1. Foreword

The conservation and management of sea cucumbers are of paramount importance because these animals fulfil an important role in marine ecosystems and are a significant source of income to many coastal communities worldwide (Conand, 1990; Conand and Byrne, 1994). The current grave status (see Glossary) of sea cucumber stocks in numerous countries can be attributed to three broad causes: rampant exploitation, ever-increasing market demand and inadequacy of fishery management. The unique life history traits of holothurians (e.g. low or infrequent recruitment, great longevity and density-dependent reproductive success) also make these species especially vulnerable to overfishing.

The vulnerability of sea cucumber populations to local extinction and the risk of long-term loss of fishery productivity have prompted several international and regional meetings of expert scientists and fishery managers in recent years. In 2003, FAO hosted a technical workshop, "Advances in sea cucumber aquaculture and management", and published a report with technical papers and recommendations for fishery management (Lovatelli *et al.*, 2004). The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) also ran a technical workshop, in 2004 in Malaysia, entitled "Conservation of sea cucumbers in the families Holothuridae and Stichopodidae", providing scientific justification and urging for the immediate need of conservation and sustainable exploitation of sea cucumbers (Conand, 2004, 2006a, 2006b; Bruckner, 2006a). In 2006, the Australian Centre for International Agricultural Research (ACIAR) organized a workshop to produce a simple guidebook to help Pacific fishery managers to diagnose the health of their sea cucumber fisheries and develop appropriate management plans (Friedman *et al.*, 2008a). The Western Indian Ocean Marine Science Association (WIOMSA) also funded a Marine Science for Management (MASMA) project to study the biology, socio-economics and management of sea cucumber fisheries to assist Western Indian Ocean countries (Conand and Muthiga, 2007).

A common recommendation from these international meetings is to help improve national fisheries management. Resource managers need prescriptive advice on what management regulations and activities are best for sea cucumber fisheries. Unfortunately, few guidebooks exist at present on managing sea cucumber fisheries, leaving fishery managers with a subjective task of drawing on management principles based on other resources. In addition, sea cucumber fisheries differ greatly in scale, cultural setting, socio-economic structure, fishing methods and in the technical capacity of the management bodies.

To meet these challenges, FAO carried out a global project on sea cucumber fisheries. The major objective was to review the global status of sea cucumber stocks and to provide support tools to improve their conservation and sustainable exploitation (Toral-Granda, Lovatelli and Vasconcellos, 2008). An international workshop was convened in November 2007 in Puerto Ayora, Santa Cruz Island, Galápagos (Ecuador) to identify management measures best suited to sea cucumber fisheries. The present technical paper is the main output of that workshop.

The purpose of this technical paper is to contribute to improved and effective management and governance of sea cucumber fisheries around the world through successful implementation of an ecosystem approach to fisheries (EAF). It presents best-practice management measures applicable to most fisheries and provides examples and situation-specific measures that may be used in some scenarios. Drawing on lessons described in the Regional Reviews of sea cucumber fisheries (Toral-Granda,

Above: Participants of the FAO workshop at the Charles Darwin Foundation Research Station, Galápagos, November 2007

Lovatelli and Vasconcellos, 2008), practical examples are presented across a diverse array of fisheries from tropical and temperate regions. Notably, this technical paper aims to assist fisheries managers in choosing regulations and action plans to maintain and restore the productive capacity and biodiversity of sea cucumber stocks and fishery ecosystems, while considering their role in the livelihoods of fishers.

The technical paper is intended for fishery managers, development and extension agencies, enforcement and trade agencies, policy officers, educated fishers and special-interest groups. It is a decision-support tool for the development of fisheries management plans and strategies for biodiversity conservation. The paper embraces an ecosystem approach to fisheries (EAF) (FAO, 2003) by recognizing the importance of sea cucumbers to rural coastal livelihoods and the socio-economic impacts of management measures. In this context, fisheries management must find a sensible balance between the need to optimize long-term benefits to fishers and the conservation of resource biodiversity. These trade-offs were discussed among the expert biologists, sociologists and resource managers at the Galápagos Workshop.

