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A Review of Octopus Fisheries Biology and British Columbia Octopus Fisheries.

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Abstract

Concern over recent trends in octopus catch and effort and industry information prompted a review of octopus fisheries biology and a detailed analysis of British columbia octopus fisheries data. We reviewed octopus fisheries biology in general and provided detailed biological and ecological information for the giant Pacific octopus, *Octopus dofleini*. We also reviewed octopus fisheries off Japan, northwest Africa, Mexico, Alaska, British Columbia, Washington, Oregon and California. We discussed in detail British Columbia dive and trap fisheries, and bycatch of octopus in crustacean trap and demersal trawl fisheries. We discussed assessment and management frameworks used in other juridictions, and suggested potential frameworks that could be applied to B.C. fisheries, and each framework's information requirements. We recommended development of a directed octopus stock assessment program; a critical assessment of existing logbook programs; development of a commercial catch sampling program to determine which species, sexes and sizes of octopus were taken by each fishery; and management measures to limit expansion of B.C. octopus fisheries, until better assessment information was available. We briefly addressed other issues arising from our discussion of B.C. octopus fisheries.

Résumé

Les préoccupations relatives à l'allure récente des captures et de l'effort de la pêche du poulpe et les renseignements fournis par l'industrie ont donné lieu à un examen de la biologie des pêches de cette espèce et à une analyse détaillée des données de ces pêches en Colombie-Britannique. Nous avons fait un examen de la biologie générale des pêches du poulpe et fourni des renseignements détaillés sur la biologie et l'écologie du poulpe géant du Pacifique, *Octopus dofleini*. Nous avons aussi examiné les pêches du poulpe réalisées au large des côtes du Japon, du nord-ouest de l'Afrique, du Mexique, de l'Alaska, de la Colombie-Britannique, du Washington, de l'Orégon et de la Californie. Nous avons traité de façon détaillée des pêches par plongeurs ou au casier de la Colombie-Britannique et des prises accidentelles de poulpes dans la pêche des crustacés au casier ou au chalut démersal. Nous avons traité des régimes d'évaluation et de gestion utilisés dans d'autres juridictions et proposé des cadres qui pourraient être appliqués en C.-B., chacun avec ses exigences de renseignements. Nous avons recommandé l'élaboration d'un programme d'évaluation du stock de poulpes; une évaluation critique des programmes de registres actuels; l'élaboration d'un programme d'échantillonnage des captures commerciales afin de déterminer l'espèce, le sexe et la taille des poulpes capturés dans chaque pêche; et des mesures de gestion pour limiter l'expansion des pêches du poulpe de la C.-B. jusqu'à ce que nous disposions de renseignements pour leur évaluation. Nous avons traité brièvement d'autres points soulevés par nos discussions des pêches du poulpe de la C.-B.

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1. Introduction

This paper is a result of concerns regarding recent trends in catch and effort and industry information on the British Columbia octopus fishery. Fisheries and Oceans Canada (DFO) is concerned that the number of participants, total effort and catch are increasing. Industry information indicates that potential food markets are developing, and that the landed price for octopus is increasing. There is continued interest in development of a directed pot fishery for octopus. DFO is also concerned that the present assessment and management frameworks for octopus fisheries in British Columbia, which apply to a low-value bait market fishery, may not be appropriate for a high-demand, high-value food market fishery.

Perry (1996) advocated a phased approach to development of new fisheries and assessment and management frameworks to ensure a controlled approach to sustainable harvest levels. The preliminary phase (phase 0) included assimilation of information on the biology and fisheries of the target species or closely related species. This was followed by a second phase (phase 1) during which assessment surveys and/or small scale, closely-managed fisheries are used to collect information identified as critical in the first phase. Once enough information has been gathered to develop assessment models, the fishery can be allowed to expand to its full commercial potential (phase 2).

Because commercial fisheries have already developed, this paper is a *post facto* phase 0 assessment of British Columbia octopus fisheries. Its objectives are:

1. To complete a literature search to gather and synthesize all available information on the biology, behaviour and ecology of *Octopus dolfeini*;
2. To critically review available information on British Columbia octopus fisheries;
3. To review fisheries for *Octopus dofleini* and major fisheries for other octopods elsewhere in the world;
4. To provide a focus for discussion of current octopus fishery issues; and
5. To provide recommendations and advice to senior managers for the rational management of the directed dive fishery, bycatch fisheries and developing pot fisheries for *Octopus dofleini* in British Columbia.

2. Octopuses of British Columbia

Although 9 species of octopuses have been recorded from British Columbia waters (Table 1), most are small or occupy offshore habitats. The giant Pacific octopus, *Octopus dofleini*, is the only species in British Columbia large enough and common enough to currently attract directed fisheries interest. Bycatch in prawn trap fisheries includes red octopus, *O. rubescens* (Hartwick *et al.* 1982; J. Cosgrove, Royal British Columbia Museum, pers. comm.).

Opistoteuthis californiana, *Cirroteuthis muelleri*, *Japatella diaphana*, *Graneledone boreopacifica* and the *Benthoctopus* species are not common at fishable depths, are generally of small size, and therefore do not attract commercial interest. *Benthoctopus leioderma* might occasionally be captured in deep prawn sets (F.G. Hochberg, Santa Barbara Museum of Natural History (SBNMH), pers. comm.), and was taken in the Strait of Georgia by the ALBATROSS from 201-311 m in June, 1903 (Smith 1974). *Octopus californicus* is a soft-skinned species, and may not be suitable for export markets such as Japan (Hochberg 1997a). *O. californicus* may account for a considerable portion of octopus caught incidentally in trawl fisheries of southern California.

Voss and Pearcy (1990) described the species *Graneledone pacifica* from several specimens collected from deep water off Oregon, although they stated they were unsure whether or not the specimens could be referred to *G. boreopacifica* due to the brevity of Nesis' description. Previous records of *Benthoctopus profundorum* Robson, 1932 should be attributed to *B. robustus* (F.G. Hochberg, SBMNH, pers. comm.). Hochberg (pers. comm.) considers *Japatella heathi* (Berry, 1911) a junior synonym of *J. diaphana*, and places *leioderma* in *Benthoctopus* not *Octopus*, primarily due to the lack of an ink sac.

Table 1. The octopuses of British Columbia.

Species	Depth Range (m)	Latitudinal Range
Opisthoteuthis californiana Berry, 1949	125-1,100	41-60°N
Cirroteuthis muelleri Eschricht, 1836	0-2,342	45-75°N
**Graneledone boreopacifica* Nesis, 1982	1,165-2,756	44-46°N
Japatella diaphana (Hoyle, 1904)	2,000-5,850	30-55°N
Octopus dofleini (Wulker, 1910)	intertidal-100	20-60°N
Oct. californicus (Berry, 1911)	100-1,000	28-65°N
Oct. rubescens (Berry, 1953)	intertidal-300	20-60°N
Benthoctopus. leioderma (Berry, 1911)	700-900	32-60°N
B. robustus Voss and Pearcy, 1990	2,800-3,660	44-52°N

References: Akimushkin (1963); Mercer (1968); Bernard (1970); Hochberg (1997a,b); Voss (1988); Voss and Pearcy (1990).

Notes: Species marked with "*" have not been recorded from British Columbia waters *sensu stricto*, but nearby records or distribution information warrants their inclusion as hypothetical species.

3. Octopuses as Fisheries Resources

Previous reviews of octopus fisheries biology include Kanamara and Yamashita (1967); Wilson and Gorham (1982); Boyle (1983a; 1987; 1990), Caddy (1983), Rathjen (1983), Voss (1983), Roper *et al.* (1984), Jefferts (1986), Okutani (1990) and Lang and Hochberg (1997). The following review draws primarily on these references: information from other sources will be directly cited. Taxonomy and common names follow Hart (1982), Turgeon *et al.* (1988) and Harbo (1997) for invertebrates, and Gillespie (1993) for fishes.

3.1. Description and Taxonomy

Octopuses are one of five orders of living cephalopods: squid (Order Teuthoidea), cuttlefishes (Order Sepioidea), octopuses (Order Octopoda), vampire squid (Order Vampyromorpha) and chambered nautiluses (Order Nautiloidea).

Octopods possess eight circumoral arms, and lack tentacles which are present in squid and cuttlefishes. The mantle is shortened, and fused dorsally with the head. The suckers are attached directly to the arms, not mounted on stalks, and lack pedicels or chitinous rings. The typical mollusk shell is reduced, vestigial or absent. Fins are absent, or set low on the sides of the mantle when present. The central tooth of the radula has one large projection and two or more small lateral cusps, and the first and second lateral teeth are multicuspid. The buccal membrane is absent, and the olfactory organ is a ciliated pit.

The Octopoda are divided into two suborders: the Cirrata and the Incirrata. Cirrate octopuses possess muscular cirri along the arms and have paddle shaped fins. They are mainly deep-sea pelagic and epibenthic forms. Incirrate octopuses possess neither cirri or fins, and are moderately deep to shallow water benthic or epipelagic forms. Cirrate octopuses have not traditionally supported fisheries. Only one of eight extant families of incirrate octopuses, the Octopodidae, is of commercial importance. Therefore, further discussion will concentrate on this family.

3.2. Distribution

Octopuses are found worldwide in marine waters (Roper *et al.* 1984). Most octopuses are benthic animals, and many are cryptic in nature, hiding in natural refuges (crevices, dens or shells) between hunting expeditions. Other species occur over trawlable bottoms. Cryptic octopuses are solitary, and do not form aggregations.

Octopuses are found from the intertidal zone to at least 1,000 m depth. They often undergo seasonal bathymetric migrations (Mottet 1975; Boyle 1983b; Mangold 1983a,b). It has not been determined whether these migrations are in response to changes in temperature or salinity, are mating/spawning migrations or are driven by shifts in abundance and distribution of preferred prey species.

This paper will refer to "inshore" and "offshore" waters. These terms refer to coastal areas within and beyond diveable depths, respectively, *i.e.*, less than or greater than approximately 20 m depth.

3.3. Life History

Terminology and definitions of life history stages used here follow Young and Harman (1988). Paralarvae are post-hatching octopuses which are pelagic, and thus have a distinctly different mode of life from older, benthic conspecifics. Subadults have shifted to the benthic habitat (*i.e.*, they are no longer paralarvae). The subadult stage ends with attainment of sexual maturity. The adult stage is sexually mature (complete spermatophores present in males, mature ova present in females).

Paralarval octopi have active chromatophore systems and functioning ink sacs, which allow them to expel an “ink dummy” to confuse a prospective predator, and facilitate escape. Mottet (1975) described countershading camouflage in pelagic paralarvae and the shift in chromatophore distribution on the body of larger paralarvae to a pattern more functional for benthic camouflage.

Length of the paralarval stage is extremely variable. Some species move directly to benthic habitat after spawning (*e.g.*, *Octopus bimaculoides*, *O. californicus*, *O. maya*, *O. micropyrsus*) while others are planktonic for weeks or months (*e.g.*, *O. bimaculatus*, *O. dofleini*, *O, rubescens*, *O. vulgaris*, *Eledone cirrhosa*).

Egg size and the presence or absence of a pelagic paralarval stage are related to geographic distribution. Octopus species that produce large numbers of small eggs have pelagic paralarvae and broad geographic distribution; species that produce fewer large eggs characteristically move directly to a benthic subadult stage, and exhibit relatively narrow geographic distributions. One exception is *O. californicus*, which has large eggs and benthic larvae, but is distributed from California to Japan. However, there is some evidence that what is currently considered to be *O. californicus* may, in fact, represent more than one species in the North Pacific, and a complex of species in the Pacific as a whole (Hochberg 1997a).

Subadult and adult octopi maintain short-term home ranges, and appear to be solitary and non-social, rather than territorial (Mather *et al.* 1985; Mather and O’Dor 1991), and may develop size-related hierarchical social structures (Mather 1980, 1984; Hochberg 1997b). They conduct more and longer hunting excursions at night, though these have been shown to depend on ration and feeding schedule in captivity. Between active periods subadult octopuses generally seek refuge in dens, or cover themselves in soft or loose substrates. Mather and O’Dor (1991) characterized subadult *Octopus vulgaris* as “exploratory and opportunistic, but inactive”, occupying a home range for several days and then moving. They speculated that risk of predation may outweigh benefits gained in defending territory from conspecifics. Risk of predation might also shape the foraging schedule and maintenance and abandonment of home ranges in octopus.

Adulthood commences with maturation of the gonads, and usually coincides with a shift in behaviour (decrease or cessation of feeding) which radically slows or even stops growth. Size and age at first maturity varies with species (Table 2), as does maximum size (Table 3) and life span.

3.4. Reproduction

Octopuses are dioescious, and fertilization is internal as a result of direct mating. Reproduction in octopi, as in other cephalopods, is characterized by large physiological commitment to the protection of both male and female gametes by production of complex structures and specific parental behaviours (Boletzky 1987a). Sexual maturation is regulated by secretions from the optic glands, which are under inhibitory nerve control possibly related to photoperiod (Wells and Wells 1972).

The female has a single ovary and paired oviducts. When mature, the ovary and oviductal glands of the female fill most of the body cavity (Pickford 1964). Fecundity varies with species (Table 4), and is a function of both egg size and body size of the female. Maturity in females is indicated by a large yellow or orange ovary, the surface of the ovary stretched and transparent, and loose mature eggs present in the ovisac.

Table 2. Size at maturity and maximum size of selected octopuses.

Species	Size at Maturity	Maximum Size
Eledone cirrhosa	M 5.0 cm ML, F 12.5 cm ML	40 cm TL, 1.2 kg
E. moschata	250-600 g	600 g
Octopus bimaculatus	n/a	152 mm ML, 1.5 kg
O. bimaculoides	n/a	120 mm ML, 384 g
O. briareus	0.5-1.5 kg	100 cm TL, 1.5 kg
O. californicus	M 60 mm ML, F 90 mm ML	120-140 mm ML, 500-600 g
O. cyanea	M 200 g, F 5 kg	220 mm ML, 6 kg
O. dofleini	M 7.5 kg, F 16.0 kg	272 kg
O. joubini	20-30 g	15 cm TL
O. maya	0.7-6.5 kg	130 cm TL, 5 kg
O. ornatus	n/a	90 mm ML, 500 g
O. rubescens	30-50 g	80-100 mm ML, 400 g
O. vulgaris	M 8 cm DML, F 12 cm DML M 260 g, F 1,100 g	250-300 mm ML, 8-10 kg

References: Hartwick and Barriga (1997), Hochberg (1997a,b), Hochberg and Fields (1980), Roper *et al.* (1984), Bravo de Laguna (1989); Young and Harman (1997), Mangold (1983a)

The male has a single large testis, and a series of sperm ducts on the left side only. Sperm produced by the male are packaged into complex spermatophores which are stored in a spermatic sac (Needham's organ), extruded during mating, passed along a groove of the specially modified (hectocotylized) third right arm. The spermatophores are placed in the mantle cavity of the female, and lodge in the openings of the distal oviducts. After exposure to saltwater the spermatophores release spermatangia (spermatophoric reaction), which are stored in oviductal glands (in *Octopus*) or travel to the ovary before releasing sperm (in *Eledone*). Maturity in males is generally indicated by the presence of complete spermatophores in Needham's sac or the penis (Pickford 1964). Spermatophores may be large with relatively few produced (8-12 spermatophores 90 cm in length per male in *O. dofleini*) or smaller and more plentiful (at least 180 spermatophores per male in *Eledone cirrhosa*) (Gabe 1975; Boyle 1983b).

Table 3. Estimated life span of selected octopuses.

Species	Estimated Life Span	Method
Bathypolypus sponsalis	2 yr.	length frequency
Eledone cirrhosa	M 14-15 mo., F 16-18 mo.	length frequency
E. moschata	15-18 mo.	n/a
Octopus bimaculatus	15-24 mo.	rearing, inference
O. bimaculoides	12 mo.	n/a
O. briareus	12-15 mo.	rearing
O. cyanea	11-15 mo.	n/a
O. dofleini	2-5 yr.	rearing
O. joubini	4-12+ mo.	rearing
O. maya	12-18 mo.	n/a
O. ornatus	n/a	
O. rubescens	12-18 mo.	rearing
O. vulgaris	12-24 mo.	length frequency

References: Voss (1983), Ambrose (1997), Hartwick and Barriga (1997), Hochberg (1997b), Lang (1997), Mangold (1983a, 1997); Solis-Ramirez (1997)

Table 4. Estimated fecundities of selected octopuses.

