Population status, fisheries and trade of sea cucumbers in temperate areas of the Northern Hemisphere

Jean-François Hamel and Annie Mercier

Precautionary management of *Cucumaria frondosa* in Newfoundland and Labrador, Canada

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SUMMARY

Data on sea cucumber fisheries in the temperate northern hemisphere are mainly available for four countries (Canada, United States of America, Russian Federation and Iceland), and commercial harvests are centered on four species (*Parastichopus californicus*, *P. parvimensis*, *Cucumaria frondosa* and *C. japonica*). Both *Parastichopus* species are primarily exploited by divers at a scale that is similar to what occurs elsewhere (e.g. tropical Indo-Pacific regions). However, harvests of the *Cucumaria* species typically involve industrialized processes (i.e. fishing boats, specialized trawls and processing plants). While *Parastichopus* fisheries date back to the early 1970s, most fisheries of *Cucumaria* are fairly new, and most of them are still in the exploratory phase, especially in Canada. The present document outlines the biological and population status, the current catches, the management measures in place, the socio-economic importance of the sea cucumber resources, the current research associated with these fisheries and the threats they may be facing.

1. INTRODUCTION

Compared to the sea cucumber trade in Asia and the Indo-Pacific, which is considered to date back some 1 000 years (Conand, 2001), the commercial harvesting of holothurians in North America is fairly new, having started in the 1970s on the west coast of the United States of America (hereinafter abbreviated to USA) and in the 1980s on the west coast of Canada (Conand and Sloan, 1989; Bruckner, 2005, 2006a,b; Therkildsen and Petersen, 2006). It spread to the east coast of Maine (USA) and to the Atlantic provinces of Canada a little over a decade ago (Therkildsen and Petersen, 2006). However, sea cucumbers have been fished for subsistence by native people for centuries along the west coast of North America (Mathews, Kookesh and Bosworth, 1990) and in Arctic Canada (Wein, Freeman and Markus, 1996).

In response to a growing demand for sea cucumber products and owing to the depletion of traditionally fished stocks, new species have been sought (Conand, 2004), including temperate and polar ones, which are slowly gaining popularity on the market. Hence, despite the abundance of some of these temperate and polar sea cucumbers, they have only recently entered the world trade for bêche-de-mer and other products. The present document covers four different species and four countries for which data are available. Some species/regions have been well studied and are therefore associated with good biological data, landing statistics and management protocols, whereas others are not well documented, leading to an unequal treatment in the following pages.

2. REGION UNDER STUDY

Although most of this chapter is dedicated to North American sea cucumber fisheries, it will also provide data for adjacent countries, which are harvesting sea cucumbers in the temperate-polar waters of the North Atlantic and North Pacific (Figure 1). On the Pacific side, this review will include the Russian Federation, the USA (including Alaska) and Canada. On the Atlantic side, it will focus on Canada, USA, Iceland and the Western Russian Federation coast along the Barents Sea. There are probably small scale fisheries occurring elsewhere, especially in Scandinavia (Norway and Sweden) (Therkildsen and Petersen, 2006), however, no reliable information pertaining to landings has been found and consequently they will not be discussed in the present document. A developmental fishery for the sea cucumber *Stichopus tremulus* has reportedly started in Norway in 2007, however it is still too early to obtain any tangible data on this initiative. Moreover, data for the Russian Federation and Iceland remain scarce.

FIGURE 1

Region under study and countries covered in this review (highlighted in yellow). The map shows the confirmed distribution of the sea cucumber species under study. The region encompasses the FAO Statistical Areas 18 (Artic Sea), 21 (Northwest Atlantic), 27 (Northeast Atlantic), 61 (Northwest Pacific), 67 (Northeast Pacific) and 77 (Pacific Eastern Central)

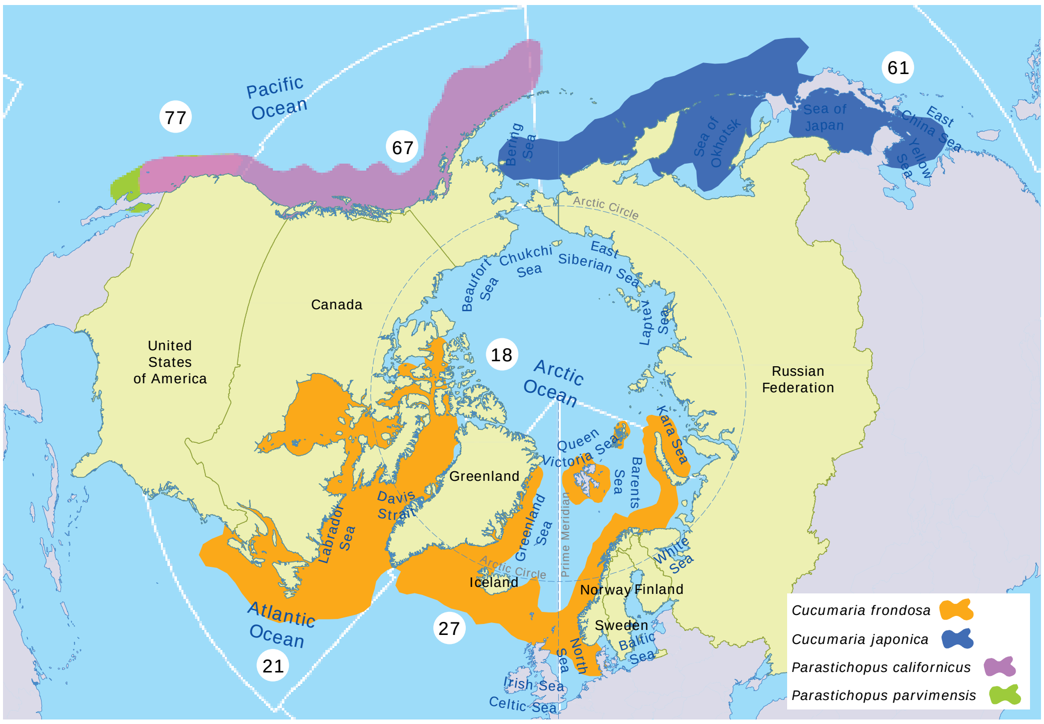


TABLE 1
Commercial species of sea cucumber (Echinodermata: Holothuroidea) found in the North Atlantic and North Pacific

Species	Common name	Order	Family
Cucumaria frondosa (Gunnerus, 1767)	Sea pumpkin; Orange–footed sea cucumber	Dendrochirotida	Cucumariidae
Cucumaria japonica (Semper, 1868)	Japanese sea cucumber; Kinko (in Japanese)	Dendrochirotida	Cucumariidae
Parastichopus californicus (Deichmann, 1937; Stimpson, 1857)	Giant red sea cucumber; Californian sea cucumber	Aspidochirotida	Stichopodidae
Parastichopus parvimensis (Clark, 1913)	Warty sea cucumber	Aspidochirotida	Stichopodidae

3. BIOLOGICAL AND POPULATION STATUS

3.1 Key taxonomic groups

Sea cucumber fisheries in the higher latitudes of the northern hemisphere focus mainly on four species: *Cucumaria frondosa*, *C. japonica*, *Parastichopus californicus* and *P. parvimensis* (Table 1; Figure 1). The first two species are the only two Dendrochirotida species harvested for human consumption in the northern hemisphere; the last two species are included in the order Aspidochirotida (Table 1).

Based on currently available estimates, *C. frondosa* is the most abundant commercial sea cucumber on the globe. It can be found in such high densities that fishers in some areas are able to catch up to 15 tonnes per day, even as bycatch of other sea products (Hamel and Mercier, 1999a) (Figure 2). Bradshaw, Ryan and Cooper (1991) indicated that a tow of five minutes will collect an average of 745 sea cucumbers in Nova Scotia (Canada). In 1988, a small fishery for *C. frondosa* developed on the east coast of the USA and has expended so rapidly that, according to available 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 (Therkildsen and Petersen, 2006). Despite this, the biomass of unexploited *C. frondosa* stocks remains extensive in local areas and most fisheries are still at the exploratory stage.

The landings of *C. japonica*, mostly by Russian Federation fishers in the North West Pacific, remain poorly documented, precluding the evaluation of its importance in the world market (Gudimova, E., Polar Research Institute of Marine Research and Oceanography, Murmansk, Russian Federation, personal communication). Conversely, data for *P. californicus* and *P. parvimensis* are readily available and show that these

FIGURE 2
Harvesting of *Cucumaria frondosa* off Newfoundland and Labrador (Canada)

COURTESY OF L. BARRETT (DFA)

two species contribute little to the world market. Note that some tropical species of commercial value are found along the coast of Florida (USA) however they are not discussed in the present document. Bruckner (2006b) mentioned that there were no known harvests of these species in federal waters of the USA.

3.2 Biology and ecology of sea cucumbers

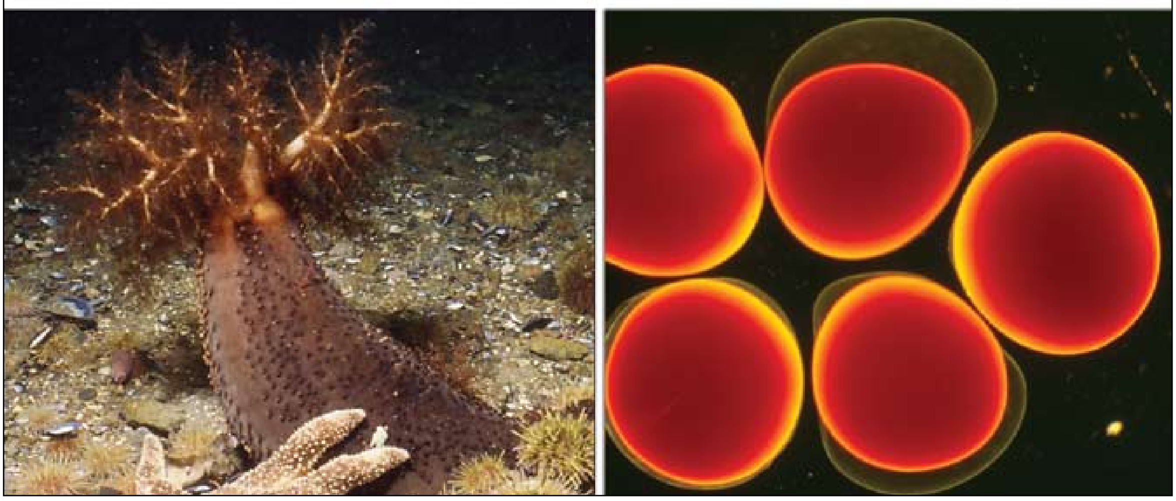
3.2.1 Cucumaria frondosa

Cucumaria frondosa (Figure 3) is among the most intensively studied species of sea cucumber; it has been the subject of numerous M.Sc. and Ph.D. dissertations, as well as several primary research papers and reports. *C. frondosa* is found in the North Atlantic from the Arctic to Cape Cod and from the Arctic to the northern latitudes of the United Kingdom, in Iceland, in the Barents Sea along the coast of the Russian Federation, in Scandinavia, the North Sea and along the coast of Greenland (Levin and Gudimova, 2000; Bruckner, 2006b). In some locations, such as in the Passamaquoddy Bay, New Brunswick (Canada), *C. frondosa* can be found in tide pools of the lower intertidal zone (Brinkhurst *et al.*, 1975) and is known to commonly occur down to 300 m (Brinkhurst *et al.*, 1975). Small specimens have recently been collected from depths of ca. 800 m along the continental rise of the Grand Banks in Newfoundland. However, *C. frondosa* is typically distributed between 20 and 100 m, with some variation between sites (e.g. Jordan, 1972; Coady, 1973; Hamel and Mercier, 1996b; Singh *et al.*, 2001; Grant, 2006).