Aligned with the EAF, the Galápagos workshop evaluated potential actions the agencies responsible for fisheries management, monitoring, surveillance and enforcement may take and the scientific knowledge needed to support management decisions. The technical paper is therefore designed for a wide readership, and not just for fisheries managers. It also provides discussion of the utility of CITES listing for the conservation of threatened or depleted holothurian species.

Although our understanding of how sea cucumber fisheries should be managed has come a long way in the past decade, much progress is still needed. Whereas Friedman *et al*. (2008a) provide a quick guide for alerting managers to problems in their fisheries and directing them to appropriate regulatory measures and actions, the present technical paper give a comprehensive "roadmap" with more detailed explanations and examples. However, this technical paper is not a completed recipe book. Rather, if needs to be seen as a "work in progress" and represent our current position along the road to developing sustainable management systems for these very important resources.

2. Sea cucumber fisheries

2.1 BIOLOGY AND ECOLOGY

There are six taxonomic orders of holothurians but most commercial species belong to the Aspidochirotida and a few to the Dendrochirotida order (Conand, 2006a). Reviews of the biology and ecology of commercial sea cucumbers are widely available (Conand, 1990; Hamel *et al*., 2001; Conand, 2006a). Only a brief overview is therefore presented here, with particular reference to fisheries management.

Commercial sea cucumbers are predominantly gonochoric; that is, they exist as males or females. However, a few species are known to be hermaphroditic (combining both sexes in the same individual). In most gonochoric species, it is not possible to distinguish males from females by their outer appearance, but sea cucumber populations generally present 1:1 sex ratios. The majority of sea cucumbers are broadcast spawners, releasing sperms and oocytes (unfertilized eggs) directly into the water column. Females can release thousands to millions of oocytes in a single spawning event. The motile sperm cells (spermatozoa) have to swim to find and fertilise the oocytes. Fertilisation success is, therefore, maximized where males and females are relatively close to each other. The release of gametes, i.e. oocytes and sperm, by adults is generally triggered by environmental cues (e.g. certain tidal conditions, lunar phases, temperature fluctuations) and chemical cues from other individuals of the same species. For example, the chemical "signature" of sperm released by males is suspected to be sensed by down-current females, which then release eggs to mix in proximity with the sperm.

Reproductive cycles are variable among species, but most tropical species tend to have a peak in spawning activity around the early summer months (Conand, 1993; Conand, 2008; Kinch *et al*., 2008a). Fewer species, like *Holothuria whitmaei*, spawn primarily in the cooler months of the year. Some commercial sea cucumbers can spawn several times per year or periodically every month, such as *Isosticopus fuscus* in Ecuador (Mercier, Ycaza and Hamel, 2007) and *Holothuria scabra* in the Solomon Islands (Hamel *et al*., 2001). Temperate species, like *Cucumaria frondosa* in Canada, usually spawn once a year in spring or early summer (Hamel and Mercier, 1996) (Figure 1). In addition to sexual reproduction, about 10 species reproduce asexually by dividing in the middle of the body; both halves re-grow necessary organs and form clones of the original individual. This mode of reproduction by *transverse fission*, as it is called, may or may not occur in different seasons than sexual reproduction among the various species (Uthicke, 1997; Conand, 2006a).

The oocytes of most commercial species of sea cucumbers are small, generally under 200 µm in diameter, and more or less neutrally buoyant when released in the water column (Mercier, Hidalgo and Hamel, 2004; Agudo, 2006). However, commercial species from temperate regions may possess large yolky buoyant oocytes that can measure up to 1 mm in diameter (Hamel and Mercier, 1996). In the case of tropical species with small oocytes, fertilized eggs will develop quickly into free-swimming larvae, sometimes in less than one day. These larvae will feed on microalgae until metamorphosis (whereas dendrochirotid sea cucumber species can have non-feeding, or "lecithotrophic", larvae) (Figure 2). The larvae spend a couple to several weeks in the water column before transforming to the final larval stage that can settle on various substrata, depending on the species (e.g. rocks, dead corals, algae, seagrass or sediments).

