

A review of the emerging fishery for the sea cucumber *Cucumaria frondosa*: Biology, policy, and future prospects

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Introduction

Sea cucumbers have been harvested for human consumption for more than a millennium. Over the past 50 years, global landings have increased steadily from about 5000 tonnes annually in the 1950s to nearly 30,000 tonnes in 2003 (Conand and Byrne 1993; FAO 2005). Originally, the fishery for these marine invertebrates were limited to a few species in the Indo-Pacific, but recently — in response to a market opening created by both depletion of traditional resources and an increasing demand for sea cucumber products — the exploitation of sea cucumbers has spread to many new regions and a number of new species are now being targeted (reviewed by Conand 1997, 1998, 2001, 2004; Conand and Byrne 1993)

One of the species that is new on the global market is the North Atlantic sea cucumber *Cucumaria frondosa*. A fishery for *C. frondosa* developed on the east coast of North America during the 1990s and has expanded so rapidly that according to FAO, as well

as national USA and Canadian statistics, the landings of this species alone in 2003 made the USA the world's second-largest producer of wild-caught sea cucumber, and Canada the fourth largest producer (Fig. 1).

Because of the global significance of these fisheries and because *C. frondosa* has become one of the most predominant commercial sea cucumber species on the world market in terms of landed weight, it is important to document and follow the developments in the exploitation of this species. Bruckner (2005) provided an overview of the *C. frondosa* fishery in the state of Maine (USA) as part of a larger summary of continental USA sea cucumber fisheries, but a fishery for this species outside the USA remains virtually undocumented in the literature. This paper aims to fill the information gap by providing an overview of the history and current status of fisheries for *C. frondosa* throughout its range, and discussing future prospects for these fisheries in the light of existing management experiences of sea cucumber fisheries in other places.

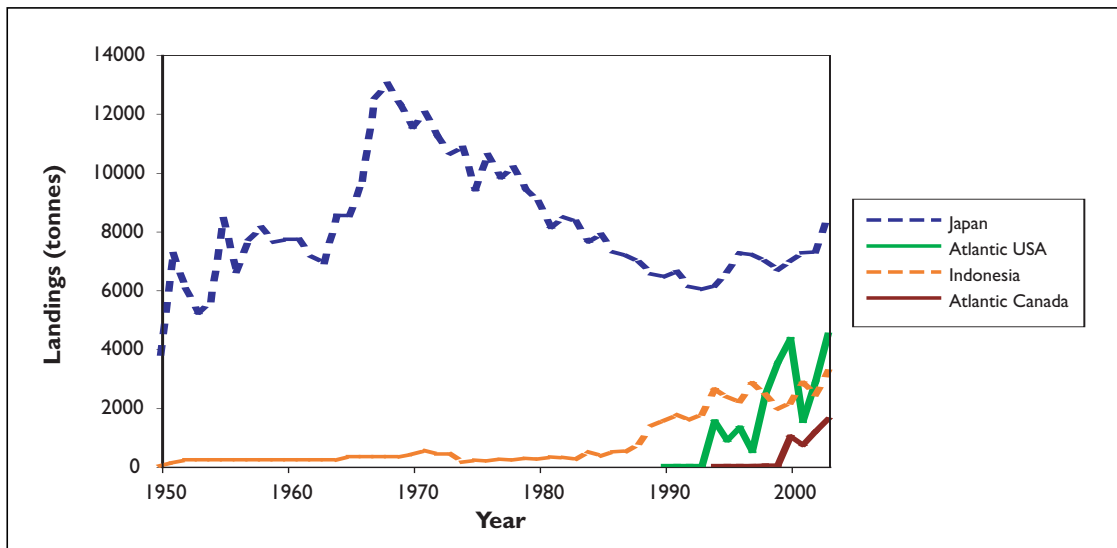


Figure 1. Total sea cucumber landings for the four countries or regions in countries producing the highest yields in 2003 (note that only landings from the Atlantic coast of the USA and Canada are included). Data source: FAO 2005 (for Japan and Indonesia), NMFS 2005 (for USA), DFO 2005 (for Canada). It should be noted that there is a reporting error in the FAO data for US Northeast sea cucumber landings in 2003. FAO reports a landing of ~9300 tonnes, but the correct figure, as reported from the Maine Department of Marine Resources and the NMFS is ~4500 tonnes.