Species	Estimated Fecundity	Method
Bathypolypus sponsalis	70-120	egg count
Eledone cirrhosa	1,010-3,800	egg count
E. moschata	100-500	egg count
Octopus bimaculatus	20,000	egg count
O. bimaculoides	200-800	egg count
O. briareus	100-500	egg strings
O. californicus	100-500	brood counts
O. cyanea	700,000	egg counts
O. dofleini	18,000-50,000; ca.100,000	egg strings; ovarian estimate
O. joubini	40-95	egg strings
O. maya	1,500-3,000	egg strings
O. ornatus	n/a	
O. rubescens	20,000-50,000	egg strings
O. vulgaris	100,000-500,000	egg strings

References: Voss (1983), Roper *et al.* (1984), Ambrose (1997), Hartwick and Barriga (1997), Hochberg (1997a,b), Lang (1997), Mangold (1983c, 1997), Hartwick (1983); Solis-Ramirez (1997); Young and Harman (1997)

Mating and spawning are separate acts, often with a considerable time interval between. Females are often fertilized long before they are sexually mature. The significance of sperm storage, and whether either males of females (or both) enjoy multiple matings is unknown. Probably most species are largely influenced by visual displays in mating. Not so for *Octopus vulgaris*, in which mating occurs at night, and cues are presumed to be chemical, rather than visual (Mangold 1997).

Eggs are attached to the roof of caves, under rocks, shells or other objects. The eggs are laid in strings or festoons by larger, more fecund species, or in strings or single layers by smaller, less fecund species. Females remain in the brooding den and manipulate the eggs with the tips of their arms and/or blow water over the eggs through their funnel. This serves to keep the eggs free of floating debris and to aerate the water. The females also protect the brooding eggs from predators. These behaviours are maintained until the females die, often before the eggs hatch.

Despite assertions that some octopuses live to spawn more than once (*e.g.*, Voss 1983), most species are semelparous (*i.e.*, die after a single breeding season). Females do not hunt or feed once spawning has commenced. Males of many species also cease feeding at maturity, and die weeks or months after spawning.

3.5. Age and Growth

No reliable method has been demonstrated to age octopuses (Voss 1983). Most estimates have been derived from rearing studies or length/weight frequencies and size at maturity (Table 2 and Table 3). Studies which rely on size frequencies are very vulnerable to gear selectivity, and thus must use a variety of capture techniques to fully sample the population. The use of size frequencies and size at maturity also hinges on the assumption that all octopi die after spawning, which is likely, though hardly proven definitively. Joll (1983) cautioned that size may not accurately represent the age of octopi if availability of food is variable, as growth is highly dependent on food intake. As most information has come from laboratory or mark-recovery studies, it is unlikely that adequate information regarding age and growth can be obtained by simply sampling commercial catches.

3.6. Trophic Relations

As adults, octopi are high-level predators, preying primarily on crustaceans, bivalves, cephalopods and other invertebrates, and occasionally fishes and fish eggs. Octopuses may opportunistically exploit the most abundant prey type available at any time.

Food capture among benthic octopi is primarily by "pouncing" on live prey which has been detected visually. Slow moving prey or dead material which is scavenged is generally located visually, explored by a single arm extended towards it, and seized by the same arm or several arms draped over it (Boletzky 1987b). Octopi may hunt prey by parachuting down over an area with the web extended, then exploring under the web with the tips of the arms to locate trapped prey. Several prey items may be carried back to a refuge before consumption.

Octopuses bite or drill prey items, and induce paralysis and death with toxic salivary secretions. Octopuses can selectively remove the flesh from crustacean prey, leaving the exoskeleton behind. Quantitative analyses of octopus gut contents are particularly difficult. Some researchers (Grisley and Boyle 1985, 1988; Boyle *et al.* 1986) have explored biochemical means of prey identification.

Paralarvae of some octopi (*O. dofleini* and *O. vulgaris*) exhibit a tactile feeding response to food particles trapped in the surface film of the water. This neustonic feeding (Marliave 1981) suggests a possible scavenging mode of feeding keyed by tactile responses, as opposed to active pursuit of live prey or falling detritus, which is largely visual (Boletzky 1987b).

Octopus growth is generally divided into two growth periods, the first an exponential growth phase, and the second a logarithmic growth phase (*e.g.*, van Heukelem 1976). Young octopuses may eat 10-20% of their body weight per day during the rapid, exponential growth phase (Mangold 1983a). During the second, logarithmic growth phase, food intake drops to approximately 5% of body weight per day.

Food conversion rates are high in octopods, mean conversion rates ranging from 37-55% depending other species (Mangold 1983a, and references therein). Conversion rates depend on prey quality, and are greater for high protein foods (*e.g.*, crustaceans) than high lipid (sardines) or carbohydrate (limpets and clams) food types. Gross growth efficiency of octopods is the highest recorded in the literature. Octopods convert approximately 50% of the food energy consumed to growth, with approximately 45% used for metabolic maintenance and 5% excreted as feces. This is in part because octopuses pre-process prey items, ingesting only the flesh and discarding the shells.

Octopuses are, in turn, preyed upon by fishes, marine mammals, seabirds, other octopuses and man (NMFS 1997).

3.7. Parasites and Disease

Hochberg (1983) reviewed literature on cephalopod parasites. *Octopus* spp. (primarily *O. vulgaris*) were found to host viruses, fungi, dinoflagellates, protozoans, ciliates, dicyemids, digenetic trematodes, larval cestodes, hirudineans and copepods. In at least one case, parasite fauna has been used to identify juvenile octopus to species (Pickford and McConnaughey 1949).

There are no reports of significant natural mortality due to parasites or disease, though mortality has occurred in attempted culture operations (Boletzky and Hanlon 1983; Hanlon *et al.* 1984; Hanlon and Forsythe 1985).

3.8. *Population Structure and Dynamics*

Octopus populations are known to experience wide variation in abundance (Rees and Lumby 1954; Boyle and Knobloch 1982). Sporadic periods of high recruitment are a normal, though unpredictable, feature of octopus population dynamics (Hartwick, Ambrose and Robinson 1984a). Population structure and absolute abundance may be a function of predation pressure, as much as migration or recruitment (Aronson 1986; Ambrose 1988; Mather and O'Dor 1991). In some tropical octopuses with annual or semi-annual life spans the fishable population may be made up entirely of a single cohort. In temperate waters, particularly with species that live longer than one year, the fishable population may be made up of more than one cohort, and exhibit a wide size range.

4. Fisheries Biology of *Octopus dofleini*

There have been regular reviews of the biology of *Octopus dofleini* (Mottet 1975; Hartwick 1983; Hartwick and Barriga 1997) which form the basis of this review. Other literature is cited directly within the report.

4.1. *Description and Taxonomy*

O. dofleini is a large, reddish-brown octopus (Hochberg 1976; Roper *et al.* 1984). The body is large and globular, and the skin is rough, with numerous skin folds and papillae. They possess two large flattened posterior supraorbital papillae. The arms are 3-5 times the length of the body. The first and second arms are the longest, and approximately equal to each other in length. The third arms are shorter, and the fourth arms shortest of all (arm formula: 1=2>3>4). The web extends approximately 1/4 of the length of the arms. The third right arm of the males is hectocotylized, with a long, slender ligula making up the distal fifth of the arm. There are 24-29 primary gill lamellae on each gill (Hochberg 1976).

Kubodera (1991) described planktonic paralarvae of *Octopus dofleini* from near the Aleutian Islands. They had short arms (approximately equal to ML), a broad head, very large eyes, scattered chromatophores across the mantle and over the eye, and a row of chromatophores down each arm. Each arm also had 20-25 suckers, arranged in pairs.

Octopus dofleini is the largest known octopod (Roper *et al.* 1984). Adults have mantle lengths exceeding 20 cm, and total weights exceeding 50 kg. Maximum recorded weight was 272 kg, an individual with an arm span of 9.6 m (Hochberg and Fields 1980).

The giant Pacific octopus, *Octopus dofleini martini*, was originally described as *Polypus dofleini* Wulker, 1910. It has also been known under the scientific names *Octopus punctatus* Gabb, 1862;

Polypus apollyon Berry, 1912; *Polypus hongkongensis* Hoyle, 1885; *Polypus gilbertianus* Berry, 1912; *Polypus madokai* Berry, 1921; and *Polypus pustulosus* Sasaki, 1920 (Pickford 1964; Roper *et al.* 1984). It has been occasionally placed in the genus *Paroctopus*. Common names include giant North Pacific octopus and, in Japan, mizudako (Roper *et al.* 1984).

Three subspecies are currently recognized: *Octopus dofleini dofleini* (Wulker, 1910, *emend.* Sasaki, 1929) of the temperate west Pacific; *O. d. apollyon* (Berry, 1912, *emend.* Pickford, 1964) in the subarctic Pacific; and *O. d. martini* (Pickford, 1964) of the temperate east Pacific (Pickford 1964). Hochberg and Fields (1980) reported a fourth, undescribed subspecies off southern California.

4.2. Distribution

O. dofleini is reported from the coastal waters of the Pacific Ocean from California through the subarctic Pacific, the Bering Sea, Sea of Okhotsk to Japan, including the Sea of Japan.

Giant Pacific octopus are found from the intertidal zone to at least 100 m depth. Bernard (1978) indicated a depth range of 23-344 m for *Octopus dofleini* in the Strait of Georgia, but he recorded no other species of octopod. Some of his deeper records may represent other species.

They are found on most bottom types, including rock, sand, sand-mud, gravel or even eelgrass beds, particularly when foraging for food. They are found most commonly on bedrock with crevices or other cover, or in boulder fields with sand-shell bottoms.

O. dofleini may be found in association with high concentrations of crustacean prey (Paust 1997), including spot prawns (*Pandalus platyceros*), Dungeness (*Cancer magister*), tanner (*Chionocetes bairdi*) and king crabs (*Paralithodes camschatica*).

4.3. Life History

Egg size is approximately 6-8 mm length by 2-3 mm width. The eggs encased in capsules bearing long stalks. Eggs are arranged in strings or festoons of 150-200 eggs, each attached by its stalk to a central strand. Cosgrove (1993) reported a mean of 172 eggs/string. The egg strings are attached to the underside of a rock surface in the brooding den (Mottet 1975; Hartwick 1983; Cosgrove 1993).

Gabe (1975) reported the following approximate timing for developmental events: 91 days post spawning - eyes visible through egg case; 97 days - DML = 1.06 mm, 3-4 suckers per arm; 110 days - chromatophores appear; 144 days - ink sac appears; 144-158 days - embryos rotate in egg cases; 158 days - DML = 3.51 mm, 11-14 suckers per arm; 160 days - hatching commences. Hatching in Gabe's observations lasted 78 days, however, eggs would only hatch when agitated by the researcher after the female had died. Cosgrove (1993) reported longer development times

(116 days - eyes visible; 152 days - embryos reversed; 195 days - hatching commenced) for eggs collected from brooding dens in the wild, however hatching was complete in all cases within a week.

In British Columbia, hatching occurs throughout the year, with a peak in April (Green 1973). The hatching period for individual broods may be as short as one week (Cosgrove 1993) or fairly protracted: 40-60 days (Hartwick 1983). Hatching of individual eggs takes several hours, and may be accompanied by an expulsion of ink (Gabe 1975).

Newly hatched paralarvae are approximately 3-4 mm DML, or 6-8 mm TL (Mottet 1975). Mean weight of hatchlings was reported to be 21.65 mg (Hartwick 1983). After hatching, paralarvae swim towards the surface. They are not neutrally buoyant, and must swim continuously by expelling water through the funnel to maintain position in the water column (Gabe 1975). Paralarvae have been collected to a depth of 900 m, but most are caught in the upper 400 m of the water column.

Paralarvae feed by gathering neustonic detritus, or actively pursuing live prey. In culture situations, paralarvae can be reared on live adult *Artemia* or frozen krill, but growth rates are increased if the krill is supplemented with amino acids, electrolytes, minerals and vitamins (Marliave 1981). Paralarvae would encounter frozen krill floating at the surface with their mantles and invert themselves, clinging to the surface interface with their tentacles. Then would then move laterally via funnel jets until they encountered food with their tentacles, at which point they would grasp the food and descend into the water column to feed. Visually oriented, squid-like attacks on copepods and amphipods have been observed both in aquaria and in field culture chambers.

Size and age at transition to a benthic habitat are not known, but pelagic paralarvae are known up to a size of 14 mm DML or 35 mm TL (Mottet 1975). Size at settlement is presumed to be at least 50 mm TL, and 3-5 g in weight. Estimates of paralarval period length range from approximately 1 month in California (Hochberg and Fields 1980) to 2-3 months in Japan (Hartwick 1983).

Off Japan, small subadult octopus (3-5 g, 30-50 mm TL) are sometimes caught in water 50 m or less, and large numbers of small subadults (0.5 kg each) are caught in trawls at 150-180 m in September-November (Mottet 1975).

Benthic octopuses live in dens, used as refuges to consume captured prey and rest between hunting forays. Large octopus use naturally occurring den sites, usually cavities between or under large rocks or bedrock cracks or fissures, often with more than one opening (Hartwick, Breen and Tulloch 1978). Active dens have characteristic midden piles at one or more entrance, made up of excavated materials and remains of prey. Smaller octopus may excavate new dens, characterized by midden piles of freshly excavated sand, having only one entrance.

Den size and size of the octopus which occupies it are related: larger octopus require larger dens (Hartwick, Breen and Tulloch 1978). These authors speculated that den selectivity by octopus would result in strong size selectivity in traps, and that this selectivity could be a useful tool for fishery management.

Giant Pacific octopus occupy dens for a relatively short period, then move to a different den site. Hartwick, Breen and Tulloch (1978) demonstrated that den sites were more evenly spaced than would be expected if the dens were spaced randomly, and speculated that *O. dofleini* might be territorial. Hartwick, Ambrose and Robinson (1984b) considered *O. dofleini* to be territorial, defending den sites and possibly food resources. Individual octopi used the same den site for up to a month, and stayed within the study area for up to 6.5 months. Some individuals were recaptured after absences of more than a month, the maximum extended absence was 177 d.

Sonic tagging by Mather *et al.* (1985) indicated that *O. dofleini* occupy home ranges of approximately 250 m^2, and that ranges overlap considerably. Although the home range was relatively stable over the 2 week observation period, tagged octopi occupied more than one den within their home range, often avoiding the den where they had been captured for tagging. Mather *et al.* characterized *O. dofleini* as solitary and asocial, not territorial.

4.4. Reproduction

The onset of sexual maturity in *O. dofleini* occurs at body weights of approximately 10-15 kg. Males mature earlier than females, at a smaller size of 10 kg. Age at maturity has been estimated at 1.5-2 years (Mottet 1975), 2-3 years (Hartwick *et al.* 1981), or, exceptionally 4-5 years for some individuals (Hartwick 1983). Extremely large individuals may be males which have not become sexually mature.

Female octopi do not necessarily spawn all of the eggs in their ovaries, thus there are two measures of fecundity: potential fecundity is the number of eggs which are produced and mature in the ovary; and actual fecundity is the number of eggs spawned per female. Actual fecundity varies with the size of the female. Estimates of potential fecundity range as high as 100,000. Actual fecundity is less, estimates ranging from 18,000 to 74,000, possibly averaging 50,000 (Hartwick 1983). Because octopuses are semelparous, this represents lifetime reproductive output.

Mating occurs in the autumn, when octopus are noticed together in pairs and aggressive actions towards divers increase (Hartwick, Thorarinsson and Tulloch 1978a). Mottet (1975) suggested that mating occurs at approximately 100 m in Japan, however, mating activities have been observed shallower in the northeastern Pacific (Hartwick 1983).

Mating involves visual displays and tactile cues, and may last 2-4 hours (Hartwick 1983). The male mounts the female from above, enveloping her body with his arms and web. Two spermatophores are transferred sequentially to the females body cavity, where they are lodged in the distal oviducts. Females mate while still immature, and a considerable time passes before spawning.

Male *O. dofleini* produce 8-10 spermatophores, and thus are theoretically capable of mating 4-5 times. There are reports of males spawning with more than one female (Hartwick 1983).

Spawning may occur at any time throughout the year in British Columbia, but is most prevalent in the winter months (Hartwick 1983). Spawning occurs in relatively shallow water in brooding dens. Spawning occurs at night, and females may continue to lay eggs for up to 15 days. Mating is not necessary for female maturation as captive females have matured and spawned infertile egg masses (F.G. Hochberg, SBMNH, pers. comm.). Gabe (1975) reported spawning to occur 42 days after mating in captive *O. dofleini*. The female spawned only at night for 15 days, finally producing approximately 35,000 eggs.

The female remains in the brooding den and care for the eggs. The female is generally in a brooding position beneath the eggs, and she reaches up with the tips of her arms to continuously agitate the egg strings (Gabe 1975). She also occasionally directs a jet of water over the eggs through her funnel. Eggs removed for aquarium rearing often suffer growth of diatoms, hydroids and other encrusting organisms. Brooding dens do not have midden heaps at their entrances, and the entrances may be partially sealed by the female using rocks and shell debris gathered from the vicinity. Brooding females have been observed between 13-30 m depths in the northeastern Pacific, and brooding in Japan is believed to occur in 50 m of water or less.