FIGURE 1

Spawning in sea cucumbers. Left: a female *Cucumaria frondosa* spawning in captivity. The orange, tightly packed, cylinders of oocytes have been expelled and will be fertilised externally by sperm released from males. Right: a male *Bohadschia marmorata* stands erect in a tropical seagrass bed and releases sperm, which disperses into the water column

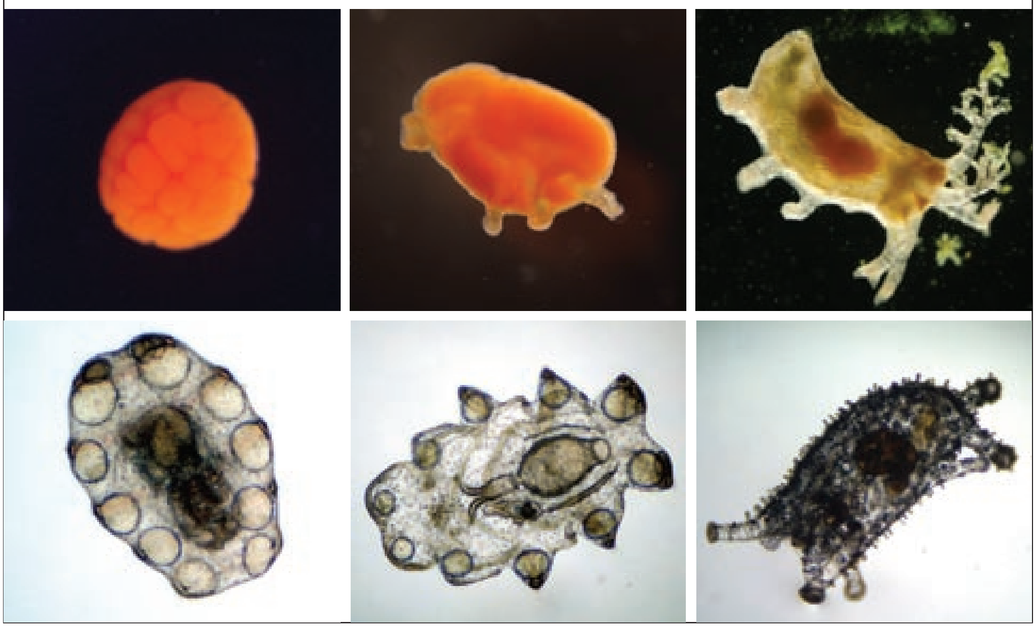
PHOTO: A. MERCIER AND J.-F. HAMEL

PHOTO: A. DESURMONT

The ecology of sea cucumber larvae is poorly understood (Conand, 2006a), but it is likely that their movement in the water column, particularly vertically, mediates their dispersal to new sites. Genetic studies indicate that large-scale larval dispersal exists for some species (Uthicke and Benzie, 2000). But evidence suggests that dispersal is relatively restricted for some other species, resulting in genetic differences in populations over relatively short distances (Uthicke and Benzie, 2001; Uthicke and Purcell, 2004). Some species are therefore more likely to provide larvae to renew populations on distant habitats, while other species seem to self-recruit and supply larvae to neighbouring sites. For reasons not yet clear, even populations of species

FIGURE 2

Embryonic and larval development of sea cucumbers. Upper photos: the dendrochirote sea cucumber *Cucumaria frondosa*. Upper left: the blastula stage, 0.9 mm, just 40 h after fertilisation. Upper centre: the pentactula larval stage, 1.3 mm long, 4–5 weeks after fertilisation. Upper right: a juvenile, 2.5 mm long, 3 months old. Lower photos: the aspidochirote sea cucumber *Isostichopus fuscus*. Lower left: the doliolaria larval stage, ca. 0.6 mm long. Lower centre: ventral view of a fully developed auricularia larval stage, ca. 1 mm long. Lower right: newly settled juvenile, measuring 1.5 mm in length



PHOTOS: J.-F. HAMEL AND A. MERCIER

with widely dispersing larvae can be slow to recover from moderate to high rates of exploitation (Uthicke, 2004; Uthicke, Welch and Benzie, 2004). For the Pacific black teatfish *Holothuria whitmaei*, a fishing rate of just 5 percent of virgin biomass per year still lead to depletion of breeding stocks (Uthicke, 2004). Evidence from other populations that have failed to recover from heavy fishing pressure also stresses that sea cucumbers are prone to "extirpation" (local extinction of stocks) and management measures should curtail fishing to conservative rates.