This football–shaped sea cucumber is ca. 25–30 cm long (Hamel and Mercier, 1996b). Jordan (1972) mentioned it can reach 50 cm when relaxed. Desrosiers *et al.* (1989) established the average live weight around 250 g in Quebec (Canada). Campagna, Lambert and Archambault (2005) reported an average between 541 and 605 g depending on depth of collection along the coast of Quebec and Ke (1984, 1987) established it around 360 g in Nova Scotia (Canada). The sex ratio of *C. frondosa* is close to 1:1 (Coady, 1973; Hamel and Mercier, 1995, 1996b).

C. frondosa mainly colonizes rocky or pebbly bottoms (Hamel and Mercier, 1996b), though they have been observed occasionally on sandy bottoms in some areas (i.e. St. Pierre Bank) of the Newfoundland Grand Banks (Grant, 2006). The typical colour is light or dark brown, but a small percentage of individuals are a pale shade of orange, or cream, seemingly with little or no pigmentation. Some individuals can be brownish with pale patches scattered over the body. *C. frondosa* uses ten ramified tentacles

FIGURE 3
***Cucumaria frondosa* in its natural habitat (left) and a group of freshly fertilized eggs (right)**



COURTESY OF J.-F. HAMEL AND A. MERCIER (SEVE) distributed around the mouth to capture particles in suspension in the water column, including phytoplankton and the tiny animalcules of the zooplankton (Jordan, 1972; Hamel and Mercier, 1998b). This species is mainly sessile, although it can display a strong escape response, detaching from the substrate and vigorously contracting its body wall, in the vicinity of one of its predators, such as the sea star *Solaster endeca*. Generally, the latter is very common where large populations of *C. frondosa* are found. Other known predators include the northern wolfish *Anarhichas lupus*. Sheffield *et al.* (2001) also indicated that *C. frondosa* was found to be part of the diet of walruses. Newly settled larvae and juveniles smaller than 1 cm are susceptible to grazing species, especially the green sea urchin *Strongylocentrotus droebachiensis* (Hamel and Mercier, 1996b).

The reproductive cycle of *C. frondosa* is characterized by an annual spawning and a generally highly synchronized gamete release (Hamel and Mercier, 1996b, c). The spawning season varies between populations from different locations (e.g. Jordan, 1972; Coady, 1973; Hamel and Mercier, 1995, 1996b,a,c; Oganesyan and Grigorjev, 1996; Singh *et al.*, 1999; Gudimova and Antsiferova, 2006). Table 2 summarizes the various spawning periods known for *C. frondosa* over its distribution range in North America and Europe.

Gametogenesis in *C. frondosa* is clearly initiated by an increase in day length around January while spawning appears to be triggered by a mix of factors, including tide, high phytoplankton concentrations in the water column and diet components (Hamel and Mercier, 1995, 1996a, 1999b). Males spawn first and the female begin to release their buoyant oocytes when the water column is already filled with spermatozoa (Hamel and Mercier, 1996c). The large reddish oocytes of *C. frondosa* measure around 0.5–0.8 mm in diameter (Figure 3); they are very rich in vitelline reserves, and they develop into lecitotrophic larvae that remain in the plankton for about 35–50 days (Hamel and Mercier, 1996b).

Detailed descriptions of spawning, fertilization and early development in *C. frondosa* are available (Hamel and Mercier, 1995, 1996b, c). Falk-Petersen (1982) reported that the oocytes were 0.65 mm in diameter and that the fecundity varied between 10 000 and 100 000 oocytes. Elena Gudimova (Polar Research Institute of Marine Research and Oceanography, Murmansk, Russian Federation, personal communication) also reported that the oocytes were 0.65 mm in diameter. Gudimova found a mean fecundity between 60 000 and 150 000 oocytes in the Barents Sea (Russian Federation). Settlement occurs preferably on rocks or pebbles, usually in crevices located in the

TABLE 2
Spawning periods of *Cucumaria frondosa* in its distribution range

Location	Spawning	References
St. Lawrence Estuary (Quebec, Canada)	Mid–June (mass spawning)	Hamel and Mercier, 1995, 1996a, b, c
Fundy Bay (New Brunswick, Canada)	April–June	Lacalli, 1981; Singh *et al.*, 2001
Nova Scotia (Canada)	End of March	Sherrylynn Rowe, DFO, Halifax, personal communication
Avalon Peninsula (Newfoundland, Canada)	February until early May	Coady, 1973
St. Pierre Bank (Newfoundland, Canada)	Early spring up to June	Grant, 2006
Avalon Peninsula (Newfoundland, Canada)	End of March up to end of April	Unpublished data
Maine (USA)	Mid–April	Jordan, 1972
New England (USA)	April to June	Medeiros-Bergen *et al.*, 1995
North Sea (Europe)	February and March	Runnström and Runnström, 1919
Northern Norway	April and May	Falk-Petersen, 1982
Barents Sea (Russian Federation)	February–April	Oganesyan and Grigorjev, 1996; Gudimova and Antsiferova, 2006

shaded area under hard substrata (Hamel and Mercier, 1996b). Medeiros–Bergen and Miles (1997) stated that juveniles of *C. frondosa* were also found in mussel beds, or on coralline algae and kelp holdfasts in Maine (USA).

The growth rate of the juveniles is very slow. Data gathered in eastern Quebec (Canada) show that the size at sexual maturity is reached at a size of about 8–10 cm, after approximately 3–4 years of growth and that the individuals grow to 12 cm in 4.5–5.5 years, reaching the commercial size (ca. 25–30 cm) in approximately 10 years (Hamel and Mercier, 1996b). A growth experiment currently under way in Newfoundland (Canada) is hinting at a similar growth rate, if not even slower (So, J., Ocean Sciences Centre, personal communication).

Hamel and Mercier (1996a, 1999b) have used *C. frondosa* to show the role of inter–individual chemical communication in the fine tuning of gametogenesis among congeners, which ensures synchronous development and release of mature gametes. This work confirmed the importance of density and spatial distribution on the reproductive success of benthic marine invertebrates. The detailed chemical composition of *C. frondosa* has been studied in Iceland (Geirsdottir and Stefansdottir, 2004), in Nova Scotia (Ke, Hirtle and Smith-Hall, 1984; Ke *et al.*, 1987) and in Newfoundland (Shahidi, 2006). Data on seasonal variations in the biochemical composition of tissues in *C. frondosa* have also been published (Girard *et al.*, 1990; David and MacDonald, 2002).

3.2.2 Cucumaria japonica

Morphologically, the sea cucumber *Cucumaria japonica* closely resembles *C. frondosa* to the point that their taxonomic relationship is disputed. The two species are commonly mistaken one for the other (Levin and Gudimova, 2000), and many scientists consider *C. japonica* as a sub–species (Saveljeva, 1941; Lambert, 1984) or a variety of *C. frondosa* (Mortensen, 1932; Panning, 1949, 1955). It has been reported by Levin and Gudimova (2000) that the species independence of *C. japonica* has been doubted since Britten (1906). Recently, Levin and Gudimova (2000) demonstrated that previous cataloguing of *C. japonica* as a sub–species of *C. frondosa* is not supported and that they truly are two distinct species. Their external anatomy still makes them hard to differentiate. The geographical distribution of *C. japonica* is also a topic of discussion; it is usually said to encompass the northeastern region of the Yellow Sea, the northeastern coast of the Honshu Island, the coast of Russian Federation in the Sea of Japan, the sea of Okhotsk, the Kuril Islands, the Kamchatka Peninsula and the Bering Sea (Levin and Gudimova, 2000). However, it has recently been argued that *C. japonica* is in fact not present in the Kamchatka and Kuril Islands areas and that another species, *C. okhotensis,* is found in these waters (Gudimova, E., Polar Research Institute of Marine Research and Oceanography, Russian Federation, personal communication). The same source indicated that the Russian Federation is planning to harvest 1 400 tonnes of this species in 2008. Considering the lack of information on *C. okhotensis*, this species will not be further discussed in the present document.

Cucumaria japonica occurs from the intertidal zone to ca. 300 m with a peak density between 30 and 60 m. Juveniles have been found in kelp forests, whereas adults colonize various substrates such as gravel, shell debris, rocks and mud (Levin, 1995; Levin and Gudimova, 2000). Like *C. frondosa*, *C. japonica* is a plankton feeder, extending its ten bucal tentacles to capture food items from the water column (Levin, 1995; Levin and Gudimova, 2000). The body of this sea cucumber is dense, cylindrical, barrel–shaped, slightly curved dorsally, especially in live animals, with a rounded or slightly stretched posterior end. The tube feet are mainly localized on the ventral surface which lies in contact with the substrate. The tube feet from the dorsal side are smaller. The maximum size recorded is 40 cm in length with an average around 20 cm (Levin and Gudimova, 2000). Large animals can reach 1.5–2.0 kg but the average is around 500 g. The colour of the body wall can be dark brown, dark purple, brown, greyish, and yellowish with the dorsal side clearly lighter. Completely white animals are also known (Levin and Gudimova, 2000). Levin (1995) stated that *C. japonica* is usually sessile and that, according to surveys, aggregations of this species move to shallow areas where the sea becomes warmer.

Kinosita and Sibuya (1941) indicated that the breeding season is a long period between early March and mid-November, and that ripe gametes are present in the gonad throughout the year. The structure of the male gonad and its maturation during the reproductive cycle was examined by Reunov *et al*. (1994) in the Popov Island (Japan Sea, Russian Federation). In winter, the male gonad is at its minimum state of development. In spring and summer, the quantity of spermatids and spermatozoa increase to reach a peak around August. The females synthesise around 300 000 oocytes of ca. 0.5 mm in diameter (Levin, 1995). Naidenko and Levin (1983) indicated that males spawn first, followed by females 2–5 hours later. According to the same investigators, the spawning season spreads from mid-April to mid-October; the green oocytes are very buoyant and reach the surface after being broadcasted. Levin (1995) pointed out that spawning occurs twice a year between April–June and September-October.

The larval development of *C. japonica* follows the pattern typical of many holothurians. The development is characterized by lecithotrophic larvae (Mokretsova and Koshkaryova, 1983; Naidenko and Levin, 1983), which are not feeding from the plankton but rather depend on endogenous nutrients (Mashanov and Dolmatov, 2000). Naidenko and Levin (1983) described the developmental biology and early growth of juveniles: the embryos hatch as pear-shaped larvae (ca. 0.5 mm) that develop into pentactulae after 6 to 10 days. Mashanov and Dolmatov (2000) wrote that the pentactula stage with complete digestive system is reached after 6 days and settlement occurs after 7 or 8 days of development. After 2 months, the juveniles were 9 mm long and the respiratory tree appeared to be fully developed. For details on the development of the pentactulae and early juveniles, see Dolmatov and Mokretsova (1995).

3.2.3 Parastichopus californicus

This species is found from the Gulf of Alaska (USA) to Cedros Island, Baja California (Mexico) between the low intertidal zone and 250 m (Cameron and Fankboner, 1986, 1989; Lambert, 1997). This is the largest holothurian species on the west coast of North America, reaching a maximum of 50 cm in length (Lambert, 1997; DFO, 2002). The average wet weight of specimens from Alaska is 225–250 g; however some can reach 500 g (Meredith, B., Alaska Department of Fish & Game, personal communication).