Females do not eat during the brooding period, and as hatching approaches they are gray and emaciated (Cosgrove 1984, 1993). They generally die just prior to or just following hatching. Gabe (1975) reported that a captive female accepted food offered to it while brooding. The female died after suffering injury in the tank, but the digestive tract was fully functional. Gabe did not relate observations of color or vigor of the female, nor did she report its weight before the beginning of brooding or after its death. Acceptance of proffered food while brooding might indicate that abstinence from feeding relates to a stronger need to maintain brooding activities when hunting activities might expose the eggs to predation or fouling. Males are also reported to die within months of spawning.

4.5. Age and Growth

Absolute ages for *O. dofleini* are not known. Statoliths, which have been used to determine age in pelagic squids, are soft and chalky in octopuses, and do not exhibit growth zones which can be interpreted to estimate age (Robinson and Hartwick 1986). Faint lines have been seen in the chitinous beaks of octopuses (Pickford 1964), but these are not consistent, and cannot be used to determine age. Robinson and Hartwick (1983) were able to correlate linear measurements of octopus beaks to live wet weight, but could not discriminate sex of the animal from these measurements.

Maximum age is likely 3-5 years (Hartwick 1983). Mottet (1975) estimated that approximately 1 year was required for subadults to reach 1 kg in size, and that sexual maturity could be achieved at 1.5-2 years of age. Maximum size may be attained in 2-3 years (Hartwick, Tulloch and MacDonald 1981). Average age at maturity is 3 years, but males may live 1-2 years longer if they do not reproduce (Hartwick 1983).

Growth rates are very rapid, based both on observed growth in aquaria and tag recaptures in the natural environment (Robinson and Hartwick 1986). Octopus hatch weighing approximately 22 mg, yet regularly achieve weights of 50 kg or more. Average daily growth rates in British Columbia ranged from 0.1-1.8% (Hartwick, Tulloch and MacDonald 1981). Little information is available on growth to 1 kg.

Growth rate may be affected by temperature, and although thermal optima are not known for *O. dofleini* (Mottet 1975), they are most frequently found in waters of 7-15°C (Hartwick, Tulloch and MacDonald 1981). Growth was reduced in the winter months. Food intake and growth decrease markedly for *O. vulgaris* at temperatures above 24°C or below 17°C.

4.6. Trophic Relations

The giant Pacific octopus is an opportunistic predator with a wide range of reported prey (Table 5). *O. dofleini* feeds primarily on crabs, bivalves, gastropods, shrimps, fish eggs, and marine fishes, including opportunistic predation on fishes captured on longlines (Hartwick, Thorarinsson and Tulloch 1978b; Hartwick and Barriga 1997; Paust 1997). Cosgrove (1987) indicated that red rock crabs (*Cancer productus*) were consistently the most important prey for *O. dofleini* in Saanich Inlet. Hartwick, Tulloch and MacDonald (1981) found *Cancer* spp., cockles and littleneck clams to be the most prevalent prey items in Barkley and Clayoquot Sounds, but noted that prey selection varied considerably between individual octopi, even in close proximity.

Octopi can swim well enough to capture relatively fast-moving prey. They also possess a salivary toxin which can be released into the water to slow or immobilize crustacean prey. They have powerful beaks for biting crustacean and fish prey, and can drill bivalve shells using their radula to rasp through the shell (Hartwick, Thorarinsson and Tulloch 1978b). Crabs are detected visually and then captured by one or more arms. Shrimps and small fish are taken by enclosing an area with the web membrane, and then reaching under the web to collect prey with the tips of the arms (Hochberg and Fields 1980).

Octopus predation on crustaceans characteristically involves beak punctures or bore holes in the carapace, and the disarticulated exoskeleton almost completely cleaned of flesh (Boyle 1997). Octopuses have salivary secretions which function both to paralyze or kill the prey item, and to begin external digestion through proteolytic and chitinolytic enzymes. This efficient removal of flesh from crustacean prey, leaving the indigestible exoskeleton uningested, contributes to the high quality diet and exceptional conversion rates and growth efficiency in octopuses.

Octopus kill bivalves and gastropods by pulling them open, breaking the shells, or drilling a hole in the shell, presumably to introduce toxic secretions (Hartwick, Thorarinsson and Tulloch

1978b; Ambrose *et al.* 1988). The octopuses and prey examined by these authors indicated that method of attack was not necessarily related to size of the predator nor to size or species of the prey. Some shells were drilled more than once, and some drilled prey were recovered live from the midden, indicating that envenomation does not always occur or is not always effective. It is not known whether shell breakage is due to pulling apart of the valves or to biting. Ambrose *et al.* (1988) indicated that octopus bore holes were likely formed by a combination of mechanical scouring using teeth on the salivary papilla and chemical dissolution of shell material.

Octopuses often carry prey items back to their dens to consume them, and remains accumulate at the mouth of the den, forming midden heaps (Hartwick, Thorarinsson and Tulloch 1978b). Most information on octopus diet in British Columbia is derived from examination of midden heaps. Inferences from midden materials can be biased, however (Ambrose 1983; Boyle 1997). Hard bivalve and gastropod shells are much more persistent than crustacean and fish remains, and may bias the perceived importance of molluscan prey relative to more transitory remains. Gastropod shells may be carried away by hermit crabs utilizing them as homes. Other materials may have been collected by octopuses out of curiosity - Cosgrove (1987) reported that markers used to locate dens had occasionally been moved into midden heaps, and a three-wood golf club was recovered from one midden. Mangold (1983a) reported that *O. vulgaris* carried crustacean remains away from the den site, and if *O. dofleini* exhibits similar behaviour, then crustacean remains would be under-represented in midden materials. Octopuses may travel considerable distances from their dens to known prey aggregations, and have been known to consume prey at sites other than the main den (Hartwick *et al.* 1981; Cosgrove 1987). Thus, the midden at the den may not reflect the complete diet of the resident.

Based on the number of octopi seen in dens during daylight dives, foraging is thought to be largely crepuscular or nocturnal (Hartwick 1983). However, individuals have been observed feeding during the day, and sonic tagging indicates considerable daytime activity and movement (Mather *et al.* 1985).

Subadult and adult giant Pacific octopus are themselves preyed upon by large fishes, marine mammals, larger octopuses and man (Table 6). Dead octopuses are scavenged by crabs and sunflower stars (*Picnopodium helianthoides*). Cosgrove (1993) observed untended eggs being consumed by majid (*Chorilia longipes*), sharpnose (*Scyra acutifrons*) and decorator crabs (*Oregonia gracilis*).

Octopuses react to predators (divers) by remaining motionless in cryptic coloration until closely approached (Hartwick, Thorarinsson and Tulloch 1978a). Once disturbed, the octopus would flee. Octopuses which had been driven from their dens would quickly descend in the water column after seeing divers, blanch to a pale coloration, and spread their interbrachial webbing. They would remain in this position for several seconds and then move quickly back into the den or towards some other cover. If cover was unavailable, the octopus would jet rapidly upwards and away, often directing a cloud of ink at the diver. This behaviour was presumed to startle a potential predator, allowing the animal time to escape. The blanching and ejection of an ink cloud is presumed to be an attempt to confuse the predator.

Table 5. Reported prey of subadult and adult *Octopus dofleini*.

	Bivalves	
Spiny pink scallop		*Chlamys hastata*
Nuttall's cockle		*Clinocardium nuttallii*
Purple-hinged rock scallop		*Crassadoma gigantea* (as *Hinnites giganteus*)
Rough diplodon		*Diplodonta orbellus*
Rock entodesma		*Entodesma navicula* (as *Lyonsia saxicola*)
California sunsetclam		*Gari californica*
Western bittersweet		*Glycymeris septentriornalis* (as *G. subobsoleta*)
Kennerly's venus		*Humilaria kennerlyi*
Macoma clam		*Macoma* sp.
Straight horsemussel		*Modiolus rectus*
Truncated softshell-clam		*Mya truncata*
California mussel		*Mytilus californianus*
Pacific geoduck		*Panopea abrupta* (as *P. generosa*)
Green false-jingle		*Pododesmus macrochisma* (as *P. cepio*)
Littleneck clam		*Protothaca staminea*
Butter clam		*Saxidomus giganteus*
Rose-painted clam		*Semele rubropicta*
Sickle jackknife-clam		*Solen sicarius*
Fat gaper		*Tresus capax*
	Brachiopods	
Lamp shell		*Terebratalia* sp.
	Gastropods	
Whitecap limpet		*Acmea mitra*
Slippersnails		*Crepidula* sp.
Rough keyhole limpet		*Diodora aspera*
Oregon triton		*Fusitriton oregonensis*
Northern abalone		*Haliotis kamschatkana*
Lewis' moon snail		*Polinices lewisi*
	Crustaceans	
Dungeness Crab		*Cancer magister*
Red Rock Crab		*Cancer productus*
Purple shore crab		*Hemigrapsus nudus*
Kelp crab		*Pugettia* sp.
Sharp-nosed crab		*Scyra acutifrons*
Horse crab		*Telmessus cheiragonus*
Shrimps		Suborder Nanantia
	Echinoderms	
Sea cucumber		Class Holothuroidea
Sea stars		Class Stelleroidea
Sea urchin		*Strongylocentrotus droebachiensis*
	Cephalopods	
Squid		Order Teuthoidea
Octopus		Order Octopoda
	Fish	
Sandlance		*Ammodytes* sp.
Sculpin		Family Cottidae
Flatfish		Order Pleuronectiformes
Rockfish		Family Scorpaenidae

References: Cosgrove (1987), Hartwick *et al.* (1981), Hartwick, Thorarinsson and Tulloch (1978b), Mottet (1975), Hochberg and Fields (1980)

Hartwick and Thorarinsson (1978) discussed den associates of octopus in British Columbia. Although the ecological relationship of many of the associated species was unclear, some species (the crab *Hyas lyratus* and the sunstar *Pycnopodia helanthoides*) were observed scavenging remains from midden piles. They also speculated that the gastropod scavenger *Amphissa columbiana* was attracted by remains in midden piles.

Table 6. Reported predators of subadult and adult *Octopus dofleini*.

	Fish	
Pacific halibut		*Hippoglossus stenolepis*
Pacific lingcod		*Ophiodon elongatus*
Spiny dogfish		*Squalus acanthias*
	Mammals	
Sea otter		*Enhydra lutris*
California sea lion		*Eumatopias jubata*
Mink		*Mustela vison*
Harbour seal		*Phoca vitulina*
Man		*Homo sapiens*
	Cephalopods	
Octopus		*Octopus dofleini*

References: Best and St. Pierre (1986), Cass *et al.* (1990), Hartwick (1983), Watson and Smith (1996), Jefferts (1986), Robinson (1983)

4.7. Parasites and Disease

We were able to find only a few references describing parasites or disease in giant Pacific octopus. Burreson (1977) described a marine leech, *Ostreobdella papillata* from giant Pacific octopus and black rockfish, *Sebastes melanops*. Hochberg (1983) related a case of unidentified dinoflagellates imbedded in the skin of *O. dofleini* from Washington State, causing lesions on the mantle. Poynton *et al.* (1992) described the protozoan *Aggregata dobelli* from the digestive tract of giant Pacific octopus from British Columbia and Washington.

4.8. Population Structure and Dynamics

Octopus dofleini are known to undergo considerable variation in abundance both month-to-month and year-to-year (Hartwick, Ambrose and Robinson 1984a,b; Paust 1997). In Alaska, abundance cycles from high to low on a 7-8 year period. The last year of extremely high abundance was 1982. Hartwick, Ambrose and Robinson (1984a,b) characterized local octopus populations as open, with their structure significantly affected by recruitment, immigration and emigration. Studies on other species (see Section 3.8) have indicated that predation pressure is also important in determining absolute abundance, population structure and foraging behaviour.

Subadult octopuses are reported to undergo two seasonal migrations from shallow water to deep water off Hokkaido (Mottet 1975). The octopuses are in deep water February-April and August-October, and abundant in shallow water May-July and November-January. Hartwick *et al.* (1982) attributed variation in trap catch rates in spring to a similar migration in British Columbia. The reason for migration is unknown, but speculation includes responses to temperature, salinity, abundance and distribution of prey species or mating/spawning behaviour (Hartwick *et al.* 1982; Hartwick, Ambrose and Robinson 1984a).

The extended spawning period and differential growth of paralarvae and juveniles results in populations which have a wide mixture of sizes at any given time (Hartwick 1983; Hartwick, Ambrose and Robinson 1984a). Small octopi become prevalent in the shallow subtidal waters of British Columbia in the late summer and autumn, but subadult octopi are generally present for most of the year. Larger animals may emigrate to deeper waters, as evidenced by lower recapture rates.

Sex ratios indicate either differential movement or differential mortality for each sex (Hartwick 1983; Hartwick, Ambrose and Robinson 1984a). In Clayoquot Sound (Hartwick, Ambrose and Robinson 1984a) females were more numerous than males in shallow water (< 20 m), but trap sampling indicated that males were more abundant than females in areas near the SCUBA census sites, perhaps indicating that behavioral differences could account for the skewed sex ratio inshore. However, catch from a Washington State fishery between 20-40 m captured mostly males. Mottet (1975) reported equal numbers of males and females from Japanese fisheries. Distribution and population structure in deeper water is unknown.

Mortality rates are likely highest in the planktonic paralarval stage due to predation and physiological stresses (Hartwick 1983; Hartwick, Ambrose and Robinson 1984a). Green (1973) estimated survival rates of 4% to 6 mm DML and 1% to 10 mm DML from catch curves of planktonic paralarvae. Mortality in small benthic subadults is likely high due to predation, intraspecific competition for den sites and cannibalism. Even large subadult and adult octopuses exhibit high incidence of scarring and missing limbs, indication that they still suffer harassment by other predators. However, evidence of healing of these injuries in tagged individuals indicates that not all harassment results in mortality.

5. Fisheries for Octopus

Many octopus fisheries are active throughout the world (Roper *et al.* 1984). Total catches of octopus have fluctuated between 245,320 and 322,999 mt between 1986-95 (Figure 1), accounting for between 10.4 and 14.1% of world cephalopod landings in those years (FAO 1997). Most octopus landings in FAO statistics are not discernible to species, with the exception of *Octopus vulgaris* and *Eledone cirrhosa*. The majority of landings are of unspecified octopus and *Octopus vulgaris*, with *E. cirrhosa* contributing a relatively minor amount.

Various types of gear have been used to capture octopus, including pots, traps, trawls, snares, drift fishing, spearing, hooking and hand collection (Rathjen and Voss 1987; Rathjen 1991). **Pots** or **Traps** are open unbaited structures designed to collect octopus by exploiting their tendency to use such refuges between hunting activities or as brooding chambers. **Traps** can also include baited structures with a closing lid or trapdoor to retain the octopus after it enters to collect the bait. **Trawls** are funnel shaped nets held open by floats on the headrope and either a beam on the footrope or a pair of doors, which is pulled across the bottom behind a vessel. **Snares** are longlines suspended off the bottom with an array of bare hooks on gangions forming a curtain across the bottom. **Drift fishing** uses handlines and baited lures which are dragged across the bottom by a drifting boat or individual floats. When an octopus seizes the lure, the line tightens, the fisher retrieves the line, removes and kills the octopus, and resets the line. **Spearing** and **hooking** of octopus is done either from a small boat or wading in shallow water. Octopuses encountered in the open are speared, and hooks are used to remove octopus from dens. **Hand collection** is accomplished by driving an octopus from its den with a chemical irritant (bleach, vinegar, fresh water, etc.) and capturing it by hand. This is done by divers or in the intertidal zone.

Octopus are frequently taken incidentally in fisheries for other species, and in some fisheries are considered nuisance species. Examples include: *Eledone cirrhosa* in the Scottish fishery for lobsters (*Nephrops norevegicus* and *Homarus vulgaris*); *Octopus vulgaris* in the English Channel fishery for *H. vulgaris* and the Florida stone crab (*Menippe mercenaria*) fishery; *O. maorum* in a New Zealand fishery for rock lobsters (*Jasus edwardsii* and *J. verreauxi*); *O. tetricus* and *O. flindersi* in Australian fisheries for rock lobsters (*Panulirus longipes cygnus* and *Janus novaehollandiae*); *O. dofleini* in northeastern Pacific crab (*Cancer magister*, *Chionocetes bairdi* and *Paralithodes camtschatica*) fisheries; and *O. dofleini* and *O. rubescens* in northeastern Pacific spot prawn (*Pandalus platyceros*) fisheries (Winstanley *et al.* 1983; Paust 1988; Boyle 1997b; Roper 1997; A. Phillips, J. Boutillier, DFO, pers. comm.). In some cases, authorities have encouraged development of octopus fisheries to reduce the number of predators and supplement the income of fishers.

