An Uncertain Future for Seahorse Aquaculture in Conservation and Economic Contexts

Amanda C. J. Vincent [1] and Heather J. Koldewey [2]

[1] Project Seahorse, Fisheries Centre, The University of British Columbia
2202 Main Mall, Vancouver, V6T 1Z4, Canada
[2] Zoological Society of London, Regent's Park, NW1 4RY, United Kingdom

Introduction

Once fisheries are overexploited, conservation and fisheries communities have a shared goal and a common commitment to adjust extraction to sustainable levels. To persist with overfishing is both biologically irresponsible and disrespectful of the long-term needs of dependent communities. Measures must, therefore, be put in place that will adjust fishing to meet regional or national intergenerational responsibilities to marine life and people alike. Ventures such as aquaculture and marine protected areas may help to move levels of extraction towards sustainability, but there are no substitutes for integrated management and reductions or alterations in effort.

Fisheries managers may not realize the potential of the conservation agencies to help with such adjustments of exploitation. The IUCN (World Conservation Union) Red List (www.redlist.org) and CITES (Convention in International Trade of Endangered Species of Wild Fauna and Flora, www.cites.org) Appendix listings are two among many conservation tools available to every country in its pursuit of sustainable fisheries. They are, however, so misunderstood that both tools are commonly miscast as the enemy of exploitation. In fact, the IUCN Red List serves as an important warning mechanism that a species (or sometimes a population) may be in trouble. It has no legal power or restrictions, unless local jurisdictions choose to confer such authority. Moreover, current listing approaches have been recast to recognize that some numeric depletion is a reality in active fisheries, while insisting that such changes must be understood (www.redlist.org/info/categories_criteria2001.html). It is important to note that most listings are completed on a global basis and may not reflect regional or national situations, each of which requires separate assessment.

Any restrictions by CITES (itself an agreement among 169 signatory nations) will be implemented at the national level, according to local conditions. A species may be placed on Appendix I, which essentially bans international trade. Far more commonly, however, CITES places species on Appendix II, a list denoting anxiety about the potential threats caused by unmanaged trade, and requiring regulation of exports. It is important to note that each individual CITES signatory nation determines how best to manage its exports so as to ensure they meet the CITES requirements. These, simply, are that exports must not be detrimental to wild populations and that exports must be legally obtained (and that live animals must be properly transported). Such requirements should provide welcome assistance to fisheries managers faced with overexploitation or illegal fishing. Moreover, CITES can sometimes add particular value to international fisheries management in at least three situations: (1) where other regional or international plans are weak, unimplemented or absent; (2) where species are of such limited commercial value that they will not be of interest to other conventions or agreements; or (3) where CITES includes fishing nations not associated with another convention that seeks to regulate extraction of species they exploit.

Given that each national government chooses how to respond to both IUCN Red Listings and CITES, domestic assessments of species of concern are terribly important to any conservation process. For any given country, the species of concern may or may not be those judged in need of support at a global level. A species considered to be globally healthy may be of conservation concern domestically, but equally a species of global conservation concern may be healthy domestically. Countries are thus faced with the challenge of determining where best to direct their own energies, with national assessments of decline and degradation. Moreover, they are charged with identifying relevant management measures.

Culturing and releases are often mooted as conservation responses that should also enhance production. Yet any such initiatives can encounter or provoke enormous ecological, economic, and social problems. It is very rare for aquaculture or releases to resolve conservation problems, even partly. It is almost impossible for them to do so unless the pressures that led to depletions have been relieved. Thereafter, it is always vital to understand the species and its status, identify a clear management goal and objectives, plan and execute the initiatives with great care, and measure the outcomes and impacts of the venture. Moreover, it is important to comply with guidance and regulations from such bodies as the Convention on Biological Diversity (CBD: www.biodiv.org) and the IUCN Reintroduction Specialist Group (RSG: www.iucnsscrsg.org). Failures in these respects can lead to intemperate action that is often considerably worse than no action at all.