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Cucumaria frondosa

Although several sea cucumber species exist in the North Atlantic and adjacent seas, only one, the orange-footed sea cucumber *Cucumaria frondosa* (Gunnerus 1767), is targeted in the current fishery. *Cucumaria frondosa* is the only dendrochirote sea cucumber that is harvested for human consumption on a significant scale globally; all other commercial species belong to the order Aspidochirota (Bruckner et al. 2003). As is typical for sea cucumbers, the biology and ecology of *C. frondosa* is still incompletely understood, but in recent years, a number of extensive studies of the growth and reproduction of this species have been carried out (e.g. Gudimova et al. 2004; Hamel and Mercier 1995, 1996a, 1996b, 1998, 1999; Medeiros-Bergen and Miles 1997; Organesyan and Grigorjev 1998; Singh et al. 1999, 2001).

Cucumaria frondosa reaches a length of 35–50 cm and has a wide distribution in the North Atlantic and Arctic Ocean including the Norwegian, Barents, and North Seas. The southern range in the western Atlantic extends to Cape Cod; in the eastern Atlantic it ranges from the far north, to south of Scandinavia and the British Isles (Jordan 1972). *Cucumaria frondosa* occurs from the intertidal zone down to 300–400 m (Brinkhurst et al. 1975), but is most common in shallower depths (Jordan 1972; Singh et al. 2001).

The main products derived from *C. frondosa* are the muscle bands that are vacuum packed and flash frozen, and the dried body wall that is boiled and dried (Feindel 2002). The dried product is about 5–10% of the wet weight (Ke et al. 1987; Feindel 2002).

Most *C. frondosa* products are sold in Asian markets. Although *C. frondosa* is smaller than most commercial species and has a thinner body wall, a market acceptance for this species has developed over the past decade. However, *C. frondosa* remains a lower-grade species that yields much lower prices than most commercial sea cucumbers. Generally, fishermen are paid about 0.1 US dollars (USD) per kilogram and the dried product yields only about USD 6–10 kg⁻¹ (Feindel 2002). This price range is clearly much lower than that for other sea cucumber species that typically yield USD 30–40 kg⁻¹ of dried body wall and more than an order of magnitude lower than certain high-value species that may fetch up to USD 110 kg⁻¹ of the dried product (Ferdouse 2004).

***Cucumaria frondosa* fisheries**

Information on fisheries for *C. frondosa* was collected from published and unpublished literature as well as personal communication with fisheries

officials in all North Atlantic countries (the affiliations of all individuals cited in the following sections are listed in the Appendix). The information was mainly collected between January and May 2005. We always attempted to obtain the most updated data, but we emphasize that all information presented in the following sections is highly time-sensitive because exploitation of *C. frondosa* is evolving and changing quickly.

Although there had been sporadic attempts to start a fishery for *C. frondosa* in Atlantic Canada since 1980, the state of Maine (USA) was the first place to develop a substantial fishery for this species (M. Lundy, pers. comm.). This fishery started in earnest in 1994 (Chenoweth and McGowan 1997) and Maine is currently the only state on the US east coast where sea cucumbers are harvested. (For a review of the history and current status of this fishery, see Bruckner 2005).

Two years after the onset of the Maine sea cucumber fishery, Canadian government agencies began assessing the feasibility of starting a fishery for *C. frondosa*; in 2000, a sea cucumber fishery had developed in several locations. Since this onset, trends in annual landings have varied between provinces (Fig. 2).