5.1. Japan

Most literature related to octopus and octopus fisheries in Japan dates back to the 1960's and 1970's (Kanamaru 1964, 1979; Kanamaru and Yamashita 1965, 1966, 1967, 1969; Yamashita 1974, 1976; Sakamoto 1975; Itami 1976). Two recent references are reviews of cephalopod fisheries (Osako and Murata 1983; Okutani 1990) that deal with octopus only briefly. Japanese octopus fisheries primarily target *O. vulgaris* in the south and *O. dofleini* in the north. Other species fished include *O. araneoides*, *O. conspadiceus*, *O. cyanea*, *O. membranaceus*, *O. minor* and *O. ocellatus* (Osako and Murata 1983; Okutani 1990).

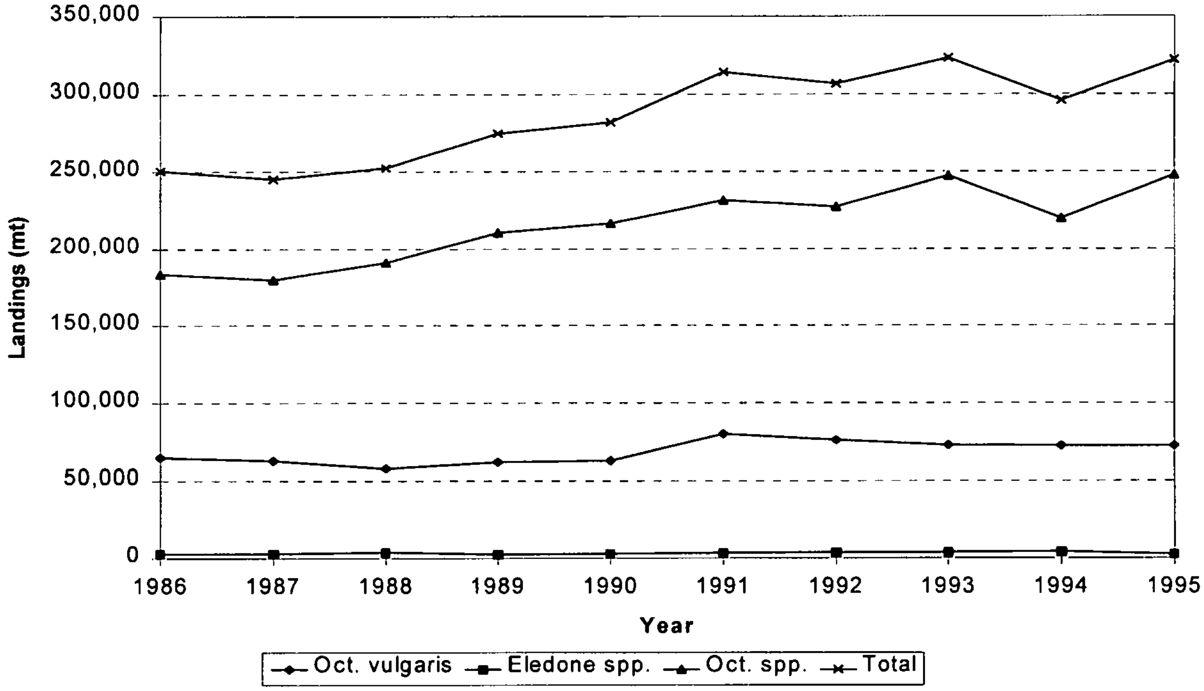

Figure 1. World landings (mt) of octopus 1986-95 (FAO 1997).

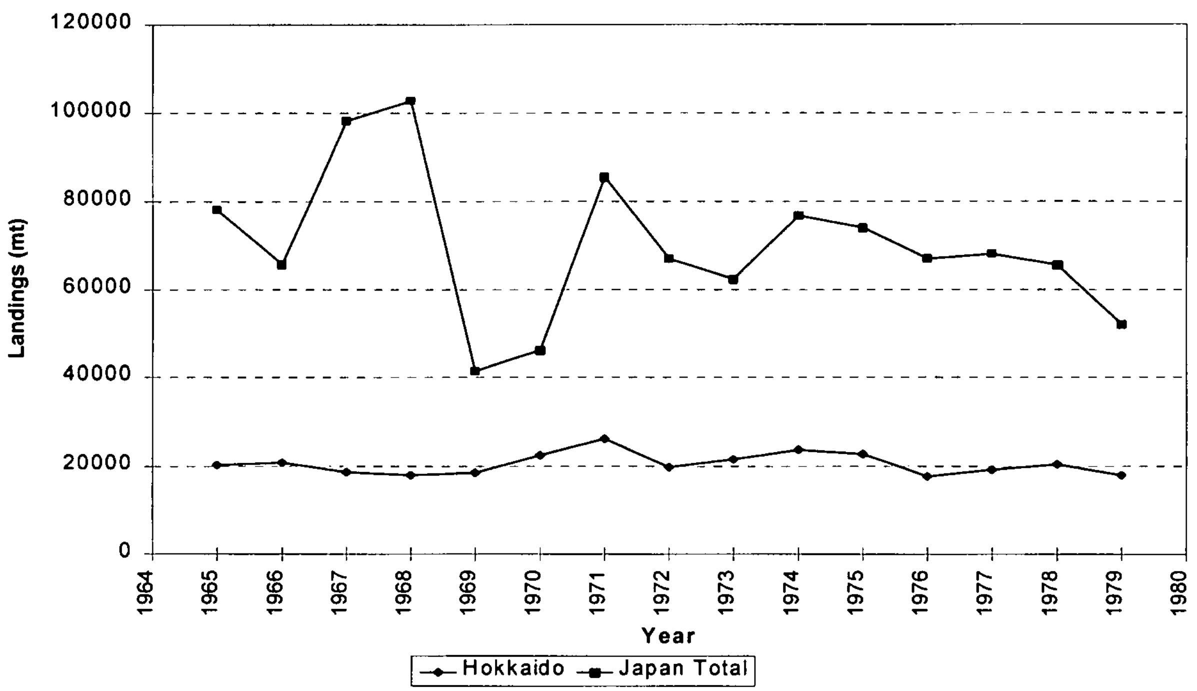

Figure 2. Annual landings (mt) of octopus from Hokkaido compared to total annual Japanese landings 1964-80 (Osako and Murata 1983).

The fishery for giant Pacific octopus occurs primarily off Hokkaido and off northern Honshu (Sakamoto 1976). Two other species, *O. conspadiceus* and *O. areneoides* are a minor component of landings from these areas. These latter two species live deeper than *O. dofleini*, are smaller, and thus are less valuable to fishers. Landings from Hokkaido accounted for 17-49% of total Japanese landings between 1964-79 (Figure 2), and averaged approximately 20,000 mt annually between 1955-79 (Osako and Murata 1983).

The Hokkaido fishery uses primarily wooden box traps, drift trolling and bare longlining. Wooden box traps are prevalent in Hokkaido because pots large enough to catch adult octopi are too heavy to be pulled by hand. The fishery primarily exploits subadult octopus between 1-15 kg (Mottet 1975).

References describing the overall state of octopus fisheries in Japan generally do not distinguish between *O. dofleini* and *O. vulgaris* fisheries. Some references describe localized overfishing, and indicate that domestic fisheries cannot fill market demand in Japan. Itami (1976) and Osako and Murata (1983) described placement of thousands of clay pots in an attempt to enhance habitat suitable for protection of small octopuses and to provide more brooding sites for mature females. We were unable to find published descriptions of assessment or management of octopus fisheries in Japan, or find recent publications that detailed catch by species.

5.2. Northwest Africa

The Saharan trawl fishery for cephalopods developed through the late 1950's and 1960's as Japanese and Spanish trawlers depleted stocks of sea bream (Family Sparidae) and switched to increased abundance of octopus (*O. vulgaris*), cuttlefishes (*Sepia officinalis officinalis*, *S. officinalis herredda*, *S. bertheloti*, *S. elegans* and *S. orbignyana*) and squid (*Loligo vulgaris* and *L. forbesi*) (Bravo de Laguna 1989). The fishery occurs on three main fishing grounds between 13 and 28°N, off the coasts of Morocco, Mauritania, Senegal, Gambia and Guinea Bissau, with the major production coming from FAO Area 34.1.3, between 19 and 26°N. It is a multinational fishery involving vessels from Japan, Spain, Morocco, Korea, Mauritania, and, to a lesser extent, Libya, Italy, Soviet Union, Greece, Panama and Taiwan. Octopus accounted for between 67,000 and 128,000 mt between 1966-84, while cuttlefishes accounted for between 24,000 and 55,000 mt during the same period (Bravo de Laguna, *op. cit.*). Between 1981-1995, cephalopod landings for FAO Statistical Area 34 (Central East Atlantic) averaged 193.6 mt, with octopuses accounting for between 57-70% of the total (Table 7).

The common octopus (*Octopus vulgaris* Cuvier, 1797) is distributed nearly worldwide in tropical and temperate waters of the Atlantic, Indian and western Pacific Oceans (Mangold 1983; Roper *et al.* 1984; Bravo de Laguna 1989). It is not known from the west coast of North America, and uncertain from the west coast of South America. It is a shallow water octopus, found from the coastline down to approximately 200 m, commonly in rocky or reef habitats, or in seagrass beds. The animals are generally found in deeper water in winter, and in shallow water in summer.

Size at maturity is relatively small (Table 2), and maximum size is approximately 10 kg, though commonly only 3 kg. Two spawning seasons are reported: May-June and September off western Africa and April-May and October in the Mediterranean and off Japan. Females lay and brood approximately 100,000-500,000 eggs in crevices or holes, arranged in strings. Spawning may extend for a month and the brooding period ranges from 25 to >100 days, depending on temperature. Females cease feeding while brooding, and most (if not all) die after the eggs hatch. The paralarvae are pelagic for 40-90 days, depending on temperature, and settle to the bottom at a size of 12 mm.

Table 7. Annual landings (mt) of cephalopods from the northwest coast of Africa (FAO Statistical Area 34) by species group, 1981-1995.

Year	Octopus	Cuttlefish	Squid	Unident.	Total
1981	121.4	36.2	34.7	-	192.4
1982	100.2	57.7	18.0	-	175.9
1983	137.0	54.4	15.6	4.6	211.6
1984	105.5	39.3	8.2	7.9	161.0
1985	98.9	46.7	7.7	14.8	168.1
1986	126.8	52.9	13.8	6.7	200.1
1987	109.3	44.6	13.8	7.3	175.0
1988	111.1	40.7	13.2	6.4	171.3
1989	120.8	47.2	15.3	6.3	189.7
1990	119.2	43.5	15.6	7.6	185.9
1991	158.3	52.7	21.2	5.1	237.4
1992	140.9	34.8	21.1	6.5	203.4
1993	156.3	36.5	29.7	-	222.5
1994	137.8	45.4	22.4	-	205.6
1995	134.8	43.0	27.0	-	204.8

Source: FAO (1992, 1997)

Although there is no biological evidence for stock discrimination, for fishery assessment purposes at least two stocks are delineated: a northern Dahkala stock and a southern Cape Blanc stock, with a fishing ground further south off Nouakchott possibly representing a third stock (Bravo de Laguna 1989; Guerra 1997). The Dahkala stock produces the highest catches, but is likely overexploited. The Cape Blanc stock is considered underexploited, and the Nouakchott stock is not assessed.

Size distribution of the catch is monitored through landing records, which split the catch into three species groups (octopus, cuttlefish and squid) and eight size categories each. A recruitment index for octopus was developed by monitoring catch rate of the smallest size class (<0.3 kg). Size composition of the catch is estimated from quality control information gathered during offloading of frozen product. This information is considered along with the results of annual trawl surveys which provide indices of biomass and abundance. Production models are used to develop yield estimates. Although there were problems in standardization of effort units, poor quality of effort data, underestimates of catch, all but one model indicated that octopus stocks were in an overexploited state.

Grant *et al.* (1981) developed a bioeconomic model of the fishery to aid in assessing management options. Their model indicated that a 2-month closure during the period of highest recruitment of octopus and cuttlefish could increase total harvest and harvest efficiency (CPUE), while a 40% reduction of total effort each month (limited entry) decreased total harvest, but increased harvest efficiency. However, neither management objectives nor the biological basis for these objectives were explicitly discussed (*i.e.*, imposition of limits on the fishery were ascribed to extension of territorial limits - stock status was not discussed).

5.3. Mexico

A mothership-based driftline fishery for *Octopus maya* has been carried out since 1949 off the Yucatan Peninsula on the Caribbean coast of Mexico (Solis-Ramirez 1997). Mothership vessels support canoes or flat-bottomed skiffs which fish octopus using baited lines attached to bamboo poles. The smaller (18-31 ft) artisanal fleet conducts day trips with 1-3 boats per mothership, and may land as much as 200 kg per trip. The larger (40-72 ft) mechanized fleet makes trips of 12 or more days with 5-7 skiffs per mothership, and may land up to 11 tons per trip. The fishery produced between 1,412 and 8,933 mt per year between 1970-86 (Table 8).

O. maya is a relatively large (60-250 mm ML) octopus which occupies a relatively small geographic distribution surrounding the Yucatan Peninsula, at depths to 50 m (van Heukelem 1983; Solis-Ramirez 1997). It is a large-egged species which lacks a planktonic paralarval stage. Fecundity is approximately 300-5,000 eggs per female. Spawning is seasonal, primarily in the winter months. Life span is approximately one year.

This fishery is an example of considerable production from a low-technology fleet using essentially artisanal methods. The fishery is managed through a specified season (Aug. 1-Dec. 15), a minimum size limit (110 mm ML), and gear restrictions (diving and hooking prohibited). These management actions were taken after analyses using Schaeffer productions models, bioeconomic models, and information on recruitment and growth derived from length frequency analyses (Solis-Ramirez 1997).

5.4. Alaska

Alaskan octopus landings averaged 63,400 lb. (29 mt) between 1986-95 (Table 9, Figure 3), and ranged between 2,000 lb. (<1 mt) in 1986 to 259,000 lb. (118 mt) in 1991 (Frenette *et al.* 1997). In northern Alaska, most octopus landings are bycatch in trawl fisheries and in trap fisheries for Pacific cod, *Gadus macrocephalus* (B. Bechtol, D. Jackson, Alaska Department of Fish and Game, pers. comm.). In Southeast Alaska, most octopus landings are bycatch in shrimp trap fisheries (D. Mecum, D. Woodby, Alaska Dept. Fish and Game, pers. comm.).

Table 8. Annual landings (mt) of *Octopus maya* from Campeche Bank and the Yucatan Peninsula, Mexico. n/a = not available.

Year	Campeche	Yucatan	Total
1970	1,108	304	1,412
1971	1,878	618	2,496
1972	2,621	967	3,588
1973	1,053	801	1,854
1974	1,355	1,853	3,208
1975	1,459	2,000	3,459
1976	2,569	1,580	4,149
1977	3,461	2,535	5,996
1978	1,584	681	2,265
1979	1,459	5,047	6,506
1980	1,862	5,507	7,369
1981	2,396	5,223	7,619
1982	2,600	4,939	7,539
1983	1,752	6,690	8,442
1984	1,506	3,804	5,310
1985	801	5,533	6,334
1986	1,525	7,408	8,933
1987	n/a	6,168	6,168
1988	n/a	5,610	5,610

Source: Solis-Ramirez (1997)

Since the 1960's, there have been efforts to develop a directed pot fishery for octopus in Alaska (Pennington 1979; Paust 1988, 1997). Trap types include wooden boxes, and modified crab and shrimp traps. An experimental fishery using tangle hook longlines in Alaska was discontinued due to considerable losses to dogfish (Paust 1997).

There is no direct assessment of octopus populations in Alaska, due to difficulties in developing estimates or indices of abundance. The directed octopus fishery is managed under special permits, on a case-by-case basis. Permits stipulate allowed areas, gear types and number of traps.

Alaskan authorities recommend that fishermen look for indicator species which are usually present in high abundance along with octopus (Paust 1997). The recommended species in Alaska are spot prawn (*Pandalus platyceros*), Dungeness (*Cancer magister*), tanner (*Chionocetes bairdi*) and king crabs (*Paralithodes camtschatica*). Hartwick *et al.* (1982) noted that high trapping efficiencies were correlated with incidental capture of red rock crabs (*Cancer productus*).

Table 9. Total octopus landings (mt) from western North America by state or province, 1950-1997.