Seahorses (family Syngnathidae, genus *Hippocampus*) have set precedents globally. They were among the first marine fishes of commercial importance to be listed on both the IUCN Red List and CITES Appendix II. Overfishing and non-selective fishing are two agents in their depletion, so management is clearly needed. We here outline what is known about these fishes and their trade, before considering the potential role the culture and release could play in rebuilding wild populations.

Trade and Conservation Status

Seahorses are found primarily in temperate seagrasses and tropical coral reefs, but also occur in mangroves and estuaries. At least 27 species occur in the IndoPacific, with new species still being proposed (Lourie et al 2004, http://seahorse.fisheries.ubc.ca/IDguide.html); adults of the different species range in maximum adult height from 2 to 28 mm. A recent review summarized extant knowledge on seahorse biology and ecology (Foster and Vincent 2004). They are generally found at low population densities, with occasionally more dense patches; such distributions may represent a combination of natural rarity and considerable depletion. These fish live about 1-5 years. Their diet of live prey apparently changes as they grow, but such relationships are poorly understood, especially when compared to their reproductive biology. Relative to their maximum size, seahorses first mature at much the size we would expect from relationships in other teleosts. All seahorse species are thought to be monogamous within a reproductive cycle, but some may be polygamous across cycles. Females transfer eggs directly to the male's brood pouch, where they are fertilized, making it difficult to assess clutch size. At the end of their pregnancy, however, males release c. 5-2000 young, depending on species and adult size. Newborn young are born at about 2-20 mm in height, at a size that is not directly related to adult size. Seahorses often maintain small home ranges, and generally swim slowly.

It appears that seahorse populations are commonly vulnerable to overexploitation, whether direct or indirect (Foster and Vincent 2004): low population densities mean that seahorses may have trouble finding a mate; possible low rates of natural mortality mean that heavy fishing will place new pressures on the population; monogamy in most species means that a surviving partner may stop reproducing, at least temporarily; male brooding means that survival of the young in the pouch depends on the survival of the male; a small brood size limits the potential reproductive rate of the pair (although this may be offset by frequent spawning and enhanced juvenile survival through parental care); and low mobility and small home range sizes mean that seahorses may be slow to recolonize overexploited areas (although this may be offset by planktonic dispersal of juveniles). Their social and spatial structure is such that those seahorses returned to the water after being caught in non-selective gear may still be damaged through physical injury, habitat disturbance, disruption of pair bonds, and displacement from home ranges.

Extensive trade surveys have revealed that a great many countries are trading a great many seahorses, with grave consequences (Vincent 1996, McPherson and Vincent 2004, Giles et al 2005, Baum and Vincent 2005, Martin-Smith and Vincent 2006). Traditional medicine (TM) – and particularly traditional Chinese medicine (TCM) and *jamu* from Indonesia – accounts for the largest consumption of seahorses, and they are also fished in substantial numbers for the aquarium and curiosity trades. Published reports have documented large and growing exploitation of seahorses, pipehorses, and pipefishes. At least 32 countries had traded syngnathids by 1995 (Vincent 1996), but this had increased to nearly 80 countries by 2001, with much of the expansion in Africa and Latin America (McPherson and Vincent 2004, Baum and Vincent 2005). Trade in Asia alone was inferred to amount to more than 45 metric tonnes (mt) of dried seahorses in 1995 (Vincent 1996), with much expansion thereafter. Seahorses in trade weigh a mean of perhaps 2.9 g, with great variation by country, region, species, and individual, hence the 1995 volume in Asia may have represented c. 15.5 million individuals.

Direct exploitation, incidental catch in non-selective fishing gear, and habitat loss and degradation (much of it fisheries-associated) have put considerable pressure on seahorse populations in many regions. Fishers and other informants reported substantial numeric declines in seahorse catches and trade, without commensurate decreases in effort (e.g., Giles et al 2005, Baum and Vincent 2005). Estimated population declines of between 15 and 50% over five-year periods have been common, with marked declines in size of landed adult seahorses (Vincent 1996). All known species of seahorses appear on the IUCN Red List of Threatened Species as Endangered, Vulnerable or Data Deficient (www.redlist.org).