The Scotia-Fundy sector (Nova Scotia and New Brunswick) has had the highest sea cucumber landings in Canada. In this region, fishers with an urchin license were allowed to take sea cucumbers prior to 2004, but now, only people holding an experimental sea cucumber license are authorized to land this species (DFO 2005a). Currently the region has issued five such exploratory licenses, and a number of regulations are in place, including a closed season from April to December, and a series of closed areas (V. Docherty, pers. comm.). As in Maine, these regulations have partly been put in place to avoid gear conflicts. In addition, no nighttime fishing for sea cucumbers is allowed in the Scotia-Fundy region, and simple gear restrictions are in place as well as a minimum size (10 cm length) for landings (DFO 2005a).

The other region where sea cucumbers are being fished include the provinces of Newfoundland and Labrador where the governments have there have issued eight exploratory licenses and have set an exploratory annual quota of 4500 tonnes (L. Barrett, pers. comm.). There is no sea cucumber harvesting and none being planned or anticipated in the near future in the province of Prince Edward Island; all attempts to establish a fishery in this region have failed due to limited stock supply (B. MacPhee, pers. comm.). Similarly, although Hamel and Mercier (1999) reported promising prospects for a sea cucumber fishery in Quebec, it has not yet been

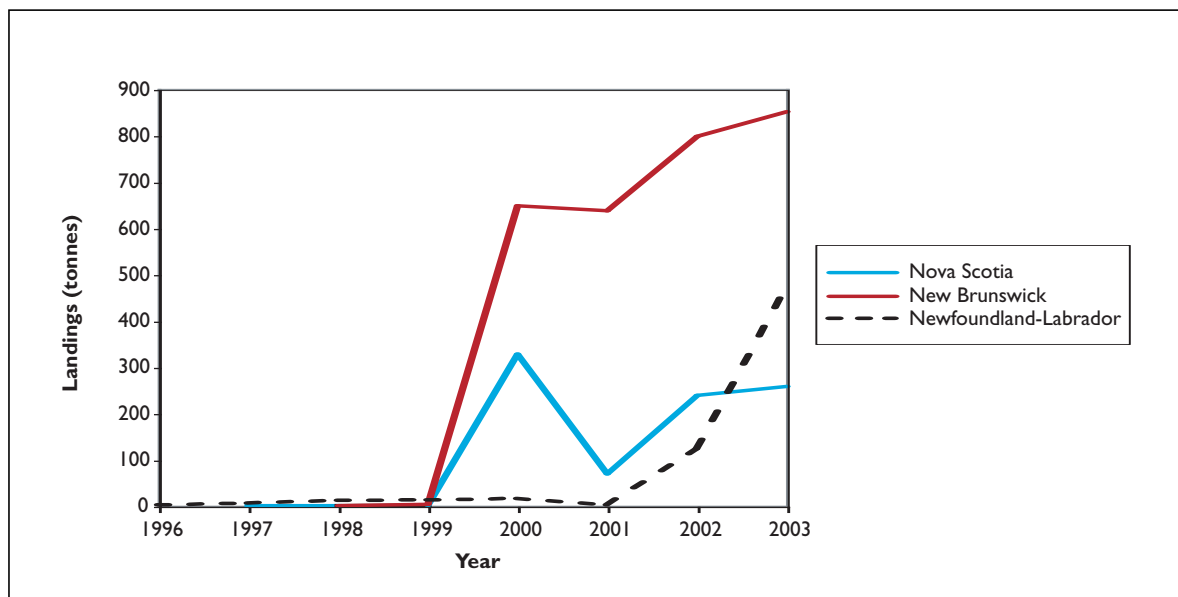


Figure 2. Sea cucumber landings in Atlantic Canadian provinces.
Data source: DFO unpublished database.

possible to establish an economically viable fishery. However, while there is presently no commercial sea cucumber fishery in Quebec, studies to assess the possibility for developing one in the future are ongoing (J. Lambert, pers. comm.).