Year	California	Oregon	Washington	British Columbia	Alaska
1950	25.7				
1951	13.3				
1952	8.5				
1953	7.8				
1954	14.0				
1955	12.0				
1956	7.4				
1957	14.1				
1958	7.1				
1959	1.2				
1960	0.7				
1961	1.4				
1962	6.0				
1963	33.9				
1964	17.6			28.5	
1965	9.2			29.4	
1966	8.0			19.1	
1967	4.2			43.6	
1968	8.0			30.6	
1969	2.1			45.3	
1970	1.8		7.6	27.5	
1971	0.8		17.9	39.6	
1972	4.8	1.3	11.8	30.4	
1973	10.6	5.0	22.7	32.7	
1974	14.8	0.0	27.5	34.5	
1975	10.6	3.3	18.1	26.8	
1976	37.1	6.6	8.0	20.9	
1977	15.6	1.8	6.8	24.5	
1978	17.7	7.3	25.9	22.0	
1979	47.8	11.0	42.1	30.5	
1980	58.9	6.4	33.6	50.1	
1981	38.4	6.4	17.7	28.8	
1982	39.4	8.5	15.7	18.1	
1983	15.3	7.6	16.3	37.1	
1984	7.0	5.9	16.2	25.1	
1985	16.7	3.5	13.1	34.1	
1986	6.1	4.3	25.8	53.2	0.9
1987	7.5	8.5	39.7	130.6	21.4
1988	12.5	21.3	60.9	209.8	33.6
1989	22.9	7.0	37.6	217.8	9.5
1990	16.0	7.7	40.9	197.2	41.8
1991	14.9	6.7	15.4	131.2	117.7
1992	21.1	9.2	27.6	117.4	20.9
1993	11.3	13.8	35.2	145.6	24.5
1994	3.4	4.3	13.7	89.0	2.3
1995	2.5	2.5	5.6	89.4	15.5
1996	4.5	7.3	9.3	139.1	n/a

Sources: Duffy (1997); Frenette *et al.* (1997); Robinson (1997); BC Catch Statistics database; J. McCrae, Oregon Dept. of Fish and Wildlife, pers. comm.; M. Stanley, Washington Dept. Fish and Wildlife, pers. comm.; M. Vojkovich, California Dept. Fish and Game, pers. comm.

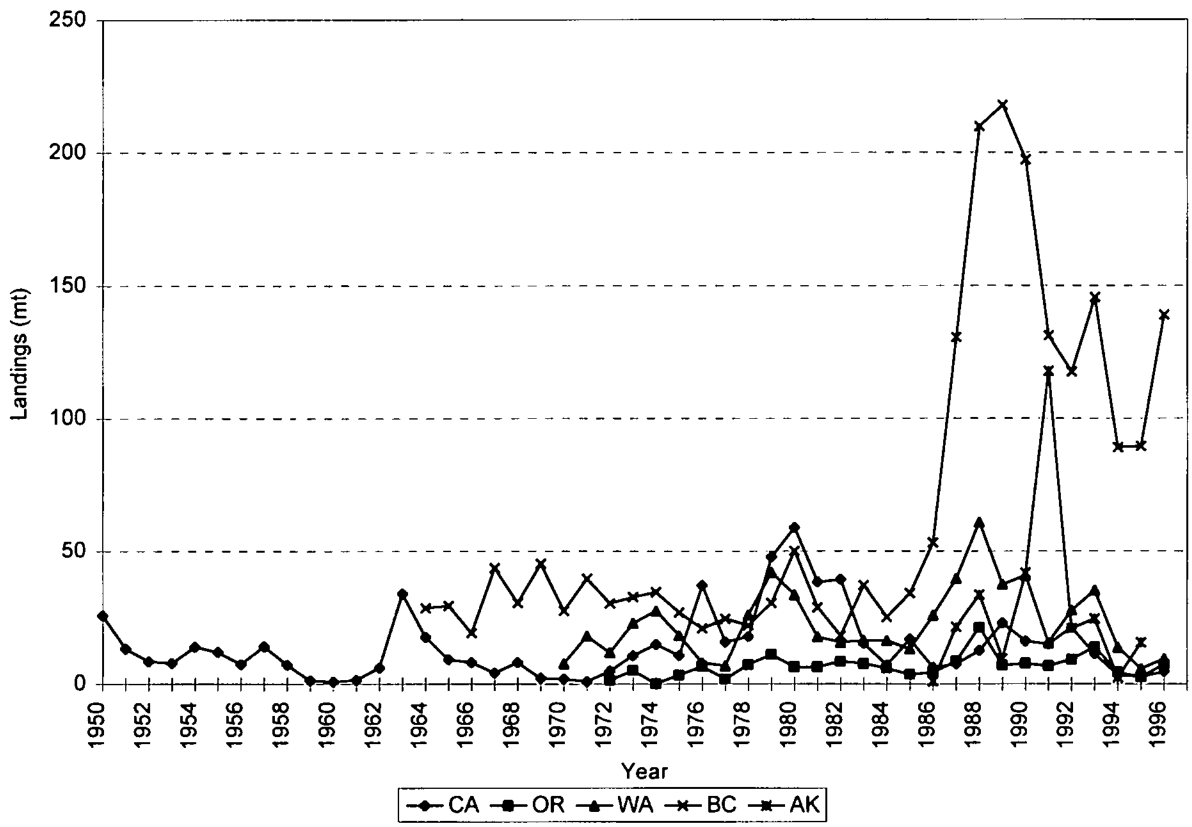

Figure 3. Annual landings (mt) of octopus from the west coast of North America, all gear types combined. See Table 9 for sources.

5.5. British Columbia

In British Columbia there are currently several commercial fisheries, in addition to recreational fishers and First Nations which harvest octopus. A directed dive fishery for octopus traditionally represents about half of the reported annual landings (Table 10), while bycatch from the trap, trawl, and hook and line (troll, longline, jig) fisheries account for the remaining. Currently there are no records available for recreational and First Nations harvest of octopus. Fishing licenses and management plans for octopus fisheries in British Columbia include only *Octopus dofleini* although *O. rubescens* is known to be present in trap catches.

Octopus weight is reported as drained weight, that is, the weight after water in the mantle cavity has been cut or inverted and drained. Recorded commercial catch records for octopus fisheries in British Columbia begin in 1964 (Table 9) and show a slow, steady increase in catch until 1990 when high market demand for bait in the halibut fishery led to landings of 209 mt. Demand for octopus bait was mainly supplied through the octopus dive fishery, which saw a substantial increase in annual catch between 1983 and 1990. With the introduction of individual vessel quotas in the halibut fishery in 1991, and access to more competitive bait sources, octopus landings decreased. Total octopus landings were 81.6 mt in 1995. Recent increased demand for octopus, which is being fueled in large part by markets in Portugal and Spain for food quality product, have resulted in increased effort and price in the dive and trap fisheries. Landings in 1996 were 153.5 mt.

Table 10. Annual landings (mt) of octopus in British Columbia by gear type, 1983-1996.

Year		Trap[1]					
	Dive[1]	Octopus[2]	Shrimp	Crab	Other	Trawl[3]	Other[4]
1983	12.32	2.34	0.80	0.00	0.00	10.20	1.43
1984	9.53	2.63	1.63	0.05	2.61	6.84	1.27
1985	16.94	0.94	2.50	0.36	0.00	4.53	3.00
1986	38.89	0.61	1.53	0.09	0.00	5.70	2.85
1987	76.48	0.12	5.66	0.13	0.22	21.09	1.55
1988	154.08	1.45	6.19	0.16	0.30	28.40	3.22
1989	152.64	0.00	7.90	0.00	1.37	22.49	5.28
1990	154.32	1.85	15.92	0.78	0.18	31.25	4.96
1991	33.52	2.36	19.40	1.41	0.00	28.71	5.41
1992	43.84	0.93	29.55	0.91	1.65	12.43	2.55
1993	67.44	2.52	37.32	0.79	0.47	34.58	2.71
1994	48.07	2.55	21.54	0.54	0.60	17.18	1.21
1995	46.80	0.00	18.31	0.63	0.00	13.17	2.66
1996	76.17	0.00	61.58	2.45	0.00	11.84[5]	1.32

Notes: 1 - from harvest logbook data.
2 - includes wooden, mesh and plastic trap categories
3 - includes groundfish and shrimp trawl landings from sales slip records
4 - includes longline, salmon troll, freezer troll, dipnet and handline landings from sales slip records.
5 - from onboard observer records for groundfish trawl and sales slip records from shrimp trawl.

There is currently limited management of commercial octopus fisheries in British Columbia. A commercial octopus 'Z-J' licence was first created in 1983 for both dive and trap fisheries. Later, in 1992, the Z-J licence was split into the Z-G (dive) and Z-P (trap) licenses, allowing for separate management of the fisheries.

5.5.1. Data Quality

Problems were encountered within the databases for each of these fisheries. Numerous keypunching and data entry errors were detected requiring extensive corrections. In addition, many of the entries which are still contained in the electronic database, and have been used in this report, are suspect. It is believed that some vessels have reported fictitious information, possibly to establish a landing history in anticipation of licence limitation. Many harvest logbook records were unusable due to incomplete or missing information (Table 11).

Biological data was calculated from the logbook databases which were edited to remove some of the extreme outliers which could not be accounted for or seemed implausible. An arbitrary decision was made to eliminate all trap entries which recorded over 455 kg/d of octopus bycatch. In addition all dive logbook entries which recorded in excess of 455 kg/diver-hr of effort were removed. This resulted in removal of 17 dive records (0.3%), 14 crab trap records (5.0%), and 5 shrimp trap records (<0.1%).

Table 11. Summary of total number of harvest logbook records available, outliers, and number of records usable for calculating CPUE and biological parameters.

Fishery	Available records	Outliers	Usable[1] records (CPUE)	Usable records (Biological)
Dive	7,748	17	5,962	5,325
Shrimp trap	17,903	5	0	591
Crab trap	280	14	0	14

Notes: 1 - refer to report Sections 5.5.2., 5.5.3. and 5.5.5. for discussion of data reliability and usable records for the dive, shrimp trap and crab trap fisheries data, respectively.

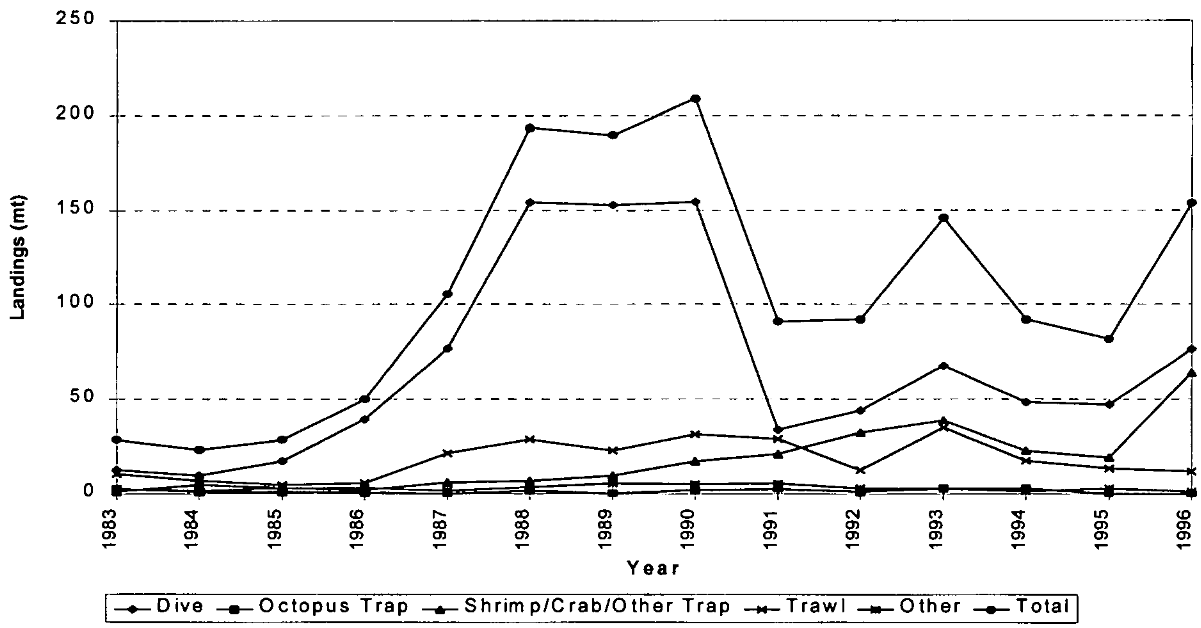

Figure 4. Annual landings (mt) of octopus in British Columbia by gear type. See Table 10 for sources.

Table 12. Annual landings (mt) by Statistical Area from British Columbia octopus dive fishery logbooks, 1983-96. Statistical Areas include offshore areas (Figure 5 and Figure 6).

	Statistical Area									
Year	1	2	3	4	5	6	7	8	9	10
1983			0.20							
1984		0.40	0.27		1.57	0.50				
1985		0.04			0.74					
1986	0.36	0.60			0.37					
1987				0.21	0.43	0.06				
1988	0.09				0.45					
1989	0.27	0.13	0.28		1.13	0.17				
1990	0.29	0.03			0.05	0.03				
1991		0.45	1.56	0.62	0.88	0.16	0.23			
1992	1.02		0.36	0.68	0.44	0.20				
1993			0.28	0.42	0.03	0.02				
1994			0.17	0.46	1.18	0.05				
1995			0.21	0.33	1.94	0.03				
1996			0.17	0.98	1.43		0.02			

	Statistical Area									
Year	11	12	13	14	15	16	17	18	19	20
1983		1.50	0.79					0.04	5.12	2.63
1984		0.14	2.00	0.03			0.22	0.14	2.57	1.65
1985		1.11	1.62	0.25		0.02	0.32	2.52	5.89	4.38
1986		3.02	3.08	0.72	0.26	0.87	4.50	4.59	10.39	8.12
1987		7.10	14.21	1.19	0.02	0.33	5.87	8.30	22.85	7.55
1988		39.41	18.53	2.55	0.74	1.21	11.0	11.05	45.3	7.34
1989	0.19	29.04	17.17	3.94	0.74	0.48	12.45	23.02	36.44	8.59
1990	3.07	40.57	10.40	3.22	0.82	3.49	10.05	17.93	30.23	8.77
1991	0.10	6.49	5.57	1.01	0.42	0.18	3.15	1.22	4.59	0.37
1992		4.94	6.50	0.49			5.36	1.52	12.73	7.90
1993		13.32	5.34	2.01			9.45	9.71	16.93	2.75
1994		9.69	1.88	1.19		0.44	8.77	6.88	9.59	1.40
1995		18.46	3.39	0.79	0.22	0.83	6.14	3.08	4.51	1.68
1996		16.10	3.79	1.03		1.62	9.19	15.67	10.96	3.00

	Statistical Area									
Year	21	22	23	24	25	26	27	28	29	n/a
1983				2.03						
1984			0.04							
1985			0.01	0.04						
1986			0.22	1.50		0.11	0.05		0.12	
1987			3.36	3.17			0.73		1.11	
1988			1.74	9.45			3.27		1.95	0.01
1989			2.85	9.99	4.47				1.29	
1990			7.09	15.24						0.18
1991			2.80	2.49	0.90				0.32	
1992							0.07		1.64	
1993			0.58	5.23					1.26	0.10
1994				4.29					2.08	
1995			0.15	3.08				0.31	1.65	
1996			0.28	8.02				0.90	3.01	

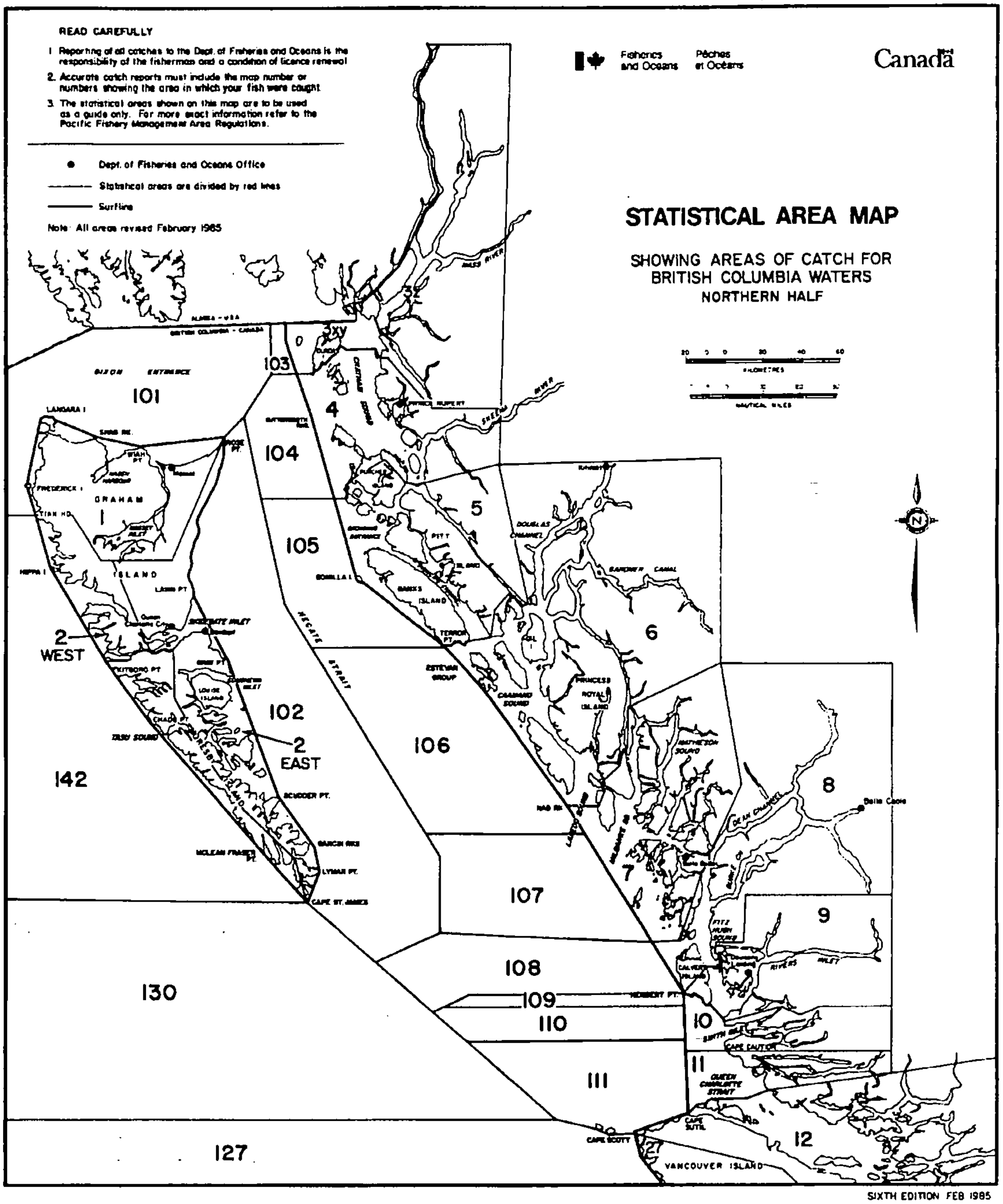

Figure 5. Statistical areas of the North Coast District of British Columbia.