CITES regulates the international trade in seahorses, as an important component of collaborative efforts to achieve sustainable use of these fishes. All seahorses were listed in Appendix II in 2002 (www.cites.org), with the regulations taking effect in May 2004. Seahorses are among the first marine fish species of commercial importance to be listed on the Convention, and represent a particularly large wildlife trade issue, by volume of animals exported each year. The CITES Animal Committee recommended that Parties seeking guidance in implementing the Appendix II listing for seahorses consider adopting a 10 cm minimum size limit, as one means of moving towards sustainable trade (Foster and Vincent 2005). Other measures will also be necessary for a successful seahorse conservation strategy.

CITES recognizes the potential role of aquaculture in arriving at sustainable trade. All cultured animals can be traded under

Appendix II. The first generation (F_1) will be treated as wild, with a requirement that exports be guaranteed not to damage wild populations. Subsequent generations (F_2 and above) from operations certified by the national government are exempt from such controls, as long as their paperwork is in order. What, then, is the potential for viable seahorse aquaculture and for benefits from subsequent releases of cultured seahorses?

Aquaculture Status

Seahorses have been cultured since the 1970s, particularly in China, but breeding and rearing seahorses has been problematic (Xu 1985, Vincent and Clifton-Hadley 1989, Dao and Hoang 1991, P ham and Dao 1991, Fenner 1998, Hargrove 1998, Truong 1998, Chaladkid and Hruangoon undated, Hormchong et al undated). The published literature from mainland China conveyed the impression that seahorse culturing was well understood (e.g., Aquaculture Institute of Shanghai 1982, Wu and Gu 1983, Shandong Marine College 1985, Publicity and Education Committee 1990). However, for many years problems with vulnerability to disease and providing the correct diet meant that these facilities were experimental rather than commercially viable. The restructuring of China's economy in the 1980s led to widespread closure of seahorse farms, just at a time when China's demand for seahorses accelerated (Vincent 1996).

Global interest in aquaculture of seahorses and other syngnathids (pipefishes, pipehorses and seadragons) has increased dramatically over the past decade, largely coincident with awareness of the seahorse trades and their associated conservation issues. Research and development into seahorse culture has been carried out by over 40 ventures in at least 20 countries, including the following: Australia, Brazil, China, Ecuador, India, Indonesia, Mexico, New Zealand, Philippines, South Africa, Vietnam, and the USA. Although historically most culture operations were located in China, recent ventures are frequently found in Australia or New Zealand. The potential to culture seahorses in closed systems means they could potentially be cultivated in many countries, but compliance with the precepts of the CBD means that any culturing should occur in range countries using systems that minimise negative environmental impacts and maximise local socioeconomic benefits.

A few recent ventures for seahorse aquaculture have been commercially successful and are working as effective businesses but most are either in the pilot stage or have failed because of commercial or technical problems. The low number of operations in each country and a lack of knowledge transfer among operations mean that the same mistakes are often repeated. Many operations close simply because they relied on overly optimistic business models, with heavy dependence on subsidies that are only available in the pilot phase and with inadequate market research. Others are still battling technical challenges – including provision of the correct diet and vulnerability to disease – and difficulties with commercial suitability. No standardized method for culturing seahorses has yet emerged, and systems vary according to location and intended market.

Seahorses are currently being cultured to supply TM and tonic products (e.g., seahorse wine), live aquarium fishes, and curios and souvenirs. The scale of seahorse culture facilities ranges from small aquariums to large pond systems and from research-based to commercial operations.

1) No culture operation that targets the TM market appears to have achieved commercial viability. Even the largest seahorse farm in China is still at the developmental stage and has not reached full commercial production. Moreover, this operation is promoting the development of new domestic markets for its products, with a particular

focus on its own brands of seahorse wine, capsules, and concentrate for TCM. Should the operation fail, such newly generated demand could add to pressures on wild populations.