Growth in sea cucumbers has been difficult to assess (Conand, 1990) because they are not amenable to conventional tagging methods (Purcell, Blockmans and Nash, 2006). However, some growth rates in the wild are available from studies using modal progression analysis, genetic fingerprinting, and the release and monitoring of juveniles. Some species, like the sandfish *Holothuria scabra* are relatively fast growing when young (Purcell and Kirby, 2006), reaching the size at first maturity (~180 g) in a year or so but take another couple years to reach an acceptable market size (Purcell and Simutoga, 2008). Similarly, Shelley (1985) estimated growth to be 14 g month^{-1} for *H. scabra* and 19–27 g month^{-1} for *Actinopyga echinites*. Uthicke (1994) found modest weight gain in *Stichopus chloronotus* of 70–80 g year^{-1}, and Franklin (1980) showed that their growth slows once individuals become large. Growth of other species like *H. whitmaei* appears slow, in the order of 80–170 g yr^{-1}, and large animals can shrink during certain periods (Uthicke and Benzie, 2002; Uthicke, Welch and Benzie, 2004). A study of *A. echinites* in southern Japan (Wiedemeyer, 1992) also found slow weight gain of small juveniles. It may thus take some species many years to reach commercial sizes. For example, the cold-temperate species *Cucumaria frondosa* from the North Atlantic was estimated to reach commercial size after 10 years (Hamel and Mercier, 1996).

Longevity has been estimated at 10–15 years for *Actinopyga mauritiana*, *A. echinites* and *Thelenota ananas* but only 5 years or so for *Stichopus chloronotus* (Conand, 1989). The results of Uthicke *et al.* (2004) led them to suggest that *H. whitmaei* are rather long-lived, potentially in the range of several decades. Field studies therefore indicate that many populations turnover relatively slowly and may not support high rates of fishing or be amenable to rotational harvest-closures that require fast growth of animals after pulses of harvesting.

Sea cucumbers are rather sluggish, in terms of their rates of displacement and can be regarded as "sedentary". Some migration from settlement habitats to adult habitats has been reported for some species (Reichenbach, 1999; Hamel and Mercier, 1996; Hamel *et al*., 2001). The limited long-term displacements of sea cucumber, compared to highly mobile species like fishes, give advantages to using marine reserves and no-take zones to protect breeding populations as sources of egg supply for fishing grounds. Marine reserves can be relatively small but in a network if the intended resources do not migrate in and out of the reserves easily (Sale *et al*., 2005). Work using a DNA fingerprinting technique shows that only few Pacific black teatfish migrated 90 m between study sites during one year (Uthicke, Welch and Benzie, 2004). Field measurements of various sized animals and subsequent modelling suggest that sandfish *H. scabra* will mostly remain within a few hundred metres of their settlement locations over a 10–year time span (Purcell and Kirby, 2006). These studies suggest that marine reserves need not be very large for protecting breeding populations of sea cucumbers for long periods. If simply for sea cucumbers and other sedentary or sessile invertebrates, no-take reserves of perhaps 50–300 hectares (0.5–3 km^2) could be sufficient.

Most of the commercial sea cucumbers are deposit feeders that consume detritus, bacteria and diatoms mixed with sediments on the seabed (Conand, 2006a) (Figure 3). Those species on hard reef surfaces "mop up" the particulate organic matter that coats rocks and benthic vegetation (Figure 3). Just a few commercial species are suspension feeders (Hamel and Mercier, 2008a). Holothurians are therefore a low-food chain group and help to recycle detritus. Some species bury in sediments and are so believed

FIGURE 3

Sea cucumbers feeding on organic detritus and microalgae. Left: *Holothuria coluber* with cream-coloured tentacles extended, feeding on detritus in sediments. Right: *Pearsonothuria graeffei* with black tentacles extended to collect microalgae and detritus on a hard reef surface

PHOTOS: S.W. PURCELL

to help oxygenate upper sediment layers and play a role in bioturbation (Purcell, 2004a; Wolkenhauer *et al*., 2009).