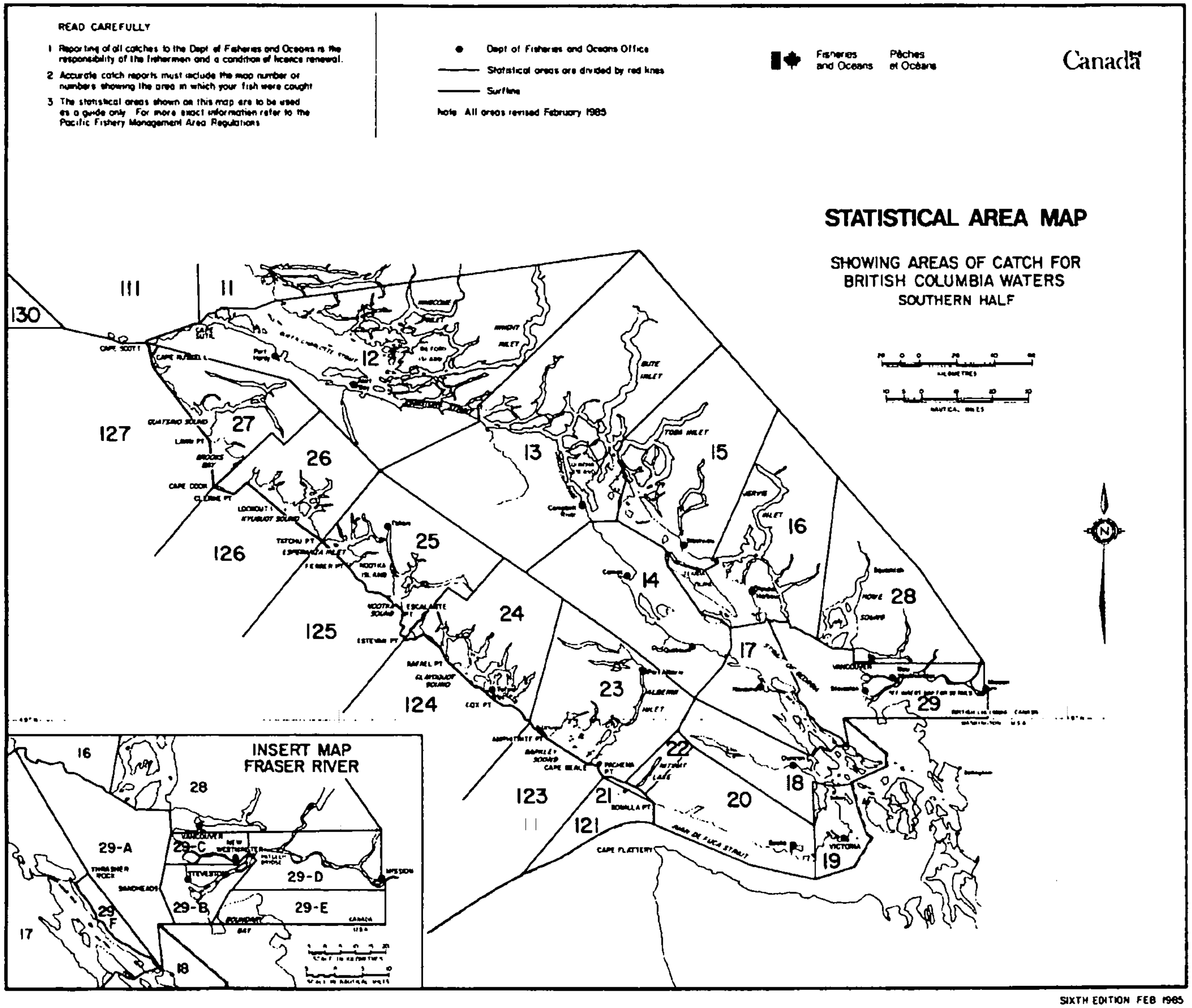

Figure 6. Statistical areas of the South Coast District of British Columbia.

5.5.2. Dive Fisheries

Harvest log information for the octopus dive fishery was first collected in 1983 with the introduction of the Z licence. Landings remained low up until 1987 when demand for octopus as halibut bait increased (Table 10). Between 1988-90, reported landings reached 154 mt, but declined in 1991, possibly as a result of the introduction of individual vessel quotas in the halibut fishery. Landings remained relatively low up until 1996 with landings decreasing to 46.8 mt in 1995. In 1996 landings increased again reaching 76.2 mt.

The octopus dive fishery has traditionally taken place in the South Coast of B.C., due in large part to the close proximity of processing and freezer facilities. Harvest locations remain highly consistent from year to year, with the majority of landings taken from Statistical Areas 12, 13, 17, 18, 19, and 24 (Table 12). Most effort in the dive fishery takes place during the fall and winter months, between September and March of the following year (Table 13). Fishers report that this coincides with octopus returning to diveable depths, 20 m (66 ft.) or shallower.

For the years 1992-96, the number of "Z-G" octopus by dive licences issued ranged from 57 to 73. Of those, the number that were actually fished ranged from 21 to 36.

The octopus dive fishery receives little management attention. The harvest of *O. dofleini* is currently licensed under a "Z-G" unlimited personal fishing licence which is designated to a vessel. With the exception of one seasonal reproductive period closure, and a few permanent closures for parks and First Nations access, the dive fishery is open coastwide year round. No minimum size limits, quotas, or minimum escapements are in effect for this fishery. No commercial biological sampling is conducted.

Table 13. Monthly effort (diver-hr) from British Columbia octopus dive fishery logbooks, 1983-96.

	Month											
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	13.0	0.0	4.2	10.7	39.8	0.0	1.8	8.3	10.6	72.0	21.7	17.1
1984	9.4	35.2	20.2	4.3	25.9	6.7	13.3	50.0	19.7	23.1	37.2	44.9
1985	42.4	86.4	8.4	7.0	0.5	25.0	21.3	25.4	28.0	39.2	39.3	69.0
1986	23.9	43.0	41.7	26.2	33.0	35.1	63.4	50.0	102.7	64.9	173.2	71.1
1987	123.7	45.8	65.0	81.5	103.9	68.1	72.6	86.2	131.5	131.0	156.7	166.4
1988	386.4	317.0	297.9	216.3	173.1	78.8	107.3	138.6	177.0	264.3	280.3	97.6
1989	140.8	180.9	187.5	127.2	93.6	84.8	76.3	147.3	237.4	288.6	200.0	232.0
1990	212.7	315.9	341.7	208.3	154.5	95.1	106.3	120.3	271.3	186.5	209.7	175.8
1991	41.3	31.5	27.9	12.8	37.0	49.9	14.3	22.3	137.0	76.7	91.5	93.8
1992	56.6	80.4	96.8	87.3	63.2	17.3	8.0	9.5	36.8	177.7	132.8	50.3
1993	79.9	103.7	138.4	54.4	32.9	53.8	58.2	84.2	150.3	209.2	96.1	83.3
1994	159.1	71.6	60.0	49.3	34.4	50.2	18.9	30.7	65.3	69.6	44.7	52.9
1995	40.8	28.8	37.3	65.6	17.7	48.3	11.0	43.1	133.4	185.1	98.8	57.1
1996	76.0	67.2	115.9	98.6	92.5	95.5	102.1	115.8	206.4	323.3	210.1	61.6
Total	1,406.0	1,407.4	1,442.9	1,049.5	902.0	708.6	674.8	931.7	1,707.4	2,111.2	1,792.1	1,272.9

Harvest information for catch and effort calculations was obtained from commercial harvest logs. Incomplete entries, accounting for 20% of the dive database, were not used in the calculations. Catch rates fluctuated considerably over the last 14 years (Figure 7). Catch per diver hour remained low during the initial years of the fishery but increased during the late 1980's and peaked in 1987 at 84 kg/hr (7.15 octopus/hr). In 1990 CPUE began to decline dropping in three consecutive years to a low of 51.8 kg/hr (4.4 octopus/hr). CPUE recovered to 90.9 kg/hr (10.5 octopus/hr) in 1994, but then again underwent consecutive drops in 1995-96. Preliminary catch rates for 1997 show a slight recovery in catch rate, rising to 62.1 kg/hr (6.9 octopus/hr) from 59.1 kg/hr (5.8 octopus/hr) in 1996.

Although fishing effort occurs primarily during fall and winter, monthly CPUE rates do not vary considerably by season (Figure 7). Monthly averages calculated over the last 14 years show only a small decrease during late spring and early summer.

Average annual maximum harvest depth per dive increased during the initial years of the fishery from 13.4 m (44 ft.) in 1983, to 18.6 m (61 ft.) in 1986 (Figure 8). Since 1986 maximum depth has remained relatively stable with the exception of years following peak harvest, 1988 and 1994. During these periods harvesters dove to an average maximum depth of 20.7 m (68 ft.) and 20.4 m (67 ft.) respectively.

Figure 7. Catch per unit effort (octopus/diver-hr) from British Columbia octopus dive fishery logbooks, 1983-96.

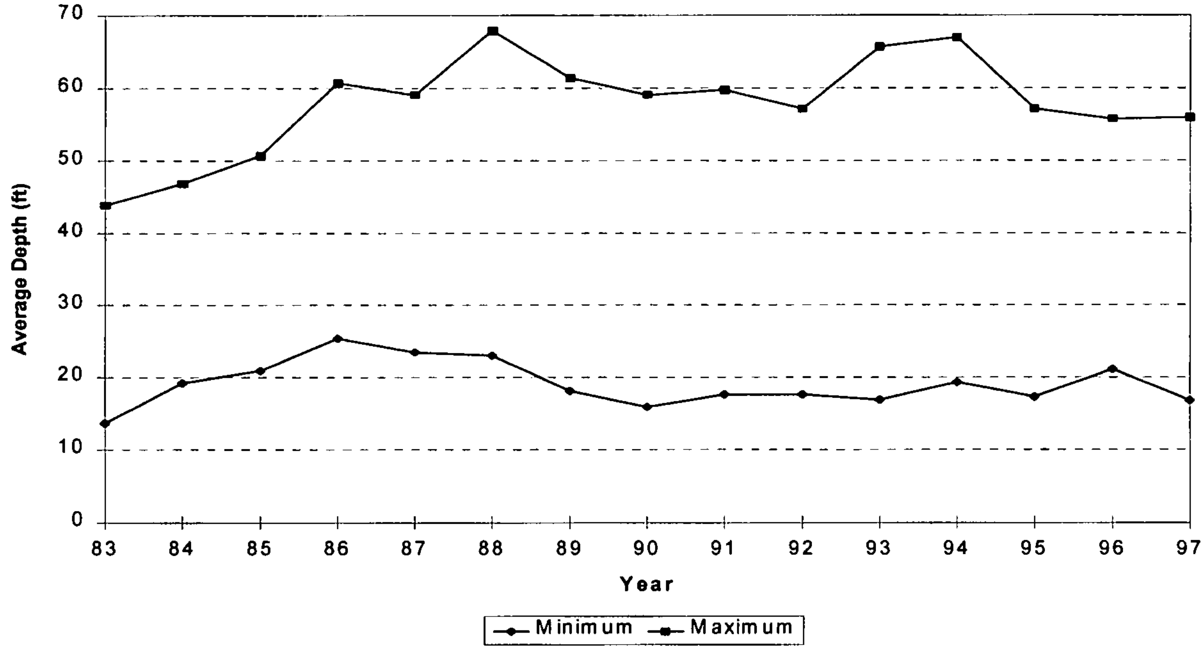

Figure 8. Annual average depths fished (ft) from British Columbia octopus dive fishery logbooks, 1983-96.

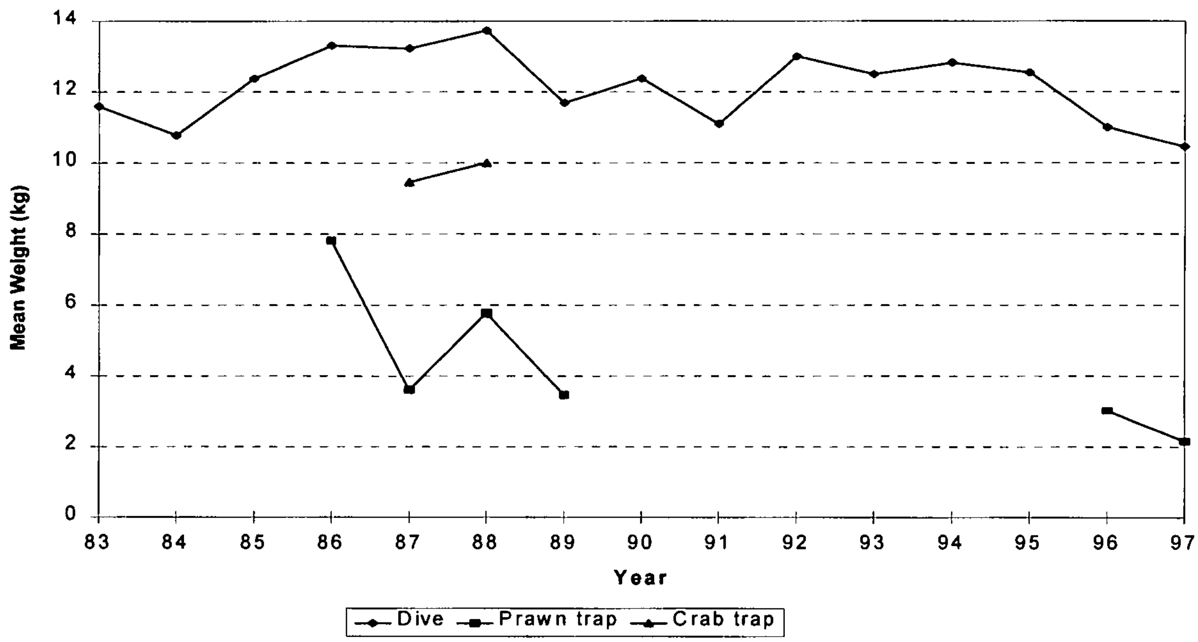

Figure 9. Average weight of octopus (kg) from British Columbia octopus fishery logbooks, 1983-96.

The average size of octopus taken in the dive fishery increased slightly during the early years of the fishery to 13 kg in 1988 (Figure 9). The average size of the octopus from the dive fishery declined slightly since 1988 to 10.9 kg in 1996. Preliminary data from 1997 shows a further decline to less than 10.5 kg. No information is available on sex ratio or maturity of octopus taken in the dive fishery.

5.5.3. Directed Pot or Trap Fisheries

There is virtually no trap or pot fishery directed specifically at octopus in British Columbia. For the years 1992-96, the number of "Z-P" octopus by trap licences issued ranged from 161 to 233. Of these, the number that reported landings ranged from 68 to 141. Examination of harvest log information produced only 8 fishers who landed octopus by trap who were not participants in either prawn and shrimp trap or crab trap fisheries. Because octopus landings are recorded on separate logbooks, and data coders sometimes did not know which trap type was used to produce the catch, gear coding records may be erroneous.

