appears promising. A clear risk with this approach is that it can be seen as a panacea where no other management systems have succeeded. In reality, strong and effective governance reform is an essential prerequisite for the establishment of effective restocking programs.

A lot of recent research undertaken in the development of sea-ranching systems provides essential background information on pathways to establishing restocking or enhancement programs. This includes all work on hatchery and nursery systems, tagging methods, transportation systems, release methods and monitoring. However, while the research area of restocking and enhancement remains one of keen interest, the realities to date of legitimate scientific investigation that can identify unambiguous impact mean that these areas are yet to be tackled. Unlike sea ranching, restocking is a 'whole-of-life-cycle' process, in which reproductive and recruitment dynamics need to be understood and accounted for in program design. Success requires that enhanced populations occupy 'source' areas where coastal currents carry larvae into areas of good habitat for recruitment and growth. If the choice of location is poor, larval mortality may be too high to provide any detectable enhancement effect.

Future research

The authors are aware of active research programs in the Philippines (hatchery, nursery systems, sea ranching, co-culture, pond culture), Vietnam (hatchery, pond culture, co-culture, sea ranching), Thailand (pond culture, sea ranching) and Malaysia (hatchery, sea ranching). Strong institutional support, as well as donor-funded programs in the Philippines and Vietnam, in particular, will ensure continued development of sea-ranching and pond-culture systems. Current research in these countries is focusing on technology and system development to diversify options for producers, and on further understanding the optimal socioeconomic and biophysical preconditions for successful enterprises. Models for scaling out technology and catalysing uptake by small-scale producers are being tested across broad geographic regions. The pond-culture industry in Vietnam is currently growing 'organically', with around a dozen farmers involved. This provides good opportunities for future research in partnership with industry. In the Philippines, a major focus in the near future will be capacity building among local institutions to support early entrants into the sea-ranching industry. The establishment of model enterprises is expected to provide a strong basis for technology uptake.

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Grace Abdala (hatchery manager) at sandfish nursery hapa in a pond at the National Integrated Fisheries Technology and Development Center, the Philippines (Photo: Cathy Hair)