Sea cucumbers are prey to a vast array of predators (Francour, 1997). In particular, invertebrate predators like sea stars, crabs and some gastropods are often reported as the culprits of mortalities. A short-term study on released sandfish shows that juveniles are prone to being eaten readily by a range of fishes (Dance, Lane and Bell, 2003). Some birds, turtles and marine mammals are also believed to eat sea cucumbers on occasion. However, some species develop passive or active mechanisms of defence (e.g. *Holothuria atra*, *Holothuria leucospilota*, *Cucumaria frondosa*) that have proved to be efficient predator deterrents.

2.2 BECHE-DE-MER MARKET

Sea cucumbers have been eaten by Chinese and other Asians for centuries for their curative and dietary properties (Conand, 1990, 2006a, 2006b). They were recorded as a tonic food as early as the Ming Dynasty (1368–1644 AD) (Chen, 2004). Foods are often first used by Chinese to treat ailments and disease, before powdered or chemical medicines. Many Asians believe that sea cucumbers can help reduce joint pain and arthritis, help restore correct intestinal and urinary function, reinforce the immune system and can treat certain cancers (Chen, 2004). To a lesser extent, sea cucumbers may also be eaten as aphrodisiacs. They are rich in protein and contain mucopolysaccharides and chondroitin sulphate, known in western medicines as treatments for arthritis and joint ailments. This correspondence with western medicine gives credit to the use of sea cucumbers in traditional Asian dietary medicines.

In the past, sea cucumbers were eaten by Asians wealthy enough to afford them for health treatments, or served as delicacies during festive periods such as the Chinese New Year. More recently, Chinese and other Asians have started to eat sea cucumbers more regularly, owing to increased affluence and greater disposable income for luxury foods (Figure 4). This increased demand is the primary cause of inflated prices of sea cucumbers globally and the driver of increased exploitation of stocks.

The main import markets are traditionally China, Hong Kong Special Administrative Region (SAR), Singapore and Taiwan Province of China. Recently, the United Arab Emirates (UAE) has also become important. All of these markets are also major re-exporting centres (Conand, 2004, 2006b, 2008). China, Hong Kong SAR is the major world market. Although China is the main consuming country, sea cucumbers are also appreciated in Southeast Asian countries and by Asians residing abroad (Ferdhouse, 2004).

FIGURE 4
Left: sea cucumbers served as a sauced dish in China. Right: wartless variety "Namako" (*Apostichopus japonicus*) from Kobe, Japan

PHOTO: S.W. PURCELL *PHOTO: J. AKAMINE*

Fresh or live animals are called sea cucumbers or holothurians, but they are usually gutted, boiled and dried before being exported to Asian markets. It is the dried body wall that is called "*beche-de-mer*", meaning "spade of the sea", or "*trepang*" or "*haishen*". Once purchased, beche-de-mer is reconstituted by gentle boiling then eaten in sauced dishes or soups. Sea cucumbers are also used in Malaysia in a wide range of products including oral jellies, body creams, shampoo and toothpaste (Choo, 2008a). Because they are a luxury food item and one that apparently delivers curative benefits, it is unlikely that the global market will wane over time, particularly if consumer affluence in China continues to rise.

The price of beche-de-mer varies greatly among species and also within species depending on the size of the animal and the care in which it was processed. Larger animals generally command a higher price per kilogram than smaller ones. The Japanese sea cucumber, *Apostichopus japonicus*, can fetch more than USD300 kg^{-1} (dried) at retail markets, if the animals are in a perfect, presentable, state (Figure 5). Some tropical species, particularly the sandfish *Holothuria scabra* and golden sandfish *Holothuria lessoni* (Massin *et al.*, 2009) can fetch almost an equivalent price for large, well-processed specimens. However, some low-value species or animals poorly processed would sell for a small fraction of this price.