All Canadian fisheries use drags similar to the ones used in Maine. As in Maine, a scallop drag was initially used, but was replaced by the modified urchin drag that appears to produce less bycatch and has a lighter impact on the seabed than the heavier scallop drag (DFA 2002a). The mean fished depth is 13–20 m and fishermen never drag below 65 m (Feindel 2002; P. Collin, pers. comm.). Initial surveys in Newfoundland suggested that diving might be a possible alternative harvesting method, and exploratory trial dives yielded up to 2700 kg day⁻¹ in certain areas. However, experimentation with this harvest technique in the Scotia-Fundy region indicated that the value of *C. frondosa* is too low to make diving a viable harvest technique (DFO 2005b).

The only European country that harvests sea cucumbers is Iceland. Although a three-month trial study several years ago suggested that *C. frondosa* could not sustain a viable fishery in Iceland, a private company is currently making another attempt at developing a fishery (A. Möller, pers. comm.). One boat has been fishing *C. frondosa* for about one year in Breidarfjordur Bay on the west coast of Iceland. So far about 80 tonnes of *C. frondosa* have been landed (K. Olafsson, pers. comm.). The future of this fishery is uncertain as the resource appears to be more dispersed and less abundant than antic-

ipated, and catch per unit of effort (CPUE) has been variable and small (A. Möller, pers. comm.).

Most other European countries have never considered exploiting their sea cucumber resource (R. Redant: Belgium, H. Geene: Netherlands, C. Stransky: Germany, E. Morgan: UK, D. McGabhann and P. Comisky: Ireland, A. Lindquist and D. Valentinsson: Sweden, A. Skak: Greenland pers. comms.). However, although there is no current activity, interest in sea cucumber fisheries is developing in several places. In Norway there is now a small-scale attempt to start both fishing and farming sea cucumbers (E. Slinde, pers. comm.). In Denmark there is no current exploratory fishery, but the Institute of Fisheries Research is initiating a project to explore the potential of a future harvest of *C. frondosa* that is currently common bycatch (J. Astrup, pers. comm.). Finally, in Ireland, the fisheries authorities receive occasional requests regarding the harvesting of sea cucumbers. *Cucumaria frondosa* appears to be rare in Irish waters, but there are several other species that potentially could be harvested in the future (D. McGabhann, pers. comm.).

In the Barents Sea, fishermen recently began harvesting *C. frondosa* (Gudimova 1998; Organesyan and Grigorjev 1998). So far there is no directed fishery for this species; all landings are bycatch from the scallop fishery. Previously, this bycatch was simply discarded at sea but since 2000, fishermen have been able to sell the sea cucumbers for processing (Gudimova et al. 2004). Thus far, landings have not exceeded 200–250 tonnes per year (Gudimova et al. 2004) and because sea cucumbers are

harvested only as bycatch, there are no regulations governing this resource.

In general, all fisheries for *C. frondosa* are still in early exploratory stages, and it is difficult to predict whether the available stock can sustain long-term exploitation. While there are several full-time sea cucumber fishermen in Maine, reports from Canada indicate that *C. frondosa* may not be able to sustain a stand-alone fishery, but that it can provide a supplement for urchin or groundfish fishermen (DFA 2002a, b, c; DFO 2005a). All surveys and reports from fishermen suggest that the distribution of *C. frondosa* is highly scattered and localized (DFA 2002c).

Prospects

Cucumaria frondosa seems to hold promise for the fishing industry in the North Atlantic and adjacent seas — a region that has previously not exploited their holothurian resources but where overexploitation and depletion of many traditional stocks have left fishing communities eager to find new target species. However, even though *C. frondosa* has quickly become one of the world's most important commercial sea cucumbers, it is obvious that fisheries for this species in most areas are still in a very early exploratory stage, and at this point it is difficult to make predictions about their future sustainability.