Parastichopus californicus is cylindrical with slightly tapered ends (Figure 4). The dorsal side of the body wall is covered by ca. 40 large papillae and many papillae of smaller size. The adults are usually mottled brown, the juveniles usually a more solid

FIGURE 4
***Parastichopus californicus* in its natural habitat. The insert shows a male spawning**

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Source: Alaska Department of Fish & Game, Commercial Fisheries.

brown or red; some white specimens were also observed. The ventral surface of the body wall is covered by numerous rows of tube feet (Lambert, 1997). *P. parvimensis*, which lives south of Monterey Bay (see section below), is very similar and can grow to nearly the same size, but the body is chestnut brown dorsally and much paler underneath; furthermore, the tips of its papillae are tipped with black instead of red. Zhou and Shirley (1996), Woodby, Smiley and Larson (2000) and Bruckner (2006b) mentioned that *P. californicus* can be found on a wide variety of substrates and under various current regimes but are most abundant in areas of moderate current on cobbles, boulders, crevassed bedrock, shells, sand and algae. The species seems to avoid mud bottoms and areas of freshwater runoff. However, a preference for harder substrates has been observed (Woodby, Smiley and Larson, 2000).

Parastichopus californicus is a slow moving deposit feeder which collects organic matter and associated micro-organisms using its 20 peltate feeding tentacles and a copious amount of mucus to trap particles such as bacteria and fungi. Maximum densities are therefore found in areas of accumulation in highly organic sediments (Cameron and Fankboner, 1989). This species ceases feeding and becomes dormant between September and early March (Lambert, 1997). Adults undergo fluctuations in body mass, body wall thickness, and muscle weight during their annual cycle as they reabsorb and regenerate their internal organs (Fankboner and Cameron, 1985; DFO, 2002). Sea stars of the genus *Pycnopodia* and *Solaster* are known predators of this sea cucumber (Cameron and Fankboner, 1989; Rogers-Bennett and Ono, 2001). A few anecdotal reports suggest that sea otters may also prey on these sea cucumbers. Muse (1998) proposed that *P. californicus* can swim to some extent to avoid predation by sea stars.

Parastichopus californicus is either male or female, but does not display any external sexual dimorphism; the sex ratio is about 1:1 (Cameron and Fankboner, 1986). This sea cucumber exhibits an annual reproductive cycle. Initiation of gametogenesis is visible by the increase in gonadal index in January or February; the maximum gonad size was recorded in June and July in British Columbia, Canada (Cameron and Fankboner, 1986). Spawning occurs in June, July and August, although the species can sometime spawn a bit earlier (Muse, 1998). Gametes are broadcasted in the water column after males and females adopt the typical posture observed in many tropical species (i.e. anterior body raised) (Cameron and Fankboner, 1986; McEuen, 1988). Spawning seems to be correlated with bright sunshine days and high phytoplankton productivity, although epidemic spawning has not been observed (Cameron and Fankboner, 1986; Muse, 1998). After spawning, the gonad begins to decrease in size (i.e. degeneration phase of the fecund tubules) to reach its smallest size at the end of the year (Fankboner and Cameron, 1985; Cameron and Fankboner, 1986). A more precise seasonal cycle of the various classes of gonadal tubules has been published by Smiley (1988). This species is apparently able to undertake seasonal migrations to different depths (DFO, 2002). The shallower populations (less than 16 m deep) seem to be the most susceptible to be involved in reproduction (Rogers-Bennett and Ono, 2001; Bruckner, 2006b). In fact, Courtney (1927), Cameron and Fankboner (1986) and Smiley *et al*. (1991) mentioned that migration to shallower waters for the purposed of spawning is observed from late April to August. Compared to plankton feeders like *C. frondosa* and *C. japonica* which are mostly sessile, *P. californicus* moves randomly, covering distances of up to 3.9 m per day (Cameron and Fankboner, 1989). Muse (1998) indicated that *P. californicus* can move as much as 100 m in 24 hours.

The light orange mature oocytes of *P. californicus* measure ca. 200 µm in diameter (Lambert, 1997). The larvae feed on plankton and remain in the water column for a period of 35 to 52 days (Lambert, 1997). However, Cameron and Fankboner (1989) observed that the pelagic phase could be as long as 65 to 125 days just to reach the auricularia stage and another 2 days were necessary for the pentactula to develop. This suggests that the spawning stock may be quite far from where the larvae settle and grow (Muse, 1998). Settlement was observed in dense mats of filamentous red algae, algae holdfast, under rocks or in crevices (Cameron and Fankboner, 1989; DFO, 2002). Cameron and Fankboner (1989) added that they can also be found on tubes of polychaete worms. The recruitment is sporadic and a high natural mortality rate is suspected (Rogers-Bennett and Ono, 2001; Bruckner, 2006b). Juvenile growth is slow, reaching 0.5 to 2 cm after a year and 4 to 10 cm after 2 years (DFO, 2002). Sexual maturity is reached after 4 years (Cameron and Fankboner, 1989; Lambert, 1997). Based on an analysis of length frequency data for the first three years of growth, commercial–sized specimens were estimated to be at least 4 years old; the oldest animals could be around 12 years of age (Cameron and Fankboner, 1989).

3.2.4 Parastichopus parvimensis

This species is common from Baja California (Mexico) to Monterey Bay (California, USA), although scattered individuals were reported to occur north, up to Point Conception (California, USA). *Parastichopus parvimensis* is found mainly in low energy environments from the intertidal down to 30 m and can reach a maximum length of 30–40 cm (Bruckner, 2006b). Yingst (1982) found that *P. parvimensis* are most abundant where the organic content of the substrate is highest, the sea cucumber being able to ingest the first two centimetres irrespectively of the size of particles. Population of small individuals from Santa Catalina Island were observed to feed on fine particulate material collected from rock rubble under the kelp canopy. Larger individuals avoid rocks; they dwell and feed on granular sediments. According to Muscat (1982, 1983) *P. parvimensis* feeds both during the day and at night, and densities of sea cucumbers increase on hard substrates, being up to ten times higher than on soft bottoms. Nonetheless, the largest specimens are found on sand and an intermediate size class on the surfaces of rocks. Muscat (1982) also mentioned that different movement patterns on soft and hard substrate are noticed, sea cucumbers on sand moving significantly more than those found on rocks.

Yingst (1982) observed an annual evisceration cycle, which affected 60 percent of individuals during October and November, causing them to cease feeding for about four weeks until minimum gut regeneration was accomplished. Muscat (1982) brought evidence of an annual pattern of intestinal growth and development, with sea cucumbers undergoing spontaneous evisceration in September and October. They can regenerate lost parts in one or two months, reaching a maximum overall body weight during the winter, probably due to resumed feeding and accumulation of gonad materials. There are dramatic seasonal fluctuations in population densities, with nearly complete disappearance from shallow water from August to November in Southern California (Muscat, 1982). There appears to be a migration downslope from the warmer, shallower areas, which occurs on both hard rock and sand substrates.

Parastichopus parvimensis does not become sexually mature until it reaches ca. 40 g in total body weight (Muscat, 1983). Muscat (1982) mentioned that this species expresses a definite reproductive cycle with spawning in May and June possibly in response to increasing water temperatures. Furthermore, according to the same author, the gonad is completely reabsorbed during September and October and the gonadal growing phase starts around January. The vitellogenic oocyte reach an average of 180 µm in diameter (Muscat, 1983). Eckert *et al.* (2001) indicated that *P. parvimensis* larvae reached the doliolaria stage in 27 days; on day 28, larvae began to settle on under sides of rocks and kelp holdfast. Juveniles reached ca. 3.5 cm long after a year of growth. Juveniles between 2 and 6 cm long are found under rocks only, whereas individuals between 8 and 12 cm dwell both on and under rocks (Muscat, 1983). This different distribution between adult and juveniles could be due to predatory pressures since juveniles are susceptible to be preyed upon by fish (Muscat, 1982). Large individuals are at least five years old (Muscat, 1983).

3.3 Background of sea cucumber fisheries

Harvesting of temperate sea cucumbers in the northern hemisphere, even when taking into account the extended geographical range covered in the present document, is focused on relatively few species: one species (*C. frondosa*) in the North Atlantic and three species (*C. japonica*, *P. californicus* and *P. parvimensis*) on the Pacific coast. For this reason, the origin and status of the fisheries will often take in account the main regional variations, when applicable.

The commercial exploitation of sea cucumbers in the northern sectors of the Pacific and Atlantic oceans has only started a few decades ago (Conand and Sloan, 1989). Harvesting of *P. californicus* began in Washington State (USA) in the early 1970s, spreading to California, Alaska and Oregon over the late 1970s and early 1980s (Bruckner, 2005). In British Columbia (Canada), the first official landings of *P. californicus* date back to 1980 (Sloan, 1986), although sea cucumbers were already harvested a decade earlier. During the same period, a small fishery for *C. frondosa* developed in Maine on the east coast of the USA, expanding into the Atlantic provinces of Canada during the 1990s (Bruckner, 2005; Therkildsen and Petersen, 2006). In Iceland, the sea cucumber fishery opened in the early 2000s (Olafsson, K., Reykofninn-Grundarfirdi ehf, personal communication). Unfortunately, we were not able to obtain historical data for the Russian Federation.

3.3.1 United States of America

West Coast

The commercial sea cucumber fishery in the USA began in the state of Washington and focused on a single species: *P. californicus*. Between 1971 and 1987, sea cucumbers were harvested by divers without any seasonal or spatial restrictions. In 1987, when depletion of sea cucumber populations became noticeable, the state established harvest districts and a restricted harvest season (ADFG, 1990). Today, most of the harvesting is done by hand using scuba diving or hookah, with only limited trawl collections under experimental fishery permits. Collection by divers for personal use/consumption is subject to a daily limit of 10 specimens (Bruckner, 2005).

In the state of California, the fishery started in 1978 and focused on two species: *P. californicus* and *P. parvimensis*. Both diving and targeted trawling are used for the capture, however trawls are restricted mainly to the south of the state and their use has declined over the past few years (Bruckner, 2006b). In 1997, divers with permits for sea urchins and abalones were allowed to collect sea cucumbers as well (Rogers-Bennett and Ono, 2001; Bruckner, 2006b).

In the state of Alaska, harvesting of *P. californicus* began in 1981 as an experimental fishery; however the first true commercial landing was recorded in 1983 in Ketchikan (Southern Alaska). Sea cucumbers are collected by SCUBA divers. The fishery was initially not subject to any regulation, and the number of divers increased rapidly when, in 1990, the Alaska Department of Fish and Game closed down the fishery to develop a management plan. In 1995–1996, 424 divers were issued permits in southeast Alaska and this number decreased to 235 in 2001–2002 (Hebert and Pritchett, 2002) and 174 in 2006–2007 (Table 3). There is currently a fishery in Kodiak and the Aleutian Islands areas (Ruccio and Jackson, 2002). Sea cucumbers were traditionally used as a food on the Northwest Coast culture area, of which southeast Alaska communities are a part. The earliest reference comes from the 1804 voyage of Urcy Lisiansky into southeast Alaskan waters (Mathews, Kookesh and Bosworth, 1990).

In the state of Oregon, the fishery began in 1993 targeting *P. californicus* exclusively (Bruckner, 2006b). Collection is by SCUBA divers and by trawl with experimental gear permits (McCrae, 1994; Bruckner, 2006b). The fishery of *P. californicus* is under the Developmental Fisheries Program. Only nine divers requested a permit for the

TABLE 3
Historical perspective for sea cucumber harvests in southeast Alaska

Season (years)	Guideline harvest levels (tonnes)	Average wet weight (grams)	Ex–vessel price (USD kg^{-1})	Number of divers
1990–91	319.6	–	1.25	143
1991–92	380.6	–	1.61	187
1992–93	499.2	–	1.94	240
1993–94	362.5	–	2.27	320
1994–95	612.8	213.3	3.45	261
1995–96	525.0	227.0	2.82	424
1996–97	426.1	203.9	2.82	294
1997–98	404.8	204.3	3.65	226
1998–99	465.5	217.9	3.41	219
1999–00	716.7	213.3	4.27	200
2000–01	509.2	213.8	4.91	220
2001–02	646.5	198.8	3.85	235
2002–03	742.7	214.6	2.77	201
2003–04	742.8	231.8	3.23	195
2004–05	626.5	224.8	4.66	194
2005–06	658.5	221.9	4.75	198
2006–07	725.2	–	4.42	174

Source: Bo Meredith, Alaska Department of Fish & Game, Commercial Fisheries.

fishery in 1993 even though 44 permits had been made available, whereas 22 divers were recorded in 1994 (Bruckner, 2006b). The number of harvesters in Oregon after 1994 remained low: five in 1997, two in 1999, one in 2000, two in 2001 and two in 2003 (Bruckner 2005).