FIGURE 5
Left: the Japanese sea cucumbers *Apostichopus japonicus* on sale in transparent bins and gift boxes in a market in Dalian, China. Right: price tag on a bin of dried high-quality *A. japonicus*; equivalent to USD460 per kg

PHOTOS: S.W. PURCELL

2.3 FISHERY TYPES

Sea cucumber fisheries are diverse in terms of ecological attributes of species, modes of exploitation, fishery history, socio-economic structures and capacity for management and enforcement (Toral-Granda, Lovatelli and Vasconcellos, 2008). They are often small-scale fisheries in the way the animals are harvested, mainly comprising fishers that collect sea cucumbers by wading or skin diving in shallow waters (Choo, 2008a; Conand, 2008; Kinch *et al*., 2008a) (Figure 6). In developed countries, sea cucumber fisheries are commonly industrialized, with fishing companies owning larger boats operated by teams of fishers, sometimes with sophisticated fishing gear (Bruckner, 2006c; Hamel and Mercier, 2008a) (Figure 7; Section 5.2). Greater and greater fleet capacity has also been an increasing theme for smaller fisheries as prices of beche-de-mer have become lucrative (Toral-Granda, 2008b; Kinch *et al*., 2008a).

FIGURE 6
Artisanal small-scale fisher in Mindanao, Philippines. Women (left) and men (centre) fish from small canoes and gather sea cucumbers in shallow water using only a mask and fins. A sea cucumber fisher in Tomini Bay, Sulawesi, Indonesia, (right) wearing simple, homemade, goggles

FIGURE 7
Industrialized fishing in eastern Canada for *Cucumaria frondosa*. Sea cucumbers are collected using a "drag" net (see *Examples and lessons learned* in Section 5.2) then dumped into a sorting tray on the fishing vessel where undersized sea cucumbers and bycatch, like sea urchins and sea stars, are removed and returned to the sea

The problems confronting small-scale and industrial fisheries are different. Small-scale fisheries often comprise a large number of lowincome fishers (see Kinch *et al*., 2008a,b; Choo, 2008a,b), who collect sea cucumbers out of tradition or as an occupation of last resort in times of economic hardship. In both cases, fishers show great reluctance or inability to cease fishing, even when sea cucumber populations become depleted. These fishers often lack formal education and live in remote areas so that they are hardly known by management agencies, making the job of working with them to implement sustainable fishing practices very difficult (see Conand and Muthiga, 2007; Rasolofonirina, 2007; Kinch *et al*., 2008b; Choo, 2008b). On the other hand, industrial-scale fishers are more commonly capable to switch to other resources and are easily contactable by fisheries agencies. But their great capital investment in boats and fishing gear means they must continue high rates of exploitation to cover financial loans and operating costs.

Most of the sea cucumber fisheries in the world are multispecies in nature (Toral-Granda, Lovatelli and Vasconcellos, 2008). There are over 60 species known to be exploited commercially and traded around the world (Toral-Granda, Lovatelli and Vasconcellos, 2008; Annex 10.1). Fisheries in the tropics tend to comprise many species (Figure 8). This is particularly true for those in the Western Pacific, Southeast Asia and the Indian Ocean, where 20–30 species can be fished and exported from a single country (Choo, 2008a; Conand, 2008; Kinch *et al*., 2008a). In contrast, temperate fisheries are more or less mono-specific (Conand, 2004, 2006a; Bruckner, 2006c; Hamel and Mercier, 2008a,b).

The habitats where sea cucumbers are fished also vary widely among various fisheries. Commercial species in the tropics are mostly fished on shallow coral reefs (Figure 9), tropical lagoons and inshore seagrass beds. Those in temperate waters can be found on rocky substrata or soft sediments, mostly in deeper waters (Figure 9). Some species seem to strongly prefer complex reef habitats (e.g. *Actinopyga lecanora*; *Stichopus chloronotus*) or wave-exposed areas (e.g. *Actinopyga mauritiana*), making them accessible only to skindivers. In contrast, species in temperate waters may occur to depths exceeding 50 m (e.g. *Cucumaria frondosa*; Hamel and Mercier, 2008a,b) and are mostly fished with “drag” nets (Figure 7).