Sea cucumbers tend to be highly vulnerable to overfishing, and sea cucumber fisheries throughout the world are generally characterized by overexploitation and boom and bust cycles (Conand 2004; Uthicke and Conand 2005). Nevertheless, there are several examples of sea cucumber fisheries that appear to be well-managed and have produced relatively stable yields over decades. Examples of such fisheries are found on the Pacific coast of North America in the states of Alaska (Woodby and Larson 1998; Woodby et al. 2000), Washington (Bradbury 1994; 1999), and California (Schroeter et al. 2001; California Department of Fish and Game 2001), and in British Columbia, Canada (Muse 1998; DFO 2005b). It is important to note, however, that all these fisheries are much smaller in volume than the current *C. frondosa* fisheries on the east coast of Canada and the USA (Bruckner 2005).

The low value of *C. frondosa* requires harvesting to be in enormous bulk to be cost-effective, creating a real concern for the sustainability of fisheries for this resource. At this point, there is no information on the size of the virgin biomass for this species, so managers do not know what fraction of the population has been or is harvested. Although *C. frondosa* is extremely abundant in some areas, the distribu-

tion may be patchy, and lack of a clear pattern of decreasing CPUE throughout the range of the fishery is not a safe indication that the resource is not being depleted. Especially for developing fisheries that target spatially structured stocks such as sea cucumbers, CPUE can be a very misleading measure of abundance because fishermen may continue to move to unexploited areas. For example, in both Washington and California, CPUE for sea cucumbers remained stable over a series of years, whereas direct assessment surveys showed severe population declines (Bradbury 1994; Schroeter et al. 2001).

Because CPUE is probably not a good measure of resource abundance, it is entirely unclear whether the abundance of sea cucumbers in the North Atlantic has already decreased in response to exploitation. The large quantities of *C. frondosa* currently landed in North America may not be sustainable, considering the slow growth of this species and the slow rate of resource renewal typically observed in sea cucumber fisheries (Conand 1989; Bruckner et al. 2003; Uthicke and Conand 2005). In general, the global experience with overexploitation in many sea cucumber fisheries may suggest that a highly precautionary management strategy should be adopted for *C. frondosa*.

However, the extent to which the global sea cucumber fishery experience will be relevant to the management of *C. frondosa* depends on a number of factors including the degree of similarities and differences in the biology and the fishing regime between *C. frondosa* and other species.

Comparative vulnerability of *C. frondosa* fisheries

Recent work on marine fish suggests that comparisons of life history parameters may be used to predict differences in how related species respond to exploitation (Jennings et al. 1998, 1999; Reynolds et al. 2001). According to theory, species that attain large sizes, grow slowly, and mature late, suffer greater population declines for a given mortality rate than smaller, faster-growing species that mature early. Phylogenetic comparisons of life history patterns have shown that this pattern is true for fish stocks from the North Atlantic (Jennings et al. 1998). It seems likely that this pattern applies across taxa (Jennings et al. 1998), so an examination of how the life history traits of *C. frondosa* compare with those of other sea cucumbers may suggest whether this species will be more or less vulnerable to exploitation than those that have been exploited for decades or centuries. Although life history traits notoriously are difficult to determine in sea cucumbers due to their lack of hard parts, low tag retention, and flexible body shapes, the magnitude of the variation in reported parameters between

species is so great that a rough inter-specific comparison can be meaningful.

Hamel and Mercier (1996a) found that the maximum size reached by *C. frondosa* after five years of growth was 10.7 cm at 20 m depth and less than 5 cm at shallower depths. These figures are much lower than reported growth estimates for any other species. *Holothuria scabra*, for example, is reported to grow to 15 cm in only one to two years (this is larger than *C. frondosa* grew in 5 years at its maximum growth-rate; Skewes et al. 2000) and *Isostichopus fuscus* is reported to grow to 21 cm in four to five years (Herrero-Perezul et al. 1999; Reyes-Bonilla and Herrero-Perezul 2003). although to some extent growth rate is correlated with water temperature, tropical sea cucumbers are not the only species that appear to grow faster than *C. frondosa*. Temperate species such as *Stichopus japonicus* and *Parastichopus californicus* also grow to larger sizes faster; *S. japonicus* typically grow to 20 cm in four years (Izumi 1991), and *P. californicus* reaches 4–10 cm after only two years and is thought to reach a commercial size of 30–50 cm at the age of four years (Boutillier et al. 1998).