2) At least five companies now supply cultured seahorses to the aquarium trade, relying on low volumes and high values: two in Australia, one in Ireland, one in Sri Lanka, and one in the USA (Hawaii). The level of production varies enormously among companies, with some of these still at the development stage. The few quoted prices on websites are US$75-370 per individual or pair, with some companies selling seahorses as part of a 'kit', along with their food. Cultured seahorses that eat frozen food are more adaptable to a home aquarium environment than wild-caught seahorses. The ratio of wild-caught to cultured seahorses in the live aquarium trade is unknown.

3) Seahorse culture facilities are diversifying. One company in Australia now sells seahorses that have died during the culture process as jewellery and marine art, with prices of approximately US$50-100. Another also serves as a tourist attraction, reporting nearly 17,000 visitors in 2004.

Both tropical and temperate seahorses are being cultured. The tropical species include *H. barbouri, H. erectus, H. fisheri, H. fuscus, H. histrix, H. ingens, H. kuda, H. mohneki, H. reidi,* and *H. trimaculatus.* Temperate species include *H. abdominalis*, *H. breviceps, H. capensis, H. whitei,* and *H. zosterae*. Most have been located in Australia and New Zealand, with a focus on *H. abdominalis*, but some ventures are also starting to culture the temperate European species, *H. guttulatus* and *H. hippocampus.* Attempts to culture *H. abdominalis* for the TM market failed because of a lack of market research and other challenges. The TM market has very specific requirements with respect to shape and spininess rather than selecting by species. Given that most marine aquaria are tropical, the market for temperate species will always be more limited than that for tropical species.

The last five to ten years have seen advances in the culture of seahorses, with the closure of life cycles over a number of generations for several species (Wilson and Vincent 1998, Payne and Rippingale 2000, Woods 2000a, b, Bull 2002, Job et al 2002) but many technical challenges remain around behavior, disease, and nutrition. The significant social and spatial structure shown by seahorses is unusual for cultured fish and needs to be considered in the facility design and species' management. As well, seahorses are vulnerable to diseases, to the extent that this is one of the constraints for commercially viable aquaculture. Laboratory and aquaculture observations have documented health problems related to bacteria (*H. kuda*: Alcaide et al 2001, Greenwell 2002), cestodes (*H. abdominalis*: Lovett 1969), micro sporidians (*H. erectus*: Blasiola 1979, Vincent and Clifton-Hadley 1989), fungi (*H. erectus*: Blazer and Wolke 1979), ciliates (*H. erectus*: Cheung et al 1980, *H. trimaculatus*: Meng and Yu 1985), trematodes (*H. trimaculatus*: Shen 1982), and marine leeches (*H. kuda*: DeSilva and Fernando 1965).

Feeding and nutrition, especially for juveniles during the first few weeks after release from the pouch, appear to be a major challenge in seahorse cultures, primarily because these fish are obligate predators. The relatively large size of seahorse juveniles (compared to other marine fish) should make them easier to rear but their ontogenetic changes in diet make it necessary to prepare a chain of live food. In general, newly released juveniles are fed 2-7 times a day with some combination of (a) newly hatched *Artemia*, (b) 24-48 h enriched and decapsulated *Artemia* nauplii, (c) rotifers (e.g., *Brachionus plicatilis*), (d) haparcticoid copepods (e.g., *Euterpina acutifrons*), and/or

(e) mysid larvae (e.g., *Mysidopsis bahia*). Adding a small amount of chopped frozen *Mysis* shrimp to nursery tanks immediately after birth may promote feeding and improve survivorship in the fry (Koldewey 2005). The gradual transfer from one live food organism to another is achieved by overlapping different feeds at the different weaning stages. At 7 days, juvenile seahorses are able to take copepods (Wilson and Vincent 1998) and juveniles of 3-8 weeks can be trained to take frozen mysids, with the transition from live to frozen food sources usually taking about a month (Koldewey 2005).