The technical capacity and human resources of fisheries agencies also vary widely among sea cucumber fisheries. Developed countries, such as Canada, the United States of America and Australia, have relatively greater capacity to conduct monitoring and analyses on fisheries and biological data and in the development and compliance of fisheries management regulations. Management measures therefore tend to be more sophisticated. In developing countries, capacity constraints limit the ability to develop

FIGURE 8
Left: a mixed catch of sea cucumbers on a fishing boat in the Seychelles. Right: at least six species of dried sea cucumber with a sales receipt in Mindanao, Philippines

PHOTO: R. AUMEERUDDY

PHOTO: R. GAMBOA

FIGURE 9
Left: a tropical sea cucumber (*Actinopyga mauritiana*) in shallow, complex, coral reef habitat, too inaccessible for fishing with trawl gear. Right: a temperate species (*Cucumaria frondosa*) at depth, on a substrate of coarse sand and shellgrit

PHOTO: S.W. PURCELL

PHOTO: J.-F. HAMEL AND A. MERCIER

or effectively implement complex management measures (e.g. individual transferrable quota schemes) or to conduct rigorous monitoring of fishery stocks. Countries in Asia generally lack management measures and the two largest exporters of sea cucumbers, Indonesia and the Philippines, do not have widespread management systems for their sea cucumber fisheries (Choo, 2008a).

The level of access rights to fishing grounds or specific resources is another factor varying among fisheries. For example, the sea cucumber fishery in western Canada and the Great Barrier Reef in Australia are divided into delineated fishing areas allocated to particular licensed fishing companies (Hamel and Mercier, 2008b; Kinch *et al*., 2008a). The fishers can leave smaller adults while fishing, knowing that they have sole rights to collect them in subsequent seasons. In contrast, open access fisheries such as the Philippines or Madagascar are plagued with the "tragedy of the commons" (Hardin, 1968) whereby fishers even collect small adult and juvenile sea cucumbers because they will be fished by their neighbour if left behind (Choo, 2008b; Conand, 2008).

The wide diversity of sea cucumber fisheries makes it impossible to prescribe a "one-size-fits-all" template for management. There are, nonetheless, some regulatory measures that are appropriate for most fisheries and some actions that all fishery managers should undertake for implementing management (Section 4). Before proceeding to appraise the merits of potential management tools, managers must first set appropriate objectives, in line with precautionary principles and a holistic approach to management, and diagnose the fishery, in terms of its ecological and social attributes (Sections 3.4 to 3.6).

2.4 GLOBAL STATUS

Sea cucumbers are fished worldwide, particularly in tropical regions (Conand and Byrne, 1994; Conand, 2006b; Toral-Granda, Lovatelli and Vasconcellos, 2008). Fisheries exist in warm waters from East Africa to South and Central America, and in temperate waters of the Mediterranean and in the North Pacific and North Atlantic Oceans. Most of these fisheries have existed for centuries, especially those in Asia (Choo, 2008a), the Pacific Islands (Kinch *et al*., 2008a) and the Indian Ocean (Conand, 2008). The Western Central Pacific and Asia are the predominant regions exporting beche-de-mer. Some fisheries are relatively new or in the process of development, such as those in Latin America (Toral-Granda, 2008a), North America and Europe (Hamel and Mercier, 2008a).

The total volume of global harvests is difficult to collate for many reasons: not all countries declare sea cucumbers separately in trade statistics of marine invertebrates; some countries import and re-export; and some animals are exported as salted or frozen, representing about half of the original whole animal weight, whereas most others are exported dried, representing roughly 5–10 percent of the live animal weight (Ferdhouse, 2004; Conand, 2006b). Including catches of sea cucumbers in countries where they are eaten, the total global catch of sea cucumbers is in the order of 100 000 tonnes of live animals annually (considering that some trade statistics are not dried animals; c.f. Vannuccini, 2004). At the beginning of the new millennium, about 6 000 tonnes of processed (i.e. mostly dried) animals were exported to Asian markets, worth over USD130 million (Vannuccini, 2004).

Countries in Southeast Asia and the Pacific are traditionally the main sources of wild-caught sea cucumbers (Conand, 1990; Ferdhouse, 2004). A decade ago, the leading exporters were Indonesia, the Philippines, Papua New Guinea, Japan, Republic of Korea, the United States of America, Solomon Islands, Fiji Islands, Madagascar, Australia and New Caledonia. However, this appears to have changed radically in recent years as some fisheries have been depleted and others have developed or are expanding (Toral-Granda, Lovatelli and Vasconcellos, 2008).