Hamel and Mercier (1996a) found that *C. frondosa* reached sexual maturity when the animals were about five years old at 20 m depth. Shallower populations of *C. frondosa*, however, did not reach sexual maturity during their experimental period of five years, and considering the significantly lower growth rate at those locations, it is probable that maturation occurs much later than age five (Hamel and Mercier 1996a). The minimum estimate of age at maturity of five years for *C. frondosa* is similar to that reported for *P. californicus* (Cameron and Fankboner 1989) and only slightly later than *Holothuria fuscogilva*, which is reported to mature at four years (Reichenbach 1999), and *I. fuscus*, which matures at four to five years (Herrero-Perezul 1999). Other species, however, such as *H. scabra* and *S. japonicus* mature considerably earlier, at one to two and two years respectively (Skewes et al. 2002; Chen 2003).

The available data suggest therefore that especially at shallow depths, *C. frondosa* matures later and grows considerably slower than several commercial species. *Cucumaria frondosa*, with a maximum size of 50 cm, is intermediate in size among commercial sea cucumbers that range from 5 cm to more than 1 m (Bruckner et al. 2003). According to theory and the analysis of Jennings et al. (1998) a smaller maximum length should make *C. frondosa* less vulnerable to exploitation than other species, but its considerably slower growth and late maturity may make it more vulnerable. Certainly the estimate of 10–15 years required for growth before re-

cruitment to the fishery is much higher than reported for any other holothurian species (Hamel and Mercier 1996a; Gudimova et al. 2004).

To contrast the findings of the life history comparison, which may suggest that *C. frondosa* is less resistant to exploitation than other species, there are several factors that could indicate that *C. frondosa* may actually have greater potential as a sustainable fisheries resource than other sea cucumbers. First, the density of *C. frondosa* appears to be much higher than that reported for other sea cucumbers. Typical densities for tropical holothurians rarely exceed a few hundred per hectare, although some species such as *Actinopyga echinites*, *Actinopyga mauritiana*, and *Holothuria atra* have been observed in aggregations of several 1000s per hectare (Conand 1994; Hamel et al. 2001). The density of the most common temperate sea cucumber on the west coast of North America, *P. californicus*, is reported to be as much as 19 individuals per meter of coastline (Boutillier et al. 1998). However, density estimates for *C. frondosa* off the east coast of North America are commonly around 5–15 individuals per square meter (ind. m⁻²) with local densities up to 50 ind. m⁻² (Singh et al. 2001). No density estimates are available for *C. frondosa* in other parts of its range, but the extremely high density of *C. frondosa* in the western North Atlantic suggests that, at least in this region, a greater virgin biomass is available. This means that greater yields may be supported over time than for more sparsely distributed species. However, although a large virgin biomass may allow for a greater absolute amount of resource extraction before the future viability of a stock is impacted, it certainly in itself does not safeguard a stock from overfishing.

One factor that may directly help protect adult *C. frondosa* from overfishing is habitat use and depth range. Hamel and Mercier (1999) suggested that because *C. frondosa* is found on underwater steep cliffs and rough terrains that are inaccessible to fishermen, such areas serve as natural refuges that will ensure that a portion of the sea cucumber population remains untouched. In addition, with current technology, fishermen do not dredge below 60 m, whereas *C. frondosa* are found down to >300 m. This means that only the top fifth of *C. frondosa*'s depth range is currently being fished so that unless harvesting behavior and technology is considerably altered, depth provides a natural refuge that would protect part of the *C. frondosa* spawning stock even in highly fished regions. Such a depth refuge has proven to be a very successful tool in the management of the red abalone in California (Karpov et al. 1998). It is uncertain, however, at what densities *C. frondosa* is found in areas currently inaccessible to fishing gear (both because of depth

and bottom topography), and whether individuals in these areas have a reproductive output that is sufficiently high to supply the more shallow and accessible fishing grounds. The reproductive cycle of echinoderms has in some cases been found to vary between depths (Keats et al. 1984; Nicholas et al. 1985).