Sourcing live food for seahorses could potentially cause local prey depletion or other negative environmental impacts, unless care is taken. Depending on the location and type of culture facility, adult seahorses are fed live foods, a combination of live and frozen foods, or entirely on frozen foods. Adults are commonly fed 2-4 times daily with live *Artemia* shrimp, *Mysis* shrimp, grass shrimp, copepods, *Gammarus*, poecilid fry, and caprellid amphipods, or with frozen mysids (e.g., *Euphausia pacifica*) and adult *Artemia*. A frozen food diet is the best choice where live foods are only seasonally available or where the seahorses are destined for the live aquarium trade, as hobbyists may have only limited access to live food.

Both juveniles and adults benefit from enriched food, especially if several enrichment products are combined. The many possibilities for enrichment include phytoplankton (e.g., *Nannochloropsis aculata, Isochrysis galbana, Tetraselmis chuii, T. suecica*), essential vitamins, commercial products of (Ω3) highly unsaturated fatty acids such as Selco, Culture HUFA, Roti-Rich, astaxanthene biological pigment Natu-Rose, AlgaMac 2000, amino acid or liquid multi-vitamins, MicroMac 70, Aminoplex, Cyclop-eze, or Beta Meal. Low cost supplements may also be locally available as an effective enrichment for seahorses (Job et al 2002). Some culture facilities offer proprietary diets for seahorses when they sell the animals.

In the context of international trade, facilities face a further challenge in finding a way to distinguish F_2 cultured animals from wild-caught or F_1 seahorses. CITES Authorities require proof that the animals are cultured (from at least F_2 generation) before they can waive export controls. Paper trails can sometimes serve to confirm that seahorses are from cultured rather than wild sources, but physical distinctions are also needed. One operation in Sri Lanka proves the captive provenance of its seahorses by culturing only an exotic seahorse species not found in Sri Lanka (*H. reidi*) but this approach can carry a serious risk of escape or release, with consequent threats to native fauna, and is often banned under national legislation (as well as running contrary to the CBD). In general, however, research is needed to supplement current technical approaches for marking and tagging sea-horses (Morgan and Martin-Smith 2004, Woods and Martin-Smith 2004). For culturing facilities, in particular, such techniques will need to be cheap, easy to apply and to recognize, and free of traits that might compromise sale or use. Good marking and tagging methods are also indispensable for release programs, in order to monitor the released animals and establish the impact, successful or otherwise, of such stocking practices.

Export of live seahorses also poses some challenges. CITES meets the worldwide transport standards defined in the IATA Live Animal Regulations, governing transport by commercial airlines. In consultation with CITES and the Marine Aquarium Council (www.aquariumcouncil.org), specific guidelines have been developed for the transport of seahorses (Koldewey 2005).

Impact of Aquaculture

Seahorse aquaculture could theoretically serve as a rewarding commercial enterprise and as a tool in the conservation of wild populations, but the real conservation benefits of culturing seahorses are still very unclear. Any aquaculture activity that removes animals from the sea, either as broodstock or for fish food, and discharges effluent into the sea will have an impact on the marine environment. Aquaculture has had numerous well-documented detrimental effects on the environment over the past few decades (e.g., Chua et al 1989, Páez-Osuna 2001, Grosholz 2002, Utter and Epifanio 2002). A reputable company will seek certification for its aquaculture operations, through its national government (where such regulations exist) and/or through impending standards from the Marine Aquarium Council (in the case of live trade).

In order to preclude waste of seahorse animals used as broodstock and risk to the marine environment, syngnathid culturing must first be economically viable. This will only happen when sufficiently large numbers of young can be reared through to market size in a cost-effective manner. Moreover, the acceptability and price of cultured syngnathids in the appropriate marketplace need to be ascertained beforehand. Given the economic uncertainties in syngnathid culturing, small-scale studies using minimal numbers of animals should be carried out prior to the initiation of any large-scale culturing efforts, in order to ensure the following:

1) The reproductive biology of the particular species has been thoroughly investigated;
2) Reliable breeding and culturing techniques have been developed;
3) The operation can repeatedly rear a sufficiently high percentage of young to market size at viable cost;
4) Cultured syngnathids will be acceptable in the trade at economically viable prices.