Three major experimental trap fisheries for octopus have been undertaken in British Columbia waters, one by DFO and two independent studies.

An experimental trap fishery was carried out in Barkley Sound, Vancouver Island, in February-March 1979 (Adkins *et al.* 1980). Wooden boxes, amphora pots, half-tire traps, paint and oil cans, Pardiac prawn traps and igloo crab traps were used. A total of 1,432 traps were hauled, and these produced 9 octopi, all less than 100 g total weight. The traps which produced octopi (wooden box, crab and prawn traps and half-tires) were set between 7-66 m depth, and all were baited with either frozen herring or perforated tins of pet food.

An experimental trap fishery was carried out from September 1981 to June 1982 in Clayoquot Sound on the west coast of Vancouver Island (Hartwick *et al.* 1982). Traplines were set inshore (mean depths 6.87-19.23 m) and offshore (37, 55, 73 and 91 m). In general, large traps (wooden boxes and whole tire traps) were most productive, and optimal soak time was 10-12 days.

Monthly trapping efficiency (octopus/trap haul x 100) on the inshore traplines ranged from 0.26-2.06%, with an overall efficiency of 0.77%. Highest efficiency was using whole tire traps, followed by large wooden box, large double tube and small wooden box traps. Trap efficiency decreased from November (1.83%) to February (0.26%) and then increased gradually to June (2.06%). If recaptures are excluded from the data, trapping efficiency declines from 1.30% in November to 0.30% in March, then increases to 1.27% in June. Overall trapping efficiency for new captures was 0.50%.

Monthly trapping efficiency of large traps on the offshore traplines ranged from 4.63-8.44%, with an overall efficiency of 6.56%. Small traps had extremely low efficiencies offshore (0.43% overall). Monthly trapping efficiency did not show a clear trend over time, other than a decrease from March to May. Trapping efficiency based on new captures only ranged from 5.94% in January to 1.54% in May (4.02% overall), and showed a decreasing trend with time.

Mean size of octopus captured offshore was higher than inshore (11.3 vs. 6.02 kg), total yield was considerably higher offshore (899.55 kg vs. 481.41 kg), and effort was higher inshore than offshore (15,922 trap hauls vs. 1,966 trap hauls). Overall CPUE was 0.458 kg/trap haul offshore and 0.030 kg/trap haul inshore.

Sex ratio was 1.03:1 (males:females) offshore, with females outnumbering males in January, February and May. Sex ratio was 1.5:1 inshore, with females outnumbering males in February and March.

An experimental trap fishery was conducted near Prince Rupert and Tofino in 1992 (Clayton *et al.* 1992). Three trap types were tested: wooden box traps and ceramic eel traps were fished on gravely bottom near Prince Rupert; and baited mesh prawn traps were fished on rocky reefs near Tofino. Overall trapping efficiency was 1.88% for the ceramic eel trap, 17.33% for the wooden trap and 23.62% for the "best 18 consecutive sets" of prawn traps. Bycatch of prawns was not reported. Mean size of octopus captured was 10 lb. (4.5 kg) in prawn traps and 25 lb. (11.4 kg) in wooden box traps. Because the traps were tested at different times and in different areas, variance in catch rates may have been due to variance in abundance of octopi, rather than trap design.

5.5.4. Shrimp Trap Fisheries Bycatch

The landing of octopus bycatch in trap fisheries is licensed under an unlimited octopus trap (Z-P) licence and is restricted to the area and time openings of the prawn fishery. No in-season management or biological sampling of octopus is conducted.

Effort in the prawn fishery, measured in the number of trap hauls, appears to have nearly tripled since 1983 reaching 4.4 million trap hauls in 1996. Estimates of industry effort derived from other than logbook information suggest that the true number of trap hauls in 1996 may have approached 7 million. Reported logbook landings of octopus bycatch since 1983 has shown a steady increase from <1 mt in 1983 to over 61 mt in 1996. Increased landings in recent years may be a result of increased reporting rather than increased catches, in expectation of licence limitation criteria based on reported landings. Additionally, prawn trap has been the default coding for octopus trap logbook entries which could not be definitively assigned to a specific trap type. Given these complexities, there is no reasonable means to assess or estimate the true extent of octopus bycatch in the shrimp by trap fishery. Accordingly, the numbers presented in Table 14 provide at best only a relative indication of the extent and distribution of the octopus bycatch trap fishery.

Table 14. Annual landings (mt) by Statistical Area of octopus from British Columbia shellfish trap fisheries logbooks, 1983-96. Statistical Areas include offshore areas (Figure 5 and Figure 6).

	Statistical Area									
Year	1	2	3	4	5	6	7	8	9	10
1983				1.36	0.06	0.65				
1984		1.00		0.05		0.14	0.18	0.55	0.02	
1985		0.37		0.01		1.47	0.04	1.02	0.01	
1986						0.55	0.32	0.38		0.47
1987		0.31	0.27	0.10	0.10	0.64	1.13	1.39	0.27	0.20
1988	0.10		0.07		0.61	1.22	0.99	2.63	0.15	
1989	0.16	0.43	0.23	0.26	0.06	0.64	0.88	0.26	0.31	0.09
1990	0.11	0.56	0.67	0.07	0.10	0.38	1.69	0.01	0.48	0.28
1991		0.07	0.83	0.01	1.00	1.04	1.71	0.17	0.89	3.41
1992		0.32	1.52	0.03	0.58	3.41	4.52	1.07	0.29	0.82
1993			0.08		0.80	6.83	9.21	1.20	1.08	1.10
1994			0.33	0.01	1.36	4.08	4.18	2.01	1.15	0.94
1995		0.64	1.09	0.93	3.93	1.92	1.93	0.43	0.60	0.16
1996		0.39	3.28	2.36	10.96	9.70	6.17	4.28	3.04	0.50

	Statistical Area									
Year	11	12	13	14	15	16	17	18	19	20
1983		0.17				0.77	0.01			
1984	0.11	0.62	0.20							
1985		0.47			0.04				0.22	0.15
1986		0.34						0.06		0.09
1987		0.48	0.11			0.27		0.10		0.35
1988		1.14	0.45	0.16	0.29	0.03		0.05		
1989	0.36	2.53	0.95	0.01	0.13	0.13		0.02		
1990	0.48	5.02	1.54	0.36	0.35	0.39	0.66	0.12	0.45	0.33
1991	0.28	3.65	1.41	0.19	1.60	0.95	0.84	1.09		1.78
1992	1.56	5.43	1.36	0.48	1.52	0.72	0.59	0.26		0.36
1993	0.37	2.49	1.31	1.58	1.01	2.11	0.89	0.87		
1994	1.75	1.97	0.85	0.62	0.93	1.22	0.48	0.80		0.07
1995	0.46	1.41	0.53	0.22	0.21	0.16	0.21			
1996	4.06	14.58	1.23	0.24	0.65	0.18	0.25	0.92		

	Statistical Area									
Year	21	22	23	24	25	26	27	28	29	n/a
1983							0.04		0.08	
1984			2.41							
1985										
1986			0.01							
1987								0.39	0.02	0.01
1988					0.07					0.13
1989					0.12	0.58				1.13
1990	0.15			0.02	0.41	1.07	1.15	0.24	0.03	0.06
1991				0.52	0.92	1.11	0.86		0.05	
1992	0.54	0.02		0.57	0.24	2.07	2.53		0.24	0.58
1993		0.26		0.33	1.16	2.75	4.00	0.03	0.21	
1994	0.45	0.31		1.72	0.14	0.48	1.16	0.03	0.10	
1995	0.39	0.20		0.33	0.13	0.64	0.31	0.03	0.01	
1996	0.04	0.30		0.05	0.77	0.90	0.91	0.26	0.11	0.32

Catch per unit effort could not be accurately calculated from logbook data as it appears that only successful fishing effort is reported. Strings of traps which did not contain octopus often appear not to have been recorded on the logs. The information that is contained in the octopus trap logbook database was generally incomplete, with only about 3% of database entries containing complete information. Average weights for octopus landed could only be calculated for 7 of the last 15 years. It is also known that *O. rubescens* is caught in the trap fisheries. This is not separately identified on the logbooks so it is not clear to what extent this species contributes to the current catch records.

The annual average weight per animal was calculated from only a few logbook entries, but has shown a decline since 1983. The average weight of octopus in 1996 was 3.0 kg, with preliminary 1997 data showing an average weight of 2.1 kg (Figure 9).

5.5.5. Crab Trap Fisheries Bycatch

Reported landings from the crab trap fishery are generally small in comparison to total landings. Logbook landings ranged between several hundred to several thousand pounds annually (Table 10). An exception was noted in 1990 when the reported crab trap landings reached more than 26 mt. All of these landings with the exception of <1 mt, were from one vessel whose harvest information is highly suspect. Area catches from trap fisheries including crab are shown in Table 14.

An Octopus Trap licence "Z-P", currently unlimited, is required for retention of octopus in the crab trap fishery, and is permitted only during time and area openings for the prawn trap fishery. No in-season management or sampling is conducted.

The majority of harvest logs for octopus in the crab trap fishery are incomplete and appear to represent only successful fishing effort. Only 5% of the entries in the crab trap logbook database contained complete information. Accurate catch per unit effort information could not be calculated with the information available. Average weights for the landed octopus could only be calculated for 1987 and 1988 using the small proportion of the logbook entries which contained complete information. The average weight per animal in 1987 was 9.5 kg and 10 kg in 1988.

5.5.6. Trawl Fisheries Bycatch

Octopus bycatch is currently permitted in the groundfish and shrimp trawl fisheries. The most accurate catch information available was taken from the catch statistics sales slip database. The shrimp trawl fishery reports only minor bycatch of octopus, typically <1 mt annually. Octopus landings in the groundfish trawl fishery have been highly variable fluctuating between 4.4 and 34.5 mt annually (Table 15).

The majority of trawl landings for octopus have been reported from the North Coast region. Area landings from the trawl and troll fisheries is reported in Table 15.

Table 15. Annual landings (mt) by Statistical Area of octopus from trawl, longline and hook-and-line fisheries sales slips, 1983-96. Statistical Areas include offshore areas (Figure 5 and Figure 6).

	Statistical Area									
Year	1	2	3	4	5	6	7	8	9	10
1983	0.21	1.87	0.17	1.93	3.56	0.09	0.01	0.48		
1984	0.42	1.46	0.05	1.77	2.47	0.16		0.11		0.04
1985	0.40	0.73	0.54	1.19	1.39	0.07		0.30	0.05	
1986	0.11	0.84		1.33	1.05	0.19	0.02	0.47		
1987	0.08	2.50		3.67	11.9	0.49		0.93		
1988	0.21	5.68	0.46	4.39	11.86	1.16	0.02	1.06		0.01
1989	0.02	4.15		4.41	10.95	0.59	0.70	1.22	0.25	0.16
1990	0.60	7.72	0.30	5.71	15.31	0.65		0.63	0.07	0.04
1991	2.69	3.46	0.40	7.21	13.02	1.28	0.56	0.27		0.06
1992	1.83	1.15	0.18	3.61	4.41	0.64	0.30	0.49	0.09	
1993	2.05	5.13	0.44	6.13	14.26	0.98		0.72	0.03	
1994	1.67	3.27	0.07	3.80	5.22	0.81	0.01	0.45		
1995	0.37	2.01		4.09	3.45	0.23	0.04	0.37		
1996	0.03	0.21	0.02	0.53	0.12					

	Statistical Area									
Year	11	12	13	14	15	16	17	18	19	20
1983	0.15	1.22	0.16	0.08	0.02		0.05	0.55	0.75	0.29
1984	0.32	0.03	0.15	0.09			0.05	0.38	0.23	0.05
1985	0.47	0.06	0.01	0.12		0.02	0.50	0.18	0.34	0.07
1986	0.60	0.01					0.06	0.38	1.20	0.25
1987	0.59	0.03		0.14		0.01	0.11	0.56	0.67	0.23
1988	1.08	0.18		0.03	0.02	0.03	0.63	0.96	1.78	0.27
1989	0.62	1.50		0.02	0.03	0.01	0.09	0.32	0.25	0.05
1990	0.59	0.40	0.26	0.12	0.01	0.02	0.11	0.09	0.71	0.11
1991	1.24	1.18	0.93		0.03	0.11			0.02	
1992	0.22	0.09	0.22				0.23		0.48	0.04
1993	3.05						0.18	0.48	0.18	0.03
1994	0.52		1.08	0.01			0.05	0.21		0.03
1995	1.40	0.10					0.03	0.04		0.06
1996	1.07	0.02								

	Statistical Area									
Year	21	22	23	24	25	26	27	28	29	n/a
1983	0.11		0.25	0.43			0.22		0.02	
1984	0.07		0.16	0.03		0.01	0.02		0.04	
1985	0.15		0.57	0.20	0.01	0.08	0.07	0.02	0.01	
1986	0.54		0.28	0.45	0.13	0.06	0.53	0.06	0.01	
1987	0.11		0.09	0.22	0.01	0.19	0.09		0.02	
1988	0.08		0.83	0.36	0.02	0.05	0.43			
1989			0.56	0.06	0.03		0.06			1.46
1990	0.34		0.50	0.74	0.27		0.16		0.08	
1991			1.85	0.08		0.02	0.44			
1992			0.84	0.31			0.05		0.04	
1993	0.06		1.22	0.91	0.20		0.19			
1994	0.07		1.63	0.28	0.08		0.21			
1995	0.01	0.02	0.80	1.00	0.20	0.03	1.55		0.02	
1996			0.01						0.05	11.21

Retention of octopus in the shrimp and groundfish trawl fisheries is currently permitted under the Fisheries Act. No in-season management or biological sampling is conducted.

5.5.7. Other Fisheries

Minor octopus landings have been recorded annually from the troll, dipnet, handline, longline, and octopus trap fisheries (Table 15). It is suspected that most of the octopus trap landings in the shellfish database (gear types 90, 93, 94, and 95) are errors in coding. Vessels reporting these landings are licensed either in the crab trap or prawn trap fisheries. Hook and line landings continue to be reported although capturing octopus with hooks, spears or other sharp implements is not allowed by regulation.

There is no quantitative information available on recreational or First Nations harvests. Sport fishers are limited to one octopus per day. Several First Nations communities harvest octopus for food, social, and ceremonial purposes. There are presently two commercial fishery closures to provide for recreational and First Nations priority access.

Octopus are also collected by universities and colleges, public and private display aquaria and by biological supply firms under the authority of scientific licenses issued by DFO for scientific, experimental, education or public display purposes. Collecting reports for 1997 indicate that 41 *O. dofleini* and 4 *O. rubescens* were taken by 4 scientific licence holders. In addition, another 31 *O. dofleini* were acquired from commercial harvesters during the commercial dive fishery, for public display purposes.

5.6. Washington

Octopus landings from Washington State averaged 49,932 lb. (22.7 mt) between 1970-1996, and ranged between 12,374 lb. (5.6 mt) in 1995 and 133,919 lb. (60.9 mt) in 1988 (Bob Sizemore, Washington Dept. of Fish and Wildlife, pers. comm.). No data is available on recreational catches. Most of the octopus catch in Washington State is incidental to trawl or shellfish trap fisheries (Mel Stanley, Washington Department of Fish and Wildlife, pers. comm.). There is also a small directed pot fishery by one or two fishers per year. Pot fishing permits limit fishers to 200 pots. While Washington tribal groups have expressed some interest, there have not been any tribal fisheries for octopus to date. Landings are not separated by species, but possibly involve both *O. dofleini* and *O. rubescens*. Octopus resources are not actively assessed or managed in Washington State.

5.7. Oregon

Oregon does not currently have a directed fishery for octopus (Robinson 1997; J. McCrae, Oregon Dept. of Fish and Wildlife, pers. comm). Landings in Oregon are bycatch in trawl, crab trap and hook-and-line fisheries. Landings averaged 19,440 lb. (9 mt) between 1987-96, and ranged from 5,469 lb. (2.5 mt) in 1995 to 46,903 lb. (21.3 mt) in 1988. Landings are not separated by species, but possibly involve both *O. dofleini* and *O. rubescens*. Octopus is allowed as a legal bycatch with any other approved fishing gear. The use of noxious substances for harvest is not allowed. Recent interest in development of a directed pot fishery for octopus has been referred to the ODFW's Developmental Fisheries Program. Octopus resources are not actively assessed or managed in Oregon.