East Coast

The fishery of *C. frondosa* on the east coast of the USA reportedly dates back to the 1970s (Sutterlin and Waddy, 1975; Seatech Investigation Services Ltd., 1981; Bradshaw, Ryan and Cooper, 1991). True commercial harvests began in 1988, expanding significantly in 1994 when the Asian markets opened up to this new resource (Chenoweth and McGowan, 1997). Scallop chain sweeps or light urchin drags were used as fishing gear. Fishing activity was concentrated in Washington and Hancock Counties with catches landed in Winter Harbor, Jonesport, Beals Island and in Eastport. The fishery has recently experienced great increases in landings, corresponding to expanding export markets (Feindel, 2002). It began in Maine with one operator and has expanded, especially since 1994. In the mid-1990 this sea cucumber fishery employed 15–20 harvesters and between 75 and 100 workers to process the product (Feindel, 2002; Bruckner, 2005).

3.3.2 Canada

West Coast

Sloan (1986) indicated that the first official landing of *P. californicus* in British Columbia (considered the first commercial harvest of sea cucumber in Canada) was recorded in 1980, although exploitation may have started as early as 1971 (DFO, 2002). The fishery itself was first regulated under commercial licence on an experimental basis in 1980 (DFO, 2002; Campagna and Hand, 2004). *P. californicus* is the only species fished on the west coast of Canada, the fishery being centered on Vancouver Island in the Georgia and Johnstone Straits and in the Puget Sound. The fishery was an open access through 1990. The number of licenses rose from 40 in 1985 to 215 in 1990. The number of vessels went from 21 in 1985 to 126 in 1990. In 1988, 124 divers where involved and 163 in 1990 (Muse, 1998). However, Muse (1998) mentioned that British Columbia's Natives harvested sea cucumbers as a traditional food in much earlier times.

The fishery in British Columbia expanded rapidly after 1980 with annual landings exceeding 1 900 tonnes in 1988. Fishing was initially permitted in the South Coast areas only and the majority of landings were taken in the Strait of Georgia until 1987. The north coast was opened in 1986 with a total annual recommended catch of 500 tonnes, although fishing did not occur there until 1987. To date, landings of sea cucumbers have been recorded from all Canadian Pacific fisheries management areas, with the exception of the north and west Queen Charlotte Islands. The central and north coasts currently support about 80 percent of the fishery (DFO, 2002).

East Coast

Although there had been sporadic attempts to initiate a fishery for *C. frondosa* in Atlantic Canada since 1980, the state of Maine (USA) was the first to develop a substantial fishery for this species in the 1980s (Therkildsen and Petersen, 2006). After the onset of the Maine fishery, provincial and federal governments in some Canadian provinces began assessing the feasibility of starting a fishery for *C. frondosa*, which developed timidly in several locations (Therkildsen and Petersen, 2006). In 1989, a small Nova Scotia fishing company located in St. Mary's Bay identified a potential market for *C. frondosa*. Today, the fishery in the Scotia–Fundy Fisheries Management Sector, which extends from the northern tip of Cape Breton to the New Brunswick–Maine border, accounts for the highest landings of sea cucumber in Canada. The fishery began with harvesters using urchin licenses, but it was rapidly restricted to holders of experimental sea cucumber licenses (DFO, 2005b). Churchill (1996) mentioned that Newfoundland's interest in *C. frondosa* began in late 1995 when large quantities of sea cucumbers were noted in the results of seismic surveys carried out on the Grand Banks. During the same period, representatives of the Department of Fisheries and Aquaculture (DFA) attended the first International Chinese Food Industry Exposition in Toronto, Canada, to promote non-traditionally harvested products, including sea cucumber, from Newfoundland and Labrador (Dooley, McDonald and Rumboldt, 1995). In Atlantic Canada, the bulk of the sea cucumber fisheries were initially carried out using modified trawls and/or scallop gear. Now, at least for Newfoundland and Labrador, a specifically designed sea cucumber drag (a government approved, standardized science tool used by the Department of Fisheries and Oceans [DFO]) is used for science surveys and directed commercial activity. The sea cucumber gear appears to be highly efficient at capture and is designed, in part, to address bycatch and bottom impact concerns that are associated more so with other harvesting gear such as scallop dredges and/or otter trawls. *C. frondosa* is also commonly harvested as a result of bycatch from scallop fisheries.

In 1997, the Canada-Newfoundland Cooperation Agreement for Fishing Industry Development carried out an exploratory trial for sea cucumber in the province and concluded that a future fishery for this species was possible. In 2002, the Department of Fisheries and Aquaculture, under the Fisheries Diversification program, surveyed potential sea cucumber fishing grounds and alternative harvesting methods. In Newfoundland and Labrador, the government issued eight exploratory licenses for the St. Pierre Bank area and licence holders have an exploratory annual quota of ca. 612 tonnes in NAFO subdivision 3Ps; in addition, two exploratory licenses have been issued in NAFO area 4R with an annual quota of ca. 90 tonnes (Barrett, L., DFA, personal communication). Also, initial surveys suggested that diving might be a possible alternative harvesting method and exploratory trial dives yielded up to 2 700 kilograms per day in some areas. However, experimentation with this harvest method in the Scotia–Fundy region suggests that it will not be financially viable (DFO, 2005a). In New Brunswick, the fishery began in 2000 with two permits emitted by the DFO in Moncton (Coulombe and Campagna, 2006).

Sea cucumber fisheries are not yet developed in Quebec (Coulombe and Fillion, 2002), although GERMA (GERMA, 1989), Ondine Inc. (Ondine, 1991), Hamel and

Mercier (1998a) and Campagna, Lambert and Archambault (2005) all surmised that *C. frondosa* could represent an interesting commercial potential. On June 11, 2002, Les Biotechnologies Atrium Inc. of Quebec and Cusimer (1991) Inc. in Mont–Louis (Gaspesian Peninsula) received funding to develop an experimental project to valorize nutraceutical products from this sea cucumber. Coulombe and Campagna (2006) stated that the interest in this resource increased in Quebec following the visit of potential buyers from the USA around 2002. Despite the interest and initial efforts, there is still no official fishery of *C. frondosa* in the St. Lawrence Estuary and Gulf areas at the moment. However, a sea cucumber processor in New Brunswick was exploring the establishment of a sea cucumber processing plant on the Gaspésie Peninsula in 2007; it is therefore anticipated that commercial sea cucumber harvests may begin in the near future in the St. Lawrence area.

3.3.3 Iceland

To the authors' knowledge, Iceland is the only European country to harvest sea cucumbers (if western Russian Federation is excluded). *C. frondosa* is common all around Iceland and is often discarded as bycatch during bottom trawls for other species. The first small landing of *C. frondosa* in Iceland is reported in 1995 (Valtysson, 2001). Therkildsen and Petersen (2006) mentioned that the future of this fishery is uncertain because the stocks seem to be lower than expected. Nonetheless, Kari Olafsson (Reykofninn-Grundarfirdi ehf, personal communication) indicated that the fishery is small and still under development but that it would continue in 2007. The same source mentioned that the company bears all costs of development with a minimal assistance from the government. There has only been one licence issued to date.

3.3.4 Russian Federation

In the Barents Sea, fishers recently began harvesting *C. frondosa* (Gudimova, 1998; Organesyan and Grigorjev, 1998). According to Therkildsen and Petersen (2006) there is no directed fishery for this species with all landings coming from bycatch of the scallop fishery. Like in Canada and the USA, bycatch was originally discarded; however, since 2000, harvesters have been able to sell this resource for processing (Gudimova, Gudimov and Collin, 2004; Therkildsen and Petersen, 2006). Landing has not exceeded 200–500 tonnes per year (Gudimova, Gudimov and Collin, 2004) and no regulation is governing this resource at the moment (Therkildsen and Petersen, 2006; Gudimova, E., Polar Research Institute of marine Research and Oceanography, Russian Federation, personal communication). The fishery of *C. japonica* on the eastern coast of the Russian Federation in the Pacific Ocean remains obscure and we were not able to find any tangible information. However, *C. japonica* is a common component of the fauna of the Sea of Japan and is also one of the most important commercial species among the echinoderms of the Far East (Mashanov and Dolmatov, 2000).

3.4 Species in trade

3.4.1 Food products

The main products derived from *C. frondosa* in Maine are: (i) the muscle bands, which are vacuum packed and flash frozen; and, (ii) the boiled and dried body wall (Feindel, 2002; Bruckner, 2006b; Therkildsen and Petersen, 2006). Ke *et al.* (1984, 1987) mentioned that the body walls were boiled for 60 min. in 3 percent NaCl utilizing a steam cooker. They were subsequently dried in a vacuum drying oven at room temperature and finally at 60 °C. In New Brunswick (Canada), the animals are first relaxed at 40 °C, then cut longitudinally and eviscerated; the muscles are removed and packed separately, the body wall is boiled and dried mechanically (Coulombe and Campagna, 2006). Bruckner (2005) indicated that the processing of sea cucumbers involved removing the anterior end with the tentacles, slitting the body lengthwise to remove the viscera, and scraping the muscles off the body wall. The body and muscles are typically boiled, dried and salted before export, while lesser quantities are marketed as a frozen, pickled or live product.

In eastern Canada, especially in Newfoundland, several new products from *C. frondosa* were tested including: (i) the cooked, salted and dried skin with the meat attached; (ii) muscles and skin (fresh frozen together or separately); (iii) aquapharyngeal bulbs (called flowers), gut, gonad and respiratory tree (fresh frozen and packed separately); and, (iv) fresh frozen muscles and skin separated (Barrett, L., DFA, personal communication). The industry tried these products over the last five years in an effort to adapt to relatively unfamiliar markets in Asia with a non–traditional Newfoundland product.

In Canada and other parts of North America, the processing of sea cucumbers is generally carried out in a semi-industrialized environment (Figure 5). An industry in New Brunswick is employing as many as 120 people during the fishing season; they are processing up to 35–40 tonnes of sea cucumber daily. This processing plant, as well as the one on Fogo Island, Newfoundland and Labrador, is currently experimenting with the prototype of an eviscerating/skinning machine devised by engineers from DFA and Memorial University (Figure 6). According to the plant owners in both provinces, the results are promising and although they would prefer to retain the services of workers for most of the processing, they can envision using the mechanical gutter/skinner for part of the process during leaner times to reduce labour related production costs.

In Iceland, *C. frondosa* is processed into a dried product (skin with muscles) and an intermediate product consisting of gutted, boiled and individually quick frozen (IQF) skin with muscles (Olafsson, K., Reykofninn-Grundarfirdi ehf, personal communication).

The main product derived from *C. japonica* captured in Far East Russian Federation is bêche-de-mer according to suppliers that are currently advertising on the Internet. However, an older report (Levin, 1995) stated that *C. japonica* was rarely used as dry product, as the Japanese consumed them raw. All harvested sea cucumbers were reportedly boiled, sliced in small pieces and sold in local shops as a salad (Levin, 1995). They also produced medicines for domestic animals and an additive for toothpastes, creams, etc. (Levin, 1995). Elena Gudimova (Polar Research Institute of Marine Research and Oceanography, Russian Federation, personal communication) indicated that the product from the Barents Sea is transformed into bêche-de-mer, though some is canned or used for medicinal purposes (see below). It would appear that 100 percent of *C. frondosa* and 80 percent of *C. japonica* from the Russian Federation are used solely for domestic consumption.