If the culture operation is to avoid adding to conservation concern, it must assess potential damage to the marine environment and implement mitigation programs before seahorse culturing is initiated. Any activity that further degrades the marine environment is unlikely to be in the interest of wild seahorse populations. Seahorse aquaculture ventures need to demonstrate the following:

Source populations are sufficiently well-understood that broodstock can be removed without damaging them;

a) The culturing operation will only remove the minimum number of wild animals required to maintain the long-term genetic health of its captive-bred broodstock;
b) Any long-term capture of wild food for the syngnathids does not negatively affect the local marine ecosystem;
a) Effluent discharged from the facility will not be detrimental to the local marine environment;
b) The risk of escape of captive-bred syngnathids into the marine ecosystem, where they could cause disease and behavioural and genetic problems, is minimised.

No comprehensive environmental impact assessments have yet been undertaken prior to the establishment of a seahorse aquaculture venture. A few culture operations have, however, adopted a responsible approach to seahorse farming, by regulating water discharges, sale of exotic species, and broodstock collection.

Seahorse aquaculture ventures need to recognise the special responsibilities inherent in working with threatened species. Culturing will only be of conservation benefit if it reduces pressures of exploitation on wild populations. A great deal depends on how the dynamics of trade affect the fishing communities in source countries that would otherwise catch seahorses. Conventional business strategies such as price competition and the development of new markets need to be tempered by a clear understanding of the local and global impacts of such strategies on wild seahorse populations.

At its best, aquaculture can potentially simultaneously decrease demand for wild-caught fish and provide sustainable income. At its worst, it either (a) fosters new demand for the species, including wild seahorses, (b) leads to drops in price, forcing fishers to catch more wild seahorses in order to meet their basic needs, and/or (c) displaces fishers onto other vulnerable resources, with consequent economic change without conservation gain. Aquaculture is likely to be of greatest conservation value where it facilitates new alternative livelihoods for seahorse fishers, thereby directly reducing pressure on wild seahorse populations. In the case of seahorses, however, technical complications mean that centralised facilities may be needed to hold broodstock and culture juvenile seahorses through the challenging early weeks before they might be dispersed to fishers for grow out.

Any culturing of seahorse species in non-source countries should actively seek to ensure that fishing communities within the source countries benefit equitably from these endeavours. Indeed, a key requirement of the CBD is the fair and equitable sharing of benefits derived from the exploitation of genetic (biological) resources between countries that commercialize these resources (generally developed countries) and the source countries (generally developing countries). Unless fishing communities derive equitable benefit from their biological resources (e.g., seahorses), there will be no reason for them to protect and manage these resources in a sustainable manner. The result may be an increase in environmentally destructive activities such as coral mining and mangrove clearance. While contributions to seahorse conservation may take many forms, the equitable sharing of benefits with source communities is important in any conservation-oriented aquaculture venture.

Current Status of Seahorse "Stock Enhancement"

The release of captive-bred or captive-held animals is often viewed as a useful method of bolstering threatened wild populations. The prospect of captive breeding for release into the wild is also sometimes used as justification for holding animals in captive populations, a means of disposing of unwanted or surplus stock, or a public relations gesture to attract support for an enterprise. All such releases must be viewed with caution and, sometimes, cynicism. No release should be attempted without guaranteed long-term financial, political, and local support.

Any release of captive seahorses needs to be managed carefully, as it has the potential to severely damage wild syngnathid populations and marine ecosystems. Many syngnathid populations are declining relatively rapidly and there may well be specific cases in the future where releases may have to be considered. However, the IUCN RSG guidelines note that formal releases are lengthy, complex, and expensive processes that require preparatory and follow-up activities. An ill-planned or casual release of seahorses could have disastrous impacts on the wild population through, for example, the introduction of disease. Thorough preparatory activities must be conducted before any release is initiated and a long-term monitoring program must be put into place. Moreover, the factors leading to the original decline in the wild population would also need to be addressed, and management plans set in place to avoid a similar extirpation of the introduced population. Casual releases are strongly discouraged.