Recent reviews of sea cucumber fisheries from around the world suggest that many are overexploited, some are depleted and a few are nascent fisheries with relatively healthy stocks (Toral-Granda, Lovatelli and Vasconcellos, 2008). In the Indian Ocean, more than half of the sea cucumber fisheries are considered overexploited (Conand, 2008). Excessive fishing has caused local extinction of breeding populations of some species and a collapse of other stocks in Egypt (Hasan, 2005) and depleted stocks to oblige a complete moratoria on fishing in India (Conand, 2008). Moratoria on fishing have been set in mainland Tanzania and Mayotte (France).

Throughout much of Asia, fisheries have been overexploited and populations are severely depleted for high-value species such as *Holothuria fuscogilva*, *H. whitmaei*, *H. scabra* and *Thelenota ananas* (Choo, 2008a). Field surveys indicate that some high-value species have also been fished to reproductive extinction in some regions of Indonesia, Viet Nam and the Philippines (Choo, 2008a,b). Fishery managers in Asian countries confront difficult challenges to deal with the sheer number of fishers, their poverty and dependence on aquatic resources, and limited technical capacity and human resources for implementing sustainable management.

In the Western Central Pacific, the vast majority of countries have exported sea cucumbers in recent years. Catches have dwindled to insignificant levels in most Polynesian countries (Kinch *et al.*, 2008a). Although Papua New Guinea was recently exporting hundreds of tonnes of beche-de-mer each year, the catch shifted to low-value species in recent years and there is compelling evidence from field surveys that stocks of high-value species have been fished to local extinction in some localities (Kinch *et al.*, 2008b). Overfishing prompted the recent closure of national fisheries in Vanuatu and Solomon Islands, which had both exported large volumes for the past two decades (Kinch *et al.*, 2008a). In 2009, depleting breeding stocks prompted a national moratorium to close the entire sea cucumber fishery of Papua New Guinea, a country traditionally among the top three global exporters of beche-de-mer. Six fisheries operate in Australia, but several valuable species are currently banned from fishing due to overexploitation, even from within the World Heritage-listed Great Barrier Reef Marine Park.

Fisheries in Latin America and the Caribbean started in the past two decades and have mostly been unsustainable (Toral-Granda, 2008a). One exception is the lucrative sea cucumber fishery in Cuba which, by all accounts, remains sustainable. After some years of heavy fishing, moratoria were imposed in fisheries of Costa Rica, mainland Ecuador, Panama and Venezuela. In Mexico, stocks of the valuable *Isostichopus fuscus* were fished to about 2 percent of the pre-fishing biomass (Toral-Granda, 2008a). In the World Heritage-listed Galápagos Islands, *I. fuscus* has been overexploited and the fishery has been the centre of aggressive demonstrations by fishers over stricter management regulations (Toral-Granda, 2008b).

Temperate sea cucumber fisheries of the Northern Hemisphere are commonly based on one of about five or six key species (Hamel and Mercier, 2008a). Temperate fisheries exist in the United States of America, Canada, Iceland, the Russian Federation, Japan and recently in parts of Scandinavia. Fisheries for species within the genus *Parastichopus* involve divers and have been active for almost 40 years. Those for *Cucumaria* species use "drag" nets from ships and are recent or in an exploratory phase (Hamel and Mercier, 2008a). Exploitation rates are increasing but fishery managers are mostly employing conservative measures. Some stocks are sizeable, like those of the temperate-polar *Cucumaria frondosa* in eastern Canada, and novel processing methods have been pioneered to use organs and muscle bands as well as the body walls of the animals, to countervail its low value as beche-de-mer (Hamel and Mercier, 2008b).

Of particular note, aquaculture in China for the cold-water *A. japonicus* has boomed in the past 15 years (Chen, 2004). Mass production of this species through aquaculture of juveniles in hatcheries and growout of adults in ponds and on artificial reefs currently rivals the total global wild captures in volume (Figure 10). Surprisingly, this does not seem to have dampened prices of the wild-caught tropical species.

FIGURE 10

Left: a commercial diver ready to collect sea cucumbers from artificial reefs in front of a hatchery for *A. japonicus* in Dalian, China. Right: *A. japonicus* harvested by the diver from an artificial reef previously stocked with cultured juveniles

PHOTO: J. AKAMINE

PHOTO: S.W. PURCELL