In USA, both species of *Parastichopus* are boiled, dried and salted (bêche-de-mer), some are marketed frozen, and as live product (Bruckner, 2006b). Mathews, Kookesh and Bosworth (1990) and Bo Meredith (Alaska Department of Fish and Game, personal communication) indicated that the muscle bands are also processed (frozen) in Alaska. The Alaskan industry has created its own market for the "meat strips" that line the inside of the body wall (Ess, 2007). We assume they are referring to the muscle bands.

In British Columbia, *P. californicus* are cut open longitudinally and viscera and internal fluids are removed in a process called splitting. The animals are processed into two products; frozen muscle strips and dried skin (DFO, 2002).

Traditional sea cucumber products can also be found marginally, for instance within native communities in Alaska (Mathews, Kookesh and Bosworth, 1990). In the past, sea cucumbers were often eaten fresh from daily catches. Drying and smoking were also described as traditional methods of preserving sea cucumbers for storage. With the advent of home freezers in the late 1940s and early 1950s, drying was abandoned in favour of freezing. Today consumers of sea cucumbers preserve them by canning or

FIGURE 5

Sea cucumber processing in New Brunswick (Canada) – fresh product is trucked to the processing plant where workers proceed with evisceration (top left); freshly cooked skin on drying racks (top right); fresh muscles bands, or meat (left centre); packaged meat (right centre); dried skin and dried aquapharyngial bulbs, or "flowers" (bottom left); dried skin being packaged (bottom right)

COURTESY OF L. BARRETT (DFA)

FIGURE 6

Prototype of an eviscerating/skinning machine

COURTESY OF L. BARRETT (DFA)

FIGURE 7
Processing of *Parastichopus californicus* in Alaska – body wall (left) and meat strips (right)

COURTESY OF BO MEREDITH

Source: Alaska Department of Fish & Game, Commercial Fisheries.

freezing. The canning process consists of par-boiling the meat, sterilizing the jars and lids, inserting meats, and sealing, whereas freezing involves boiling the sea cucumber meat, draining and storing it into plastic freezer bags.

3.4.2 Other derivatives

Over the years, several scientists and companies have developed ways to valorize the processing by-products of sea cucumbers by extracting nutraceuticals from them. Red Oil produced from *C. frondosa* intestines and body–wall were used in an adjuvant arthritis model in rats to study their anti-inflammatory properties (Glenn, 1966; Winter and Nuss, 1996). Bruckner (2006b) mentioned that the by-product of processing from *C. frondosa* is marketed in the USA as nutritional supplement providing chondroitin (NutriSea®), and is also sold as a treatment for arthritis in humans (ArthriSea® and SeaCuMAX®) and pets (Sea Jerky®) on the USA and Canadian markets (Coastside Bio Resources, Stonington, Maine, USA). The latter also offer a full line of nutritional formulas for humans, dogs, cats, horses and pigs[1]. The by-product is also marketed as compost in Maine (Bruckner, 2006b).

It is believed that *C. frondosa* contains chemicals that inhibit harmful prostaglandins involved in causing pain and arthritis. They are also rich in nutrients needed by cartilage including chondroitin and mucopolysaccharides, and several vitamins and minerals. One product supplies a unique jerky-type treat made of sea cucumber which dogs find quite palatable. Each jerky treat provides 1 200 mg of chondroitin. These treats are perfect for dogs and/or cats that are difficult to medicate. The jerky treats can also be used in conjunction with other similar pill supplements, as it is unlikely to overdose a pet on glucosamine or chondroitin[2]. Several supplements made from *C. frondosa* extracts are sold for human consumption as well[3].

Extracts from the sea cucumber *C. japonica* may be useful in the therapeutic management of the Epstein–Barr viral infection (Spainhour, 2005). Mulcrone (2006) indicated that, in eastern Russian Federation, an increasing demand on *C. japonica* has led to concern for this species for both food and cosmetic products.

[1] *Source*: http://www.coastsidebio.co.uk/.
[2] *Source*: http://www.glucosamine-arthritis.org/arthritis-pets/holistic-approaches4.html.
[3] *See for example the following sources*: http://www.vuru.com/supplements/product?productId=1389&lastCategoryId=313; http://www.ihealthtree.com/buried-treasure-joint-ease-complete-16oz.html.

3.5 Population status

Within the vast territory covered by this review, which encompasses extremely long coast lines and countless islands and bays, estimations of biomass, density and catch per unit effort (CPUE) are limited and sometime incomplete. Furthermore, biomass and density are not always established in the most suitable location for the global understanding of stock levels and management needs. Notwithstanding these limitations, this report has tried to compile the most complete and up to date sets of data available for the territory and species under study.

3.5.1 Cucumaria frondosa

Therkildsen and Petersen (2006) indicated that most fisheries for *C. frondosa* are still at the early exploratory phase, and it is difficult to predict whether the available stocks can sustain long term exploitation. Indeed, the large *C. frondosa* landings in eastern Canada and USA may not be sustainable in view of the slow growth of this species (Hamel and Mercier, 1996b).

Campagna, Lambert and Archambault (2005) demonstrated that *C. frondosa* was found in relatively high abundance in Quebec along the north coast of the Gaspesian Peninsula. In general, the species was more abundant at 10 m and became less abundant with increasing depth. The lowest values were found between 50 and 80 m. The highest average CPUE was 2 138 kg m^{-1} h^{-1} with an average density of 1.6 ind. m^{-2} at 10 m depth. The highest values of biomass recorded were 3 798 tonnes, 5 677 tonnes and 5 010 tonnes. The total biomass for this area of 813 km^2 would be around 61 000 tonnes.

Bradshaw, Ryan and Cooper (1991) described CPUE based on capture using ring scallop bags of 182 sea cucumbers per minute in Nova Scotia in 1991. They indicated that with each tow lasting 10 minutes, it would take about 3 tows to fill a boat that can hold 2 300 kilograms (Bradshaw, Ryan and Cooper, 1991). Coulombe and Campagna (2006) mentioned that a single boat in the Bay of Fundy, New Brunswick (Canada) could harvest 9–10 tonnes per day.

DFA (2004) reported that the CPUE for *C. frondosa* in the Strait of Belle Isle, Newfoundland, was equivalent to 553 kilograms over a 15 minutes tow. Dive surveys in Pistolet Bay yielded up to 2.2 ind. m^{-2}. An earlier report (DFA, 2003) measured catches of 275–325 kilograms in 10-minute tows in the Strait of Belle Isle, northern Newfoundland. The Marine Institute (MI, 2006) indicated that densities of *C. frondosa* on the St. Pierre Bank (Grand Banks, Newfoundland) were 0.22 ind m^{-2} on rocky substrata, 0.34 to 0.44 ind. m^{-2} on sand and shell bottoms, and 0.72 ind. m^{-2} on gravel-cobble beds. The Marine Institute (MI, 2004) noted sea cucumber densities between 0.16 to 0.58 ind. m^{-2} on the St. Pierre Bank. The total catch on St. Pierre Bank during one 24-hour exploratory fishing trip using 8 tows of 10–30 minute duration was 1 190 kilograms of sea cucumber. From some exploratory dive fishing trips, a single diver reportedly collected 907 to 1 360 kilograms per day in Notre-Dame Bay, Newfoundland (DFA, 2002b). Specifically, a 2 to 3.5 hours dive in Bonavista Bay will yield a landing of 1 450 kilograms, whereas diving in Notre-Dame Bay will yield 149 kilograms from the lesser productive areas.

Bruckner (2005) stated that there is concern associated with the Maine sea cucumber fishery in that most of the fishing effort is concentrated within three locations in eastern Maine, and there are anecdotal reports of some sites having been fished out. Nonetheless, Bruckner (2006b) indicated that the population densities can reach 5 ind. m^{-2} and populations can comprise up to 50 percent of the benthic biomass. Dive surveys using transects showed the patchy nature of the species, with abundances ranging from 0.01 to 7.45 ind. m^{-2}, with substantial differences in size and weight of animals between sites (Bruckner, 2006b).

In Iceland, the natural density of *C. frondosa* is not known; the best 10-minute tow yielded 1 200 kilograms, but the usual harvest is commonly between 1 and 500 kilograms per 20-minute tow (Olafsson, K., Reykofninn-Grundarfirdi ehf, personal communication). Although densities were not stated, captures of *C. frondosa* in the Barents Sea are reportedly stable (Gudimova, E., Polar Research Institute of Marine Research and Oceanography, Russian Federation, personal communication).

3.5.2 Cucumaria japonica

Data on this species are scarce. Dulepov, Scherbatyuk and Jiltsova (2003) indicated that densities fetched 7.6 ind. m^{-2} for the Great Peter Bay in Far East Russian Federation based on data gathered by a semi autonomous underwater vehicle. Because this value was established using image analysis, it might be overestimated. In Aniva Bay (Russian Federation) *C. japonica* has been observed to display a patchy distribution with reported maximum densities of 0.3–0.9 ind. m^{-2} [4]. Levin (1995) reported that the highest registered density was around 40 ind. m^{-2}. More precisely, possible catches were estimated at 2 300 tonnes in the Sea of Japan, 2 000 tonnes in Kuril Islands, and 11 800 tonnes in the Sea of Ochotsk.

3.5.3 Parastichopus californicus

The DFO (2002) mentioned that early southern British Columbia harvesters targeted populations of *P. californicus* in areas close to the harbour, where diving was easy and the resource abundant. Researchers and managers felt that only a small proportion of the stock was being harvested, and that many sea cucumbers were left untouched in these areas. The fishery therefore expanded to more remote northern areas, but remained targeted on very accessible locations. Still today, large areas of the coast have not been visited by the commercial sea cucumber fleet. Surveys conducted in various areas of the coast indicate that sea cucumber population densities vary considerably with habitat type. Density estimates from almost all surveys are significantly higher than the conservative estimate of 5.08 sea cucumbers per meter of shoreline. *P. californicus* populations extend below the safe diving depth of 20 m where extensive harvesting cannot be conducted (DFO, 2002). In British Columbia, the densities are estimated at less than 0.25 ind. m^{-2} (Bruckner, 2006b). The CPUE values supplied by Muse (1998) for *P. californicus* in British Columbia are in kg per diver per hour: 372 in 1983, 347 in 1987 and 617 in 1992.

Woodby, Smiley and Larson (2000) indicated that the depth distribution of *P. californicus* was investigated in the vicinity of Sitka Sound, Alaska. Sea cucumber densities were greatest in shallower waters with ca. 70 percent of the sea cucumbers observed above 15 m, and 70 percent above 20 m. Average densities were 0.03 m^{-2} in deeper water and 0.3 m^{-2} at SCUBA diving depths. The deepest sea cucumber was observed at 87 m (Woodby, Smiley and Larson, 2000). In Southeast Alaska, Zhou and Shirley (1996) used a submersible to measure densities which reportedly varied from 0 to 267 ind. ha^{-1}. The highest density recorded was 0.23 ind. m^{-2}.