At present, there are no formal stock enhancement programs for seahorses. There are, however, anecdotal reports of seahorse releases (juveniles and/or adults), purportedly as a conservation action to supplement local populations. An apparently universal lack of monitoring makes it impossible to assess the positive, negative or neutral effects of such releases. More recently, though, a proposed remediation project has sought technical advice from the IUCN RSG, an approach that is strongly recommended. Hopefully, any work that proceeds will include rigorous assessment of its costs and benefits.

The four main types of releases need to be differentiated because they differ in the severity of their impacts (RSG: www.iucnsscrsg.org):

- *Translocation* would be the transfer of wild syngnathids from one site to another where conditions may be different. Translocated syngnathids may be held in captivity for variable periods of time before being released into the new site.
- *Supplementation* would be the release of captive syngnathids into an area where a wild population still exists.
- *Re-introduction* would be the release of captive syngnathids into an area where the local population has been extirpated (gone extinct locally).
- *Introduction* would be the release of non-native (exotic) syngnathids into an area where there has never been a population of that species.

Most seahorse releases in the past have been informal attempts at translocation or supplementation, with all the attendant risks for recipient wild populations. Three main conservation issues may arise from either planned or accidental releases: (1) disease transmission, (2) genetic threats, and (3) community disruptions.

1. Disease transmission

The release of captive animals must be managed carefully to diminish the risk of disease transmission to wild populations. While disease undoubtedly occurs in wild populations, it is unlikely to reach the proportions and severity seen in many culturing facilities where animals are often maintained at unnaturally high densities in artificial conditions. All animals in captivity, unlike those in the wild, may survive for long periods of time because of the absence of predators and use of medications. Most worryingly, disease treatments have the potential to hide the effects of a disease-causing organism without necessarily eradicating it. Thorough screening procedures are, therefore, essential in any program that transfers captive seahorses into the wild.

The risk of disease transmission is increased when non-native seahorses are introduced into an area. Introduced seahorses may bring with them new disease organisms against which local species may have little or no natural resistance. The potential for disease transmission from captive to wild populations has also been highlighted, in the salmon and prawn aquaculture industries in North America, Asia, Europe, and elsewhere (e.g., Krueger and May 1991, Landesman 1994, Roberts and Pearson 2005). Where these impacts have occurred, the effects on wild populations have been severe.

2. Genetic threats

The genetic diversity of wild populations could be threatened when captive-bred animals are released into the wild. Captive-bred animals are usually obtained from a very limited number of parent animals (founders). Their genetic diversity may, therefore, be quite low in comparison to levels in the wild. If large numbers of these animals are released into an area, there is a very real risk that they could swamp the genetic diversity of the recipient wild population, thus lowering its overall genetic diversity in the long term.

A loss of variability is problematic as genetic diversity acts as a safeguard against randomly occurring events such as disease epidemics and environmental changes that may otherwise destroy entire local populations. Without this diversity, populations are far more vulnerable to such events. Risks are exacerbated if the released seahorses are from a captive population that differs genetically from the wild population as this may also lead to fundamental alterations in the genetic structure of the wild population.

The artificial conditions associated with culturing may result in captive-bred fishes having different genetic traits from those in the wild. Thus, the released fishes may be genetically less adapted to conditions in the natural habitat (Cooke et al 2001, Ireland et al 2002). In the simplest case, the released animals die soon after release, with relatively few conservation consequences. If, however, these animals survive to breed with wild conspecifics, unsuitable genetic traits may be passed on to future generations. This could eventually lead to a reduction in the long-term viability of the wild population, as has occurred, for example, in trout (Leary et al 1993, Garcia-Marin et al 1998)

3. Community disruptions

The release of captive seahorses into areas where wild populations of the same species are present brings risks; a sudden influx of new individuals into a small area could result in changes in the social structure of the wild population as a result of increased competition for food, shelter, and mates. Such alterations in social and community structure may have negative effects on the viability of the wild population.