Hamel and Mercier (1996b) reported that in the Gulf of Saint Lawrence, the gonadal index of *C. frondosa* individuals at 10 m remained slightly lower than that observed at 110 m, whereas Singh et al. (2001) found that in Passamaquoddy Bay, individuals at shallow depths had higher dry gonad weights than deepwater individuals. Because of the small difference in both sets of measurements, the inverse results of the two studies and the fact that both studies found that the seasonal reproductive patterns were roughly similar at both depths, it appears that *C. frondosa* may have similar reproductive potential at all depths.

One factor indicating that reliance on natural refuges may be a viable management strategy for *C. frondosa* is its relatively long planktonic larval duration of 48–49 days (Hamel and Mercier 1996a). Although *P. californicus* has an even longer larval stage of 65–125 days (McEuen 1987), most other sea cucumber species are planktonic for much shorter periods before they settle (e.g. *S. japonicus* 12–13 days, Chen 2003; *H. scabra* 13 days, Hamel et al. 2001; *H. fuscogilva* 14–21 days, Friedman 2005; *I. fuscus* 22–27 days, Hamel et al. 2003; and *H. nobilis* 28 days, Martinez and Richmond 1998). The longer larval stage of *C. frondosa* may facilitate recovery of depleted areas because broodstock can be imported from locations that are protected from fishing. Although dispersal is dependent on a number of factors, including local oceanographic conditions, planktonic larval duration has been shown to be at least partly associated with the connectivity of marine populations on a regional scale (Doherty et al. 1995) and may therefore make refuges a viable option.

In addition to these ecological considerations, it appears that current economic forces may also help protect *C. frondosa* against overfishing because, paradoxically, the factor that is, perhaps, the greatest threat to the fishery's sustainability — the low economic value that necessitates the capture of enormous biomass for the fishery to be economically viable — may at the same time help maintain *C. frondosa* populations at moderate population densities. For more valuable sea cucumber species, it is worthwhile for fishers to search out individuals even when they are at extremely low densities. For example, Boutillier et al. (1998) reported that in British Columbia, Canada virtually all sea cucum-

bers have been removed in areas that have been searched by a dive harvester. However, because *C. frondosa* yields such a low value per landed kilogram, it is not economically viable for fishermen to keep fishing a given area until all sea cucumbers have been harvested. As soon as CPUE drops below a certain threshold, fishers will either move to a new area or stop fishing altogether because they will lose money by continuing. Thus, while economic extinction of the *C. frondosa* fisheries is a real possibility, it seems that unless extremely severe Allee effects occur (Courchamp et al. 1999; Stephens and Sutherland 1999; Petersen and Levitan 2001), it is unlikely that fishing will endanger *C. frondosa* with biological extinction risks, as has occurred for other sea cucumber species as a result of fishing (Bruckner et al. 2003). It is important to note, however, that although *C. frondosa* may not become extinct, the loss of the fishery due to overfishing could cause significant economic hardship to fishermen. Furthermore, the ecological impacts of a great reduction in the biomass of sea cucumbers are unknown.

Potential future changes in the market price for *C. frondosa* may considerably alter the dynamics of fisheries for this species and the risk of biological overfishing. Price increases seem possible as suggested by Ferdouse (1999, 2004). The market is virtually insatiable, and supply from other areas may dwindle due to overexploitation, but for now the low value of *C. frondosa* may offer some protection for the species. Although the apparent slow growth rate and relatively late maturity suggest that *C. frondosa* could be more vulnerable to exploitation than other sea cucumber species, the high density and the potential for natural harvest refuges that would protect a portion of the spawning stock indicate great potential for developing and maintaining sustainable fisheries for this species. It remains to be seen whether 1) this potential is realized through prudent management, 2) whether *C. frondosa* remains one of the world's most important commercial species in terms of landed weight, or 3) whether fisheries for this species will follow the cycle of most sea cucumber fisheries globally: that of boom and bust.

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