Bruckner (2006b) reported that harvested sites in California showed densities that were 50–80 percent lower than in the non-fished areas. For instance, at an established reserve in northern California, densities averaged 2 200 ind. ha^{-1}. Another set of data from a newly established reserve (Punta Gorda Ecological Reserve) ranged from 250 to 790 ind. ha^{-1}, taking into account the large size classes of sea cucumbers exclusively (Rogers-Bennett and Ono, 2001; Bruckner, 2006b). Until 1996, an average of 75 percent of the annual catch came from the trawl fishery in southern California. Between 1997 and 1999, the dive fishery accounted for 80 percent of the take. Recent surveys showed a 50–60 percent decline in abundance between 1994 and 1998, but no correlation

[4] *Source*: http://www.sakhalin2.ru/en/documents/doc_lender_eia_12.pdf.

was noted between decline in abundance and data on landings. The only increase in abundance (39 percent) was noted at two no-take reserves (Rogers-Bennett and Ono, 2001; Schroeter *et al.*, 2001).

In Washington State, CPUE from 1983 show that the minimum in those days was around 75 kg diver h^{-1} and the maximum around 130 kg diver h^{-1} (Bradbury, 1994). Data recorded in this state at the time clearly demonstrates the impact of the fishery on the stock of sea cucumbers with a decline of up to 70 percent: sea cucumber densities were around 0.35 ind. m^{-2} before the fishery opened and dropped to 0.1 ind. m^{-2} just after (Bradbury, 1994).

In Oregon, *P. californicus* densities are between 0.1 to 0.22 ind. m^{-2} at depths of 80 to 130 m (Bruckner, 2006b). In Washington, the CPUE between 1995 and 1998 (Bradbury, 1999) varied from 56 to a maximum of 80 kg diver h^{-1}.

3.5.4 Parastichopus parvimensis

Schroeter *et al*. (2001) provided density values for *P. parvimensis* in California before the onset of the fishery, varying from 0.2 to 21.1 individuals per 10 m^2. The onset of the fishery in the same site marked a drastic decline (by 33–83 percent) in population densities. The CPUE expressed in kg per boat per day varied from a site to another between 1993 and 1999. For instance, it fluctuated around 453 kg in San Nicolas Island, around 340 kg in Santa Barbara Island, and around 181 kilograms in San Miguel (Schroeter *et al.*, 2001).

3.5.5 Accuracy of stock assessments

Accurate estimates of available stocks are instrumental to the sustainable management of any fishery. At present, the assessment of commercial stocks is largely based on fishery-dependent data such as catch per unit effort (CPUE), which can generate biased indicators of stock abundance (Schroeter *et al.*, 2001). It has been stated that marine reserves could play a valuable role in providing more reliable information on stock assessment (Schroeter *et al.*, 2001). A number of studies on fish have revealed higher abundances and larger sizes in no-take reserves when compared to the outside; others have reported higher abundance and larger fish in a given site after its designation as a no-take zone (Rowley, 1992). However, such comparisons between harvested and control areas are not appropriate in the case of most environmental impact studies; the best assessment is obtained by comparing population changes in affected and pristine areas before and after the impact occurs (Underwood, 1993; Stewart-Oaten and Bence, 2001). Regrettably, the so-called BACI “before-after, control-impact” design is generally inapplicable to established fisheries because data on stocks before fishing and/or data from a suitable control site are not available. The situation may be different with emerging fisheries, for which no–take reserves that use proper monitoring programs offer a powerful means of assessing the status of harvested stocks and their likelihood for sustainability (Schroeter *et al.*, 2001).

3.6 Catches

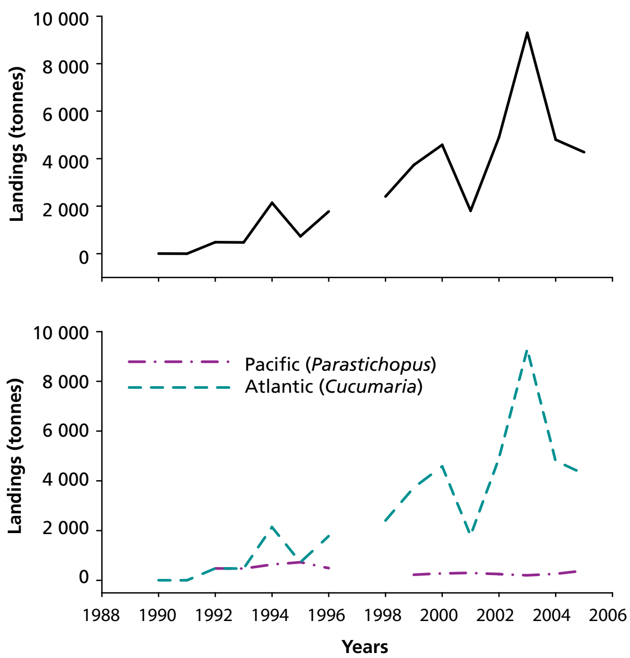
This section presents traditional and commercial activities as well as landing figures for three of the four species covered by this review, and for all countries except the Russian Federation where records were not found (Gudimova, E., Polar Research Institute of Marine Research and Oceanography, Murmansk, Russian Federation, personal communication). When possible, the landing data are further detailed by state or province (for USA and Canada), otherwise it is provided for the whole country, such as Iceland.

Various methods have been used to fish sea cucumber in North America: both *P. californicus* and *P. parvimensis* are mainly harvested by divers (Bruckner, 2006a). In Alaska, harvesting is restricted to hand picking. Divers use SCUBA tanks or surface supplied air and gather the animals in mesh bags for transport to the surface (Woodby, Smiley and Larson, 2000). In Washington, Oregon and California, both dive and trawl fisheries are being used; in British Columbia divers use converted salmon boats between 7 and 13 m. The typical operation involves three to four people, including two divers and a tender (Muse, 1998). All Canadian and USA fisheries on the east coast use dredging gear similar to the one used in Maine and these activities can therefore be considered more "industrialized". Scallop gears were initially used, but they were eventually replaced by the modified urchin drags that appear to yield less bycatch an have a lighter impact on the seabed (DFA, 2002a). In Iceland, harvesters use the same gear as in eastern Canada (Olafsson, K., Reykofninn-Grundarfirdi ehf, personal communication), whereas in the Russian Federation, the scallop dredging gear is used for sea cucumber harvesting (Gudimova, Gudimov and Collin, 2004).

Harvest methods for subsistence by aboriginal communities in southeast Alaska, while incorporating new technology, do not differ very much from traditional methods. Mathews, Kookesh and Bosworth (1990) indicated that harvests were confined to low tide using poles or bare hands for collection. Most harvesters were found to use a wooden pole of 2.5–5 m. Fish hooks of various types and lengths were often tied to end of the pole to lift the sea cucumbers closer to shore. Another type of pole used consisted of a bamboo pole 2.5–3 m long with sixteen penny nails driven through, and used to rake the cucumbers in. Other harvesters used cockle rakes, small dipnets, and brailers (Mathews, Kookesh and Bosworth, 1990). Another harvest method is incidental catch by commercial seining in which aboriginal communities are involved. Seine nets used in shallow waters sometimes become fouled with sea cucumbers, which then have to be removed manually from the nets. Individuals working on the seine boats may retain the cucumbers for family use (Mathews, Kookesh and Bosworth, 1990).

Sea cucumber landings in the USA have been inconstant but generally rising since 1990 (Figure 8). Catches on the Atlantic coast (*C. frondosa*) are much more important and therefore account for the general trend with a peak around 9 000 tonnes in 2003 and a subsequent decrease to values around 4 000 tonnes in 2004 and 2005 (Figure 8). Landings for *P. californicus* on the Pacific coast are an order of magnitude lower with maxima of 600–700 tonnes in 1994–1995 and values of ca. 200–400 tonnes in 2003–2005 according to FAO Fishery Statistics (Figure 8). However, a recent report (Ess, 2007) states that guideline harvest levels throughout southeast Alaska have stayed healthy since 2000 at around 600–700 tonnes (Table 3).

FIGURE 8
Commercial landings for the United States of America



Source: FAO Fishery Statistics 1950–2005.

Official landings for Iceland are very fragmentary, with reported values of 2 tonnes in 1995, 27 tonnes in 2003 and 208 tonnes in 2005 (FAO Fishery Statistics 1950–2005). However, there is information that catches roughly totalized 50 tonnes in 2003, 200 tonnes in 2004, 300 tonnes in 2005 and 150 tonnes in 2006 (Olafsson, K., Reykofninn-Grundarfirdi ehf, personal communication).

Unlike the USA and Iceland, Canada does not keep separate records of landings for sea cucumbers but rather chooses to include them within the larger category of benthic invertebrates (e.g. FAO Fishery Statistics). Nevertheless, data were obtained from provincial representatives of the various DFO offices to illustrate the trend of this growing activity in Canada. Landings for *P. californicus* in British Columbia are shown in Figure 9, whereas landings of *C. frondosa* in New Brunswick, Newfoundland, Nova Scotia and Scotia-Fundy regions are detailed in Figure 10.

Unfortunately, data from the Russian Federation remain unconfirmed despite numerous attempts to contact authorities involved in fisheries regulation and management.

FIGURE 9
Commercial landings of *Parastichopus californicus* in British Columbia (Canada)

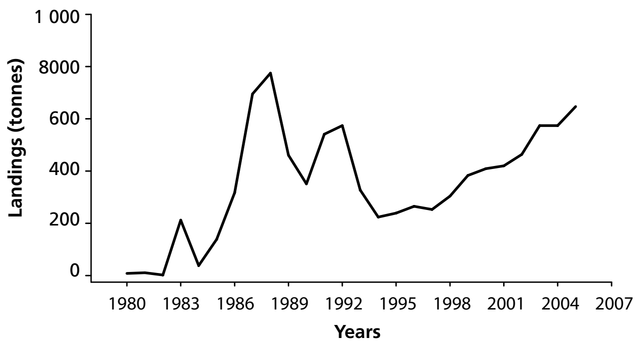
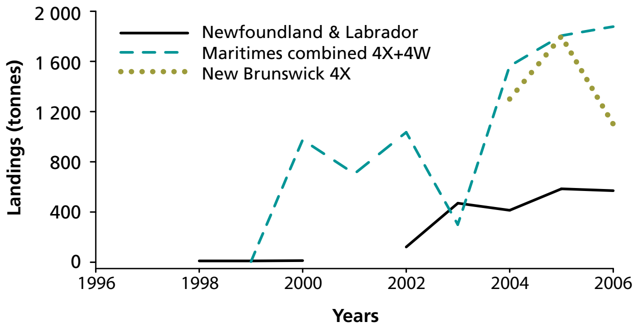


FIGURE 10
Landings of *Cucumaria frondosa* in the Atlantic provinces of Canada based on data provided by DFO and DFA



3.7 Management measures in place

There have been some problems associated with sea cucumber fisheries, including the potential for overexploitation, habitat damage, removal of bycatch species, illegal fishing, and conflicts with other resource usages. In many locations, sea cucumber landings increased rapidly following the exploratory phase, but some fisheries have also experienced decreases in the number of sea cucumbers landed per dive or per trawl, and overexploitation has been reported in some areas (Bruckner, 2005).

3.7.1 United States of America

In the USA, sea cucumber fisheries can be separated into those occurring in state waters, each being managed by individual states; and those going on in the 200-mile zone off the coast, which are managed by NOAA Fisheries in coordination with Regional Fishery Management Councils (Bruckner, 2006b). In the present document, we will discuss only cases where state management is involved.

Current sea cucumber management practices in Alaska have provided sustainable harvests and consistent quality. Divers rotate their effort between 16 harvest areas, some of which are divided into more than 20 sub–areas in an effort to maintain sustainability throughout the fishing grounds (Ess, 2007).