Risk of disruption to marine communities is perhaps most pronounced when exotic species are introduced into an area. Such introductions may disrupt the structure and function of the local ecosystem, and lead to the extirpation (localized extinction) or extinction of native species. In most cases, the introduced species dies shortly after being released because of incompatibility with the new environment.

In numerous well-known cases, an introduced species thrives in new waters (Arthington 1991, Kaufman 1992, Townsend 1996, Mariusz and Krzysztof 2005). The introduction of an exotic seahorse species into the marine environment, therefore, could potentially lead to the establishment of a viable population that may compete with local species for food and habitat. Such a development could have severe detrimental impacts on the local species and community. Numerous examples of problems associated with the introduction of exotics into aquatic systems exist all over the world, particularly in freshwater. Australia, for example, has a list of noxious introduced fishes, such as the ubiquitous tilapia, goldfish, and carp, which are to be destroyed when caught.

Conclusion

Seahorse aquaculture has received widespread attention because of concerns over declines in wild seahorse populations, and recognition of their high economic value and marketability. Many seahorses are threatened species (www.redlist.org) and all are now listed under CITES Appendix II (www.cites.org). Seahorses are among the largest wildlife trade issues by volume under CITES management. Conservation action is clearly needed, both to revive wild populations and to permit continued exploitation. Such actions will need to include reductions in fishing effort, but could also involve aquaculture, were it implemented in an economically sensible and ecologically sensitive manner.

Seahorse aquaculture globally is still at the early stages of development. Most companies operating for more than five years appear to have focused on providing low volume, high value seahorses for the live aquarium trade. While techniques for culture have improved dramatically over the last 5-10 years, very few facilities are currently operating on a commercially viable scale, largely because of continued technical and financial challenges associated with rearing seahorses.

Conservation benefits of seahorse aquaculture have often been highly questionable, despite many claims as to their aims and achievements. Before commercial seahorse culturing can become useful for seahorse conservation, it will need to achieve economic viability, neutralise environmental impacts, and enhance conservation value. Meeting only the former two conditions will result in commercial enterprises that do little to assist global efforts to protect wild seahorses. In contrast, ventures that also address the global conservation impacts of their activities could potentially have significant conservation benefits. In particular, seahorse aquaculture operations need to do the following:

- Avoid promoting (directly or indirectly) new or increased trade in wild seahorses
- Address their impact on subsistence fishers, and thus wild seahorses and other marine life
- Respect international conventions such as the CBD.

It will always be better to increase the viability of wild populations than to bring animals into captivity for rearing and subsequent release. Release of captive seahorses into the wild is an increasingly common activity around the world and is often mistakenly viewed as a valuable contribution to the conservation of wild seahorses. However, releases can potentially severely harm wild populations of seahorses and will seldom be an appropriate management action. Instead, conservation of wild populations primarily requires alleviation of pressures that caused the declines and their associated concerns. Any conservation action requires that goals, objectives, methods, indicators, and targets be clearly defined. On the rare occasion when planning justifies a release, it is essential that a comprehensive monitoring and assessment programme also be implemented to understand the impacts of such action.

Facilities that are engaged in breeding and rearing seahorses are in a strong position to contribute to research needed for conservation action. From a technical aspect, much more information on seahorse diets and diseases is needed, with appropriate public documentation and dissemination of findings. Aquaculture facilities and CITES Authorities alike also require marking techniques that enable the easy identification of cultured seahorses in trade. Furthermore, considerable research is needed on life history parameters that could advance seahorse conservation and management, including (a) fisheries dependent and fisheries-independent abundance estimates, (b) age- or stage-based natural and fishing mortalities, (c) growth rates and age at first maturity, and (d) intrinsic rates of increase and age- or size-specific reproductive output. Such information would contribute greatly to conservation in the wild, which must, after all, be our first priority with any species of concern.

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