In southeast Alaska, each fishing area is run on a three year rotation and harvested at a rate of 6 percent a year (Meredith, B., Alaska Department of Fish & Game, personal communication). Thus, in any given area that is open for harvest, approximately 18 percent of the surveyed biomass is removed; this area will remain closed for the next two years. Before the sea cucumber fishing season opens on the first Monday of October, dive surveys are conducted in each of the harvest areas to be targeted that year. Woodby, Smiley and Larson (2000) added two conservative measures into the development of the harvest rate managed by the Alaska Department of Fish and Game: (1) a 50 percent reduction to account for the possibility that the model assumption is incorrect, and (2) an approximate reduction of 30 percent to account for sampling error in the assessment survey. A third safety measure consists of counting only sea cucumbers occurring at depths above 15 m in the population size estimates. Ruccio and Jackson (2002) also mention that the Alaskan fishery of *P. californicus* closes down during the spawning season. Finally, harvest divers can only obtain permits for sea urchins or for sea cucumbers but not both (Bruckner, 2006b).

In Washington, the *P. californicus* fishery is a year-round dive operation. From 1971 to 1986, the fishery was opened in all areas. However, following signs of overfishing, the Washington State Department of Fisheries implemented a rotational harvest from 1987 to 1992 (Bradbury, 1994). Now, the experimental trawl fishery is closed during soft–shell Dungeness crab period and in shrimp areas. An experimental trawl fishery occurs in specific locations using beam trawl gear with a maximum beam width or otter trawl with a minimum mesh size (Bruckner, 2005). For each area, the quota is determined using surplus production models and estimates of biomass from catch-effort data, video surveys, and dive surveys. Bruckner (2005) stated that the current management in Washington includes spatial closures, licensing of collectors and an annual quota. Seven area closures for the dive fishery have been established in the current management plan and trawling is prohibited in shrimp areas. Other regulations for trawlers include no fishing in waters less that 20 m deep. Divers in Washington need to submit their logbooks every month with data on date, depth, location and amount of captures (Bruckner, 2006b).

In Oregon, the fishery of *P. californicus* is conducted by divers. Harvest by trawl required an experimental gear permit until 2003. The target species has been placed under category B of the Development Fisheries List (species in category B are underutilized and are not under another state or federal management plan, and have not shown the potential to be a viable fishery), which includes species with less potential for viable fisheries; a permit is therefore no longer required (McCrae, 1994).

In California, both *P. californicus* and *P. parvimensis* are harvested. A special permit was required for sea cucumber harvest in 1992–1993. Separate permits for each gear type and a limit on the total number of permit were implemented in 1997. There are no restrictions on catch (Rogers-Bennett and Ono, 2001; Schroeter *et al.*, 2001). Bruckner (2005) adds that a maximum of 111 dive permits and 36 trawl permits were issued in 1997, and this declined to 95 divers and 24 trawl permits in 2004. There are no restrictions on catch but trawling is prohibited in some conservation areas and along the shore of most islands (Bruckner, 2005).

In Maine, for the fishery of *C. frondosa*, the "urchin drag" gear used is limited to 167 cm in width and 670 cm in length, and a head bail constructed of <3.8 cm round steel stock (Feindel, 2002). Regulations were implemented in March 2000 under the 1999 Sustainable Development of Emerging Fisheries Act (Bruckner, 2005). The act included restrictions to limit the fishing season with closure between 1 July and 31 September. It also defined gear size, and established a maximum number of endorsements, with licences given only to individuals that had sold 100 000 kilograms during the previous year. Licensed fishermen are required to submit logbooks that provide information on catch, time at sea, area fished and catch value (Feindel, 2002). No incidental takes are allowed, only take through targeted, licensed fishery (Bruckner, 2006b).

3.7.2 Canada

In British Columbia, the annual *P. californicus* fishery lasts for about three weeks in October, when muscle weight is greatest and the animals have reabsorbed their internal organs (DFO, 2002). The commercial fishery is a small limited–entry (i.e. 85 licences) dive fishery that is managed by individual quota (DFO, 2002). Of the 85 licences delivered in 2003 in British Columbia, 15 belonged to native peoples (James, 2003). Quotas are calculated by multiplying estimates of shoreline length, sea cucumber density, individual weight and harvest rate (DFO, 2002). The total allowable catch can be increased in surveyed areas when the measured density estimates are calculated to be higher than the precautionary baseline density estimate. Only 25 percent of the coast is open to the commercial fishery. Up to an additional 25 percent may be used to conduct research, and the remaining 50 percent is closed to harvesting until biologically-based management is possible. Abundance surveys and experimental fisheries are being conducted to estimate biomass and evaluate exploitation rate options (DFO, 2002). All landings are monitored by an independent industry-funded firm, dockside landings are only at designated ports, and licence holders pay a fee (Bruckner, 2006b).

In general, the fisheries for *C. frondosa* are still at the early exploratory stage, and it is difficult to predict whether the available stocks can sustain long term exploitation (Therkildsen and Petersen, 2006). Sea cucumbers tend to be highly vulnerable to overfishing, and their harvest throughout the world are generally characterized by overexploitation (Conand, 2004; Uthicke and Conand, 2005). The relatively low value of *C. frondosa* on the market and the high cost of labour in North America require harvesting to be significant in order to be cost effective (Therkildsen and Petersen, 2006) generating a real concern over the sustainability of this resource.

The Scotia-Fundy sector of Nova Scotia and New Brunswick has issued five exploratory licenses, and a number of regulations are in place, including a closed season from April to December, and a series of closed areas (Therkildsen and Petersen, 2006). In addition, no night time fishing and simple gear restrictions are in place as well as a minimum sea cucumber size of 10 cm in length for landings (DFO, 2005b).

In New Brunswick the fishing season is from 1 January to 31 March, in order to protect the breeding animals and the juveniles (Coulombe and Campagna, 2006). Unfortunately, there is no quota or size restriction. An observer is present on the fishing vessels 20 percent of the time to validate the logbook and bring samples back. The two fishermen involved collected about 500 tonnes each for about 9–10 tonnes a day (Coulombe and Campagna, 2006).

In Newfoundland, although the *C. frondosa* fishery is still in an exploratory phase, the season is set by industry with processor(s) and fishers agreeing to an opening and closing date (Barrett, L., DFA, personal communication). Closure is usually after all fishers have harvested their respective 76 500 kilograms quota (for a total of 612 000 kilograms, wet weight, free water included). In 2006, the fishery opened around the first of June and closed in the second week of September. In previous years, harvesting went on longer into the season. The processor usually tries to work it such that employees get the maximum hours of labour without too much overlap with other species. The minimum length requirement for harvesting is 10 cm. This is measured at dockside while the animal still retains at least part of its free water content. Undersized catches are usually estimated by length but with some level of uncertainty considering the plastic nature of the animals. In Newfoundland and Labrador, the government has issued 10 exploratory licenses (i.e. 8 in NAFO subdivision 3Ps and 2 in NAFO area 4R) in 2006 and reports an exploratory annual quota of ca. 612 tonnes in 3Ps and ca. 90 tonnes in 4R (Barrett, L., DFA, personal communication).

3.7.3 Iceland

No real management plans are in place in Iceland. Kari Olafsson (Reykofninn-Grundarfirdi ehf, personal communication) indicated that their fishing boats have cameras onboard recording as they enter the fishing area and as they leave the area but, unfortunately, they have no means of comparing these images adequately.

3.7.4 Russian Federation

There is apparently a basic management plan in the Russian Federation for both *C. frondosa* (Barents Sea) and *C. japonica* (North Pacific) according to Elena Gudimova (Polar Research Institute of Marine Research and Oceanography, Russian Federation, personal communication). *C. frondosa* from the Barents Sea is subject to a fixed fishing season from August to December. For *C. japonica*, a fishing season is established with no-take-zones and gear restriction. Unfortunately, we could not obtain more information.

4. TRADE

Commercial markets for *P. californicus* exist locally in cities such as New York and San Francisco (USA), and Vancouver (Canada), as well as in Asia (Mathews, Kookesh and Bosworth, 1990). The main exports of *P. californicus* from British Columbia are toward China Hong Kong SAR, Taiwan Province of China, mainland China and Republic of Korea, and toward some domestic markets in Canada and in the USA (DFO, 2002; Lambert, 2006). In Alaska, up to the early 2000s, the meat strips were send to China Hong Kong SAR, and the skins to Taiwan Province of China (Ess, 2007). A few years ago, markets shifted and everything now goes to China. The muscles are routed to southern China via China Hong Kong SAR while skins go to markets in northern China (Ess, 2007).

While guideline harvest levels throughout southeast Alaska have stabilized at around 600–700 tonnes since 2001, ex-vessel prices (i.e. prices received by a captain for the catch) have been varying (Table 3). The 2000–2001 season saw ex-vessel offers climb to values around USD 4.91 kg^{-1}, watched them slip to a low of USD 2.77 kg^{-1} during the 2002–2003 season and enjoyed a rebound to values around USD 4.50 kg^{-1}since 2004 (Ess, 2007) (Table 3).

Bruckner (2005) indicated that sea cucumbers harvested in the Pacific USA are exported to China Hong Kong SAR, Taiwan Province of China, mainland China and Republic of Korea. Exports of *Parastichopus* (both species) were worth USD 0.07 kg^{-1} in early the 1980s, a value that increased in 2005 to USD 0.82 kg^{-1}; processed sea cucumbers sold for up to USD 9 kg^{-1} (Bruckner, 2005). Barsky (1997) reported that ex–vessel prices in California averaged USD 0.32 kg^{-1} in 1995.

Ex–vessel prices per tonne in British Columbia were USD 195 in 1984, USD 854 in 1989 and USD 1 821 in 1994 (Muse, 1998). Native people in British Columbia earned CAD 200 000 (ca. USD 199 500) in 2003 from the fishery of *P. californicus* (James, 2003).

Most *C. frondosa* products are sold on Asian markets. In Maine, fishermen are paid USD 0.05–0.06 per unprocessed sea cucumber. Internal muscle bands and dried body wall are the primary exports, and are currently worth about USD 1.59 kg^{-1}. These sea cucumbers are processed in Maine or shipped to Seattle for processing. Subsequently they are shipped to mainland China, China Hong Kong SAR, Republic of Korea, Singapore, Taiwan Province of China and Japan. Chinese markets in San Francisco, New York and other cities purchase a portion of the catch (Bruckner, 2005). Although *C. frondosa* is smaller than most tropical commercial species and has a thinner body wall, a market acceptance for this species developed over the past decade. However, *C. frondosa* remains a low grade species that yields much lower prices than most commercial species (Therkildsen and Petersen, 2006). Generally, fishermen in Maine are paid USD 0.10 kg^{-1} and the dried product yields only about USD 6–10 kg^{-1} (Feindel, 2002).

In Canada, similar prices are paid per kilo to the fishermen; however precise figures are not always openly divulged by local processors. In 2006, the price paid to the harvester in Newfoundland was USD 0.48 kg^{-1} for wet weight and was based on a company dockside sampling for "free water" retention (Barrett, L., DFA, personal communication). In New Brunswick, the 2006–2007 prices were around USD 0.27 kg^{-1} for gross weight including water content, whereas in Nova Scotia, the reported price for 2006 was ca. USD 0.32 kg^{-1} for what comes out of the vessels (Barrett, L., DFA, personal communication). The same source indicated that the New Brunswick and Newfoundland sea cucumber catches are offloaded at dockside, monitored by the DFO, and then trucked to the plant for processing. Plant workers make between USD 7 and 23 h^{-1}; on average, they can extract ca. 23 kilograms of muscle/meat per day and receive wages of ca. USD 3.78 kg^{-1} (Barrett, L., DFA, personal communication). Another source reported that fishers in New Brunswick received between USD 0.13–0.18 kg^{-1} for non-drained weight of fresh product and the main buyers were in China Hong Kong SAR (Coulombe and Campagna, 2006). There is only one trader in Newfoundland with its main office in Toronto and a possible transit via British Columbia before exportation toward Asia. Products in decreasing order of value are: the dry skin (USD 13–15 kg^{-1}), the muscle bands or "meat" (USD 9–10 kg^{-1}) and the dried aquapharyngial bulbs or "flowers" (USD 3.75 kg^{-1}) (Barrett, L., DFA, personal communication).

In Iceland, the fishermen are paid a fixed monthly salary for the duration of the fishery. The products are shipped by Reykofninn-Grundarfirdi ehf to buyers in Asia (China, Korea, Singapore and Malaysia) either directly or through private sales companies (Icelandic or foreign) (Olafsson, K., Reykofninn-Grundarfirdi ehf, personal communication). Prices paid to fishers and exporters in Iceland were not divulged. No data are available for Russian Federation.

5. SOCIO–ECONOMIC IMPORTANCE

5.1 Commercial fisheries

North American fisheries are threatened by the same factors that are affecting global fisheries, including collapsing fish and invertebrate stocks due to overexploitation and to environmental degradation resulting from pollution and habitat loss. With the closure of some fisheries and the decline of others, fishers in North America are avidly looking toward new resources to increase or maintain their incomes. In some remote locations such as isolated villages on the eastern and western coasts of Canada, a number of social issues arise from employment shortages. As resources from the sea become depleted, new generations of young workers are leaving their home town to seek out new opportunities.

For thousand of communities along the coast of North America, fishing and fish processing are still important components of the local economy, although far fewer now depend exclusively on fishing than in the past. Generally speaking, communities close to the sea, and not just those that rely on the fishery, maintain strong ties to their region and demonstrate fierce independence. And even though fishing activities and processing operations are highly modernized, these occupations have always been seen as a way of life.

Mason (2002) mentioned that with the collapse of the Newfoundland cod stocks the local fishers of various regions were the group most closely identified with the tragic social and economic fallout from the closure of the fishery, as many families and communities were almost totally dependent on the fishery for their livelihoods.

Many fishing communities have developed other activities alongside fishing, like peat harvesting and processing, agriculture, mining and forestry. Tourism, which has been a natural addition to the economy of coastal regions, offers some interesting potential in the long term. There are, however, a number of maritime areas that have never been able to create an alternative to their fishing industry, and they continue to benefit from only a small percentage of the value of their fisheries resource (Beaudin, 1997).

There is no real dependence on sea cucumber harvests anywhere in North America, these fisheries either being experimental or too small to provide substantial income, at least when compared to full-fledged fishing activities. Sea cucumber fisheries are seldom considered essential but one interesting complement is the "recycling" of sea cucumber bycatch to complete net income. Sea cucumbers are a valuable resource that, when harvested in a sustainable fashion provides or could provide important income to many North American fishers and their families. While sea cucumber landings are relatively small in comparison to that of other sea products, they have the potential to become a significant source of income. Most industries related to sea cucumbers in Canada represent just a small portion of total provincial gross domestic product, although they contribute to job creation and the overall economy. The value of sea cucumber harvests may appear negligible in the context of the entire North American fishing industry but it is valuable on a small scale to those individuals who depend on it at times when economic opportunities are limited especially in remote, coastal outposts.

5.2 Traditional harvests

Sea cucumbers are of continuing importance to aboriginal people of the First Nations in Canada, who harvest them for food, as well as for social and ceremonial use. The level of sea cucumber harvest by First Nations in British Columbia is unspecified at this time. A small recreational fishery occurs for sea cucumbers, however landings for this activity remain unknown (DFO, 2002). The Inuit of Belcher Island (Nunavut, northern Canada) are traditionally a marine-oriented community and their diet includes the sea cucumber *C. frondosa* (Wein, Freeman and Markus, 1996). Ninety-three of 102 families poled confirmed that they consumed *C. frondosa*, making sea cucumber a dominant component of their diet (Wein, Freeman and Markus, 1996).

In the USA, more precisely in Alaska, the sea cucumber *P. californicus* was found to be one of the main species harvested for subsistence in native communities. Sea cucumbers were traditionally used as a food in the Northwest Coast culture area (Mathews, Kookesh and Bosworth, 1990). Not surprisingly, commercial harvests account for the largest quantity of sea cucumbers removed from the field, although subsistence harvest by autochthones can be quantified. Mathews, Kookesh and Bosworth (1990) provide data expressed as the total number of 25-litre buckets of gutted sea cucumbers harvested per southeast Alaska community, including estimated total weight harvested in kg. These data are interesting in that they allow comparison between what is harvested through the recently opened fisheries and through the long lasting traditional activities. For instance, in the village of Klawock, 239 buckets of gutted sea cucumbers were harvested in 1987, corresponding to ca. 4 336 kg. In Wrangell, the harvest was estimated at 3 773 kg; in Thorne Bay, 2 213 kg; in Sitka, 2 068 kg; in Craig, 980 kg; in Hollis, 925 kg; in Metlakatla, 707 kg; and in Edna Bay, 526 kg. According to Mathews, Kookesh and Bosworth (1990) some community members placed sea cucumbers high on their list of important subsistence resources and harvested them in substantial numbers. Others harvested sea cucumbers only if they were readily available and if other more desired subsistence species were not available or became limited. In 1990, yearly harvests ranged from 150 to 700 sea cucumbers per household in the studied communities (Mathews, Kookesh and Bosworth, 1990). In 1987, over half of the households in Hollis reported gathering sea cucumbers, and nearly 58 percent of the households reported making use of sea cucumbers. Furthermore, 50 percent of all households in Edna Bay reported harvesting sea cucumbers in 1987, in amounts averaging 1.4 buckets or 25 kilograms of gutted sea cucumbers per household. In Klawock, in 1987, 18.3 percent of the households harvested sea cucumber, and 34.1 percent reported using sea cucumbers for food (Mathews, Kookesh and Bosworth, 1990).

According to Mathews, Kookesh and Bosworth (1990) sea cucumber management in the Alaskan region illustrates a typical issue having to do with the effects of commercialization of a resource which has a history of being used solely for subsistence. One aspect of this problem relates to the likelihood of overfishing the resource to the point of rendering it unusable for subsistence activities. In the specific case of sea cucumbers, it is likely that the resource might be removed from subtidal areas, through a commercial dive fishery, to a degree that is commercially sustainable but with the insidious result of decreasing the availability of sea cucumbers in locations where they are gathered as subsistence food. In this respect, identifying "refuge" or "community use" areas, not accessible to commercial fishing, can become a desirable management tool to protect important subsistence harvest areas. Of course, this approach would require a better definition of subsistence harvest areas. Another management option would be to set harvest quotas in specific areas that would not remove enough of the available sea cucumber biomass to disrupt subsistence activities. This would require awareness of the size of the sea cucumber stock in a given area, prior to any harvesting. These and other management approaches are being considered as a part of the sea cucumber management planning effort in Alaska (Mathews, Kookesh and Bosworth, 1990).

Another key aspect of the commercialization issue relates the involvement of the community in the commercial development of the resource, in order to provide local economic benefits and some degree of local management control (Mathews, Kookesh and Bosworth, 1990). A governance policy that would favour local participation in the fishery might include weekly fishery closures, or requirements for regional, shore-based processing. This would entail a significant shift in perception as commercial sea cucumber exploitation is largely viewed in many communities as a phenomenon whereby large, well-financed, out-of-state vessels and crews would compete with local harvesters (subsistence and commercial), for a limited resource. In certain areas, informal local agreements have been used to avoid such conflicts among user groups (Mathews, Kookesh and Bosworth, 1990).

6. CURRENT PROJECTS AND STUDIES

According to Bruckner (2006b) there is no sea cucumber farming in the USA for either *P. californicus* or *P. parvimensis*. However, preliminary investigations of co-culture scenarios have been undertaken: Ahlgren (1998) examined the assimilation of fouling debris from salmon net pens by *P. californicus*, and Paltzat *et al*. (2006) studied the co-culture of the Pacific oyster *Crassostrea gigas* and *P. californicus*.

Therkildsen and Petersen (2006) recently mentioned that an attempt was being made at starting sea cucumber farming in Norway. In western Canada, aquaculture of *P. californicus* was reportedly attempted some years ago by using settled juveniles on oyster culture lines and relocating them elsewhere for growing (Sutherland, 1996); however, the results of this initiative could not be found. In eastern Canada, to our knowledge, no land-based rearing has been attempted so far, except for the reproduction and growth of *C. frondosa* within the boundaries of academic research, such as the M.Sc. project of Justin So under the supervision of Annie Mercier (Ocean Sciences Centre, Memorial University of Newfoundland). The latter project is also looking at various biological parameters, including gene flow of *C. frondosa* over its geographical range, health status of populations found on various substrates, and impact of predators on the natural stocks. This study is partly being funded by government agencies and the local industry wishing to acquire the biological data required by the novel Emerging Fisheries Policy before opening a new commercial fishery. In this context, various other projects related to *C. frondosa* are being developed in Newfoundland. Stock assessments are being made by the DFO and DFA in collaboration with various fishers on the St. Pierre Bank (Newfoundland Grand Banks).

The Fisheries Technical University in Vladivostok in the Russian Federation has a sea cucumber breeding programme at Slavanka, which rears holothurians that reproduce in mariculture facilities much more rapidly than wild counterparts. The sea cucumbers are exported to the Republic of Korea and China (Johnson, 2004). Kari Olafsson (Reykofninn-Grundarfirdi ehf, personal communication) indicated that there was no aquaculture programme involving *C. frondosa* in Iceland.

7. ADDITIONAL THREATS TO SEA CUCUMBER POPULATIONS

Because of intense naval traffic, the coasts of the Atlantic and Pacific oceans in the northern hemisphere are susceptible to oil spills which can impact the ecosystem, including sea cucumber populations, especially within the shallow subtidal or intertidal zones where sea cucumbers commonly dwell.

In eastern Canada, it is common to setup micro–electric power plants on rivers, thereby modifying the hydrodynamics and indirectly unbalancing the primary productivity, which can consequently interfere with the spawning, development and recruitment of some coastal benthic populations. Deforestation, which can increase runoff of terrigenous material, could also have an impact on already established populations. In some areas like the Hudson Bay (northern Canada), an increase in freshwater runoff generates decreases in salinity in some coastal locations, which could affect some populations of sea cucumbers (*C. frondosa*). These bursts of freshwater are generally the results of hydroelectric power dams producing more or less electricity, thus alternately retaining and releasing large amounts of freshwater. Populations from Hudson Bay, the Nunavut Hudson Bay Inter-Agency Working Group, or Nunavuummi Tasiujarjuamiuguqatigiit Katujiqatigiingit, presented a body of evidence from scientific and traditional knowledge, suggesting that the decreases in salinity, increases in ice cover and changes in the bays' currents could affect sea cucumber populations among other resources (Nunatsiaq-News, 2006).

Industrial countries like USA, Canada and Russian Federation are releasing significant amounts of industrial and domestic wastes in coastal waters, which can affect the sustainability of the resource by reducing their reproductive capability.

Overall, the biggest threat remains overfishing despite the regulations or management programmes that are implemented. Illegal fishing has been reported to occur in California, whereas some regions like southeast Alaska, are concerned about potential conflicts between subsistence and commercial harvesters (Bruckner, 2005).

Furthermore, the use of dredges can destroy the benthic ecosystem and directly or indirectly affect the sea cucumber populations and other resources as well including non target species. The DFO (DFO, 2002) mentioned that conservative management was appropriate until the impact of localized removal of *P. californicus*, a detritus feeder, on seabed ecosystems could be ascertained.

All North American commercial species, to our knowledge, have long embryonic and larval periods and present very slow growth rates, therefore minimizing their potential for aquaculture and stock enhancement programmes, unless novel more cost-effective applications can be discovered and developed to make the investment in aquaculture worthwhile (e.g. pharmaceuticals, nutraceuticals).

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