5.8. California

California landings of octopus are primarily incidental catches in trawl fisheries for other species. Landings averaged 31,002 lb. (14.1 mt) between 1950-1996, and ranged from 1,610 lb. (0.7 mt) in 1960 to 129,597 lb. (58.9 mt) in 1980. Landings are not separated by species, but may include *O. bimaculatus*, *O. californicus*, *O. rubescens* and *O. dofleini* (Ambrose 1997; Duffy 1997; Hochberg 1997a,b). Recreational landings are unknown. Octopus resources are not actively assessed or managed in California (M. Vojkovich, California Dept. of Fish and Game, pers. comm.).

6. Discussion

Managers' concerns that current assessment and management frameworks would be inadequate to monitor and control large-scale, high-demand fisheries for octopus are justified. There are problems with corporate databases that preclude meaningful analyses of catch and effort for most fisheries currently underway. Information currently gathered from fishery logbooks, sales slips or on-board observer programs are inadequate for direct assessment of octopus populations. The literature does not provide much guidance in the form of detailed and timely descriptions of proven assessment and/or management strategies for octopods.

6.1. Assessment and Management of Octopus Fisheries

There is little guidance from the literature for development of assessment programs for octopus. Octopus are not actively assessed anywhere on the west coast of North America, and no literature was found to describe the assessment of octopus populations in Japan. Assessment of the Saharan trawl fishery for *Octopus vulgaris* is through monitoring of catch rates and size distribution of catch which is largely dependent on quality control checks by industry during offloading.

Assessment of octopuses in British Columbia would be a complex and costly task. Combined SCUBA/trap surveys are required to assess octopi throughout their bathymetric distribution, and each gear type presents different sampling biases. Assessment of population indices from fisheries data is hampered by the quality of the data submitted; inconsistencies in how it is coded, stored and accessed; uncertainty surrounding the biases relevant to each gear type; lack of biological sampling of commercial catches; and the fact that the fishery has been driven largely by market demand, not abundance or availability of octopi.

Elsewhere on the Pacific coast the management of directed octopus fisheries are primarily through monitoring of catches and effort and limiting opportunity through short-term (AK) or annual permits (WA, OR, CA). Some tropical fisheries, like the fishery for *Octopus maya* in the Yucatan, are managed with minimum size limits, restricted seasons and controlled gear types (Solis-Ramirez 1997). However, these measures were taken only after it was apparent that the resource was overexploited.

Mottet (1975) discussed management options for a directed octopus fishery. These options and additional measures identified by the authors in preparation of this report include:

1. Size Restrictions. Size limits are effective in trap or pot fisheries because animals that cannot be retained can be released unharmed. It is less likely that animals captured by trawl can be successfully released. Traps can be designed to accommodate a size limit, as the volume of the trap to a certain extent determines the size of the animal captured. Mottet recommended size restrictions which allow removal of the size classes normally lost to mortality through competition for some limiting resource. For example, if a certain size class suffers high mortality through cannibalism or predation during competition for limited den sites, then removal of some of the animals which would have been lost will increase production, presumably at no net loss to the population. However, if this logic is taken to its extreme, one might advocate fishing newly settled recruits. This situation is untenable for a dive fishery that selects large subadult or adult octopus.

2. Species Management by Size Selection. In the shrimp trap fishery, octopus which are less than 1 kg may be *O. rubescens*, a species for which there is even less biological information available than *O. dofleini*. Accordingly, differential protection can be provided by establishing a minimum 1 kg size limit. The extent to which this species may have contributed to the commercial fishery landing history is unclear, and we do not know if preferential protection of *O. rubescens* is necessary. However, the shrimp trap fishery has reported increased landings in recent years (Table 10), and some portion of these landings are *O. rubescens*.

3. Sex Restrictions. Sex restrictions are effective because the sex of captured octopus can be accurately determined externally by examination of the third right arm for a hectoctylus. However, the benefits of conserving one or the other sex of octopus are unclear. A significant benefit could be gained if female octopus which had mated (before exhibiting signs of maturity) were protected from removal from the population. The question is then, at what size do female octopus generally mate? Since males can mate with more than one female per season, then the target sex ratio for the population might be several females to each male. If male octopus can only mate with 4-5 females in their lives, how many males can be removed before reproductive output of the population is affected? The first step in

finding answers to these questions would be determining the sex ratio of local populations in the absence of exploitation.

4. <u>Seasonal Closures</u>. Where there is sufficient biological knowledge of potentially affected stocks, seasonal closures can be used to protect critical life stages. For example, *O. dofleini* spawning and brooding can occur throughout the year but is concentrated in the winter months. Therefore a winter closure appears attractive as a management measure. However, for this species this may not be necessary as the brooding females do not forage and are effectively protected from trap or bycatch fisheries by their behaviour. In this case, a winter seasonal closure may only serve to reduce fishing opportunity on the residual male octopus which are no longer required to sustain the population. Related to discussions under sex restrictions, an appropriate seasonal closure might be determined by increased presence of mated females, which could be protected long enough to allow them to spawn.

5. <u>Area Closures - Refugia</u>. In the absence of biological information, large area closures can be an effective management tool if applied with due consideration for the behavioral and life stage characteristics of the species. Refugia should be significant stock production areas rather than marginal habitats. They must be large enough to effectively accommodate migratory movements. Where different life stages utilize differing habitats, consideration must be given to life stage vulnerability outside of the protected areas. If there is a significant stakeholder interest in the stock, or marine protected area initiatives in progress, provision of the protected areas is best coordinated with the other stakeholders in an attempt to accommodate multiple goals. Large scale area closures can be used to protect octopus populations until assessments indicate that the fishery can safely expand, a management strategy used in the B.C. sea cucumber fishery (Boutillier *et al.* 1996).

6. <u>Migrations and Management Actions</u>. Do the octopus protected by area closures remain in the area in which they are protected? Japanese literature suggests that migrations are primarily vertical bathymetric migrations, although tag recoveries do not definitively prove that octopus remain in the same general geographic area throughout their life (Kanamaru and Yamashita 1966,1967,1969). Some tagged octopus that left study areas off the west coast of Vancouver Island returned after more than a month's absence (Hartwick, Ambrose and Robinson 1984a,b). No tagged animals were recovered from deeper water surrounding the study area, so the destination of animals that left the inshore study area is unknown. Although considerable larval dispersal might be assumed for an animal whose larvae are planktonic for a period of months, the benefits of breeding refugia to the coastwide population remain unknown.

7. <u>Enhancement</u>. Enhancement requires knowledge of which resource is limiting survival, and which size of animal needs more of that resource. In Japan, ceramic pots are distributed to enhance octopus habitat by providing refuges and brooding dens (Itami 1976; Osako and Murata 1983). Rearing of animals through a critical stage may be possible, but not economically attractive. We consider enhancement of octopus populations to supply a new fishery inadvisable because we cannot predict collateral effects on established fisheries for crustaceans (crabs and prawns in particular) in adjacent areas.

6.2. Issues in Existing Fisheries

6.2.1. Data Quality and Accessibility

Presently one of the most pressing issues for the management of the octopus fisheries is the need to obtain reliable catch and effort data. Logbook information from the crab and shrimp trap fisheries are plagued with incomplete entries which do not reflect true effort in the fisheries. In addition, catch information collected from some fisheries, such as groundfish (trawl) and rockfish (hook and line) is no longer included in the DFO corporate fish slip collection program, creating the need to track and analyze several databases. There is also concern that landings in the shrimp trawl fishery may not be effectively captured due to octopus logbooks not being a requirement for bycatch retention in these fisheries.

6.2.2. Dive Fishery

Overall, the dive fishery presents the fewest problems. Harvest logbook data is relatively complete, and of generally good quality. The fishery accesses only a portion of the available stock due to depth constraints on divers, and effort varies seasonally, with lower effort levels May-August and in December.

Our concerns regarding potentially increased effort and catch from the dive fishery could be addressed through several actions. First, licence issue could be limited. Limiting the number of licenses would at least provide a theoretical cap to potential effort. However, the licence is designated to a vessel, not an individual, and no limit is currently imposed regarding the number of divers who can fish from a single vessel. This loophole restricts the effectiveness in capping absolute effort.

We also have noted that a large proportion of landings came from relatively few Statistical Areas. While there is concern that effort concentration might lead to localized overharvest, the fact that these areas have sustained these landings for several years, and fishers have not had to explore new areas to maintain catch levels, are indications that the level of harvest from these areas is not excessive. Should catches, effort or CPUE develop decreasing trends in high-effort areas and effort increase in previously unfished areas, other information will be required to assess stock condition.

Future assessments should endeavor to analyze catch and effort data at a finer resolution to determine trends within Statistical Areas. This may be accomplished through examination of charts (currently provided as a condition of licence), or through changes to harvest logbooks that require latitude and longitude information for each fishing operation.

Divers routinely use household bleach solutions to drive octopi from their refuges to be captured in open water. The bleach is an irritant that elicits a strong escape response. The success of the dive fishery at present may largely depend on the use of chemical irritants. Bleach is easy to obtain, cheap and effective. It's specific gravity is greater than seawater which aids its delivery into a den. The use of bleach in the marine environment may have detrimental effects on other marine life living in and around the den site. Noxious substances are illegal in California, Oregon and Washington State octopus fisheries. Household bleach is a deleterious substance as defined in the Fisheries Act Section 34.(1). The deposit of deleterious substances in fish bearing waters is prohibited in Fisheries Act Section 36.(3). Under the Fisheries Act, the definition of a deleterious substance does not depend on dilution characteristics or expected dilution conditions.

Household bleach is a liquid solution of sodium hypochorite, usually a 5.25% solution (52,500 mg/L). Chorine is toxic to most marine organisms at concentrations of 1 mg/L. Toxic effects have been reported at concentrations as low as .006 mg/L (McKee and Wolf, 1963; Thurston *et al.,* 1979). Concentrations as low as .01 mg/L may not protect some economically important marine organisms (Thurston *et al.,* 1979). DFO has recommended in the past that residual chlorine levels discharged to fish bearing waters should not exceed .2 mg/L at the point of discharge (O. Langer, 1976).

The fish anaesthetic quinaldine is used in Washington State by aquarium collectors. Vinegar, lemon juice (Anderson 1997), and clove oil has also been used or proposed as an alternative. Household vinegar is a solution of 4 to 10% acetic acid (4,000 to 10,000 mg/L), although it may rise as high as 30% in glacial acetic acid. Acetic acid has toxic effects on fish and aquatic invertebrates in the range of 25 to 75 mg/L. No information on lemon juice toxicity has been found. The citric acid component of lemon juice is toxic to fish and aquatic invertebrates in the range of 120 to 900 mg/L. Quinaldine (2 methoxyquinoline) is in general use as a fish anaesthetic in the aquaculture industry. After use, a 60 day clearing period is required before the fish may be marketed. Quinaldine has a specific gravity equivalent to household bleach. It is marketed as a clear yellow liquid of 95 to 98% concentration. It is toxic to fish and aquatic invertebrates in the range of 5 to 52 mg/L.

On the basis of the above, the relative toxicity of these solutions from greatest to least toxicity is household bleach > quinaldine > vinegar > lemon juice. It is estimated that dilution rates in excess of 50,000:1 would be required to reduce common household bleach to threshold acutely toxic concentrations, the level at which some lethal toxic effect would still be expressed on some organisms. Dilution at 2.5M:1 would be required to achieve DFO recommended point of discharge concentrations. Because of its availability as a concentrated product, dilution rates in excess of 200,000:1 could be required to reduce concentrated quinaldine to below threshold toxic levels.

For bleach and quinaldine, dilution in and around den sites is considered to be insufficient to reduce these chemicals to non-toxic concentrations in sufficient time to prevent collateral damage to other organisms which may be present within or adjacent to the den site. Discussions with octopus fishers should be initiated to work towards a better solution.

6.2.3. Shrimp and Crab Trap Bycatch

Bycatch reported from shrimp and crab trap fisheries present several problems. Harvest logbook data quality is unreliable. Effort is grossly underestimated because octopus logbooks tend to only report trap strings which produce octopus. Most harvest logbooks reporting octopus bycatch from other trap fisheries are incomplete.

The shrimp trap fishery captures more small octopus than other trap or dive fisheries. There are likely two species of octopus (*O. dofleini* and *O. rubescens*) in landings from this fishery, and the relative proportions of the two species in the catch are not known. Current management plans and licence conditions specify only *O. dofleini* as a legal catch. Whether or not *O. rubescens* can support a fishery is not known: it is not fished commercially elsewhere in it's range.

Whether the increase in reported landings represents new pressure on octopus stocks is uncertain, as they likely represent increased retention due to better markets and increased reporting to establish landings should licence limitation be considered. We suspect that octopus that were not retained in the past were killed and discarded, as they are known to be significant predators of the target species. At the least, they were exposed to predators if they were discarded alive, and the fate of discards remains unknown.

The octopus trap fishery is limited to those times of year and locations where the shrimp by trap fishery is open. In the past 3 years, the coastwide shrimp by trap fishing season has been reduced from 230 days to 109 days. Crab trap fishers have expressed concern that the shortened fishing period for octopus by trap fishing no longer permits them to control this important predator species by means of a legal harvest.

6.2.4. Trawl Fishery Bycatch

Retention of octopus in the shrimp and groundfish trawl fishery is permitted by conditions of licence under the authority of Section 67.(2) of the Pacific Fishery Regulations, 1993. Bycatch in the trawl fishery appears to decline rapidly after 1994. This is an artifact of the data collection process in the sales slip database. Sales slips are no longer coded for fisheries with full observer coverage (groundfish trawl and hook and line rockfish), as these catches are included in observer data by an independent service bureau. Octopus catch records from the service bureau do not routinely get incorporated into the corporate sales slip database. The records are also not incorporated into invertebrate fishery log book data records.

6.2.5. Hook and Line Fisheries

Landings of octopus from hook and line fisheries (longline, troll and handline) continue to be reported although capture of octopus is not allowed by hooks or other sharp objects under Section 67.(1) of the Pacific Fishery Regulations, 1993. Since 1987, these landings have accounted for no more than 3.75% of total octopus landings. Octopi are regularly observed which have survived cuts to the mantle and web and amputation of one or more arms. In late 1997, fishers who had reported octopus landings from these fisheries were advised by letter that such landings are illegal.

6.2.6. Directed Octopus Pot Fisheries

Of the 233 Z-P octopus by trap licenses issued in 1996, only 8 licence holders did not participate in either shrimp by trap or crab by trap fisheries. One licence holder was solely an octopus by trap fisher. The other 7 also held licenses in salmon. Some licence holders also held licenses in the lingcod (2) and inside rockfish (4) fisheries.

The economic viability of a directed octopus pot fishery will depend on the relationship between the size of the boat, the crew size, the number of traps that can be set or pulled in a day, trap efficiency, the number of days that traps are allowed to soak, vessel operating costs, and market value of the landed product. Over a longer term, selection between wooden trap designs and non-wooden traps will affect gear replacement rates. Gear losses will also affect the economic profile.

Given that trap efficiency appears to be low in this fishery, large numbers of traps will have to be set to achieve economic viability. This relationship would improve if landed values increased. Opinions on the effect of bait on trap efficiency are mixed; some feel that bait is not required or may be counterproductive (Paust 1988) while others were relatively successful fishing baited traps (Clayton *et al.* 1992). However, it is not clear if it is the bait itself that is attractive to the octopus, or if the bait attracts crab and shrimp which in turn attract foraging octopus. In the latter case, promotion of an octopus trap fishery using baited traps could have incidental impacts on other commercially valued species.

From experience in the prawn and shrimp trap fishery, fishers in coastal vessels can pull 600 to 1,000 traps a day. Hartwick (1982) suggested that maximum offshore trap catch rates are achieved with 10-12 day soaks. This suggests that to maximize catch rates, fishers may want to set 6,000 to 12,000 traps if they intend to harvest on a daily basis.

Octopus are found on bottom areas utilized by prawn and crab fisheries. The prawn fishery began to experience gear crowding problems on the grounds when the fleet gear inventory exceeded 80,000 traps. The crab trap fishery has also experienced gear crowding in some areas and trap limits have been voluntarily imposed. The experience from these trap fisheries is that the extent of fishable ground is limited, and unlimited gear deployment will create problems.

There is a relationship then between the number of traps that a directed octopus trap fisher may be able to fish, and a hypothetical maximum number that the grounds could accommodate which will define the maximum number of licenses which could theoretically participate in the fishery on a full time basis.

The foregoing points to a potential serious conflict with the existing shrimp by trap and crab trap fisheries. If there is a directed octopus trap fishery independent of the shrimp by trap and crab trap fisheries, there is a high risk or certainty of gear conflicts with the existing fisheries. As maximum octopus concentrations often coincide with maximum occurrence of these prey species, gear separation on the grounds is unlikely for simultaneous fisheries.

There is a potential secondary impact achieved by gear loss in the octopus trap fishery. Gear loss will occur in any trap fishery. It can be lost due to weather, hang ups in recovery, loss of buoys or relocation of gear by barge and vessel traffic. If the gear is wooden traps, then natural degradation processes by boring organisms (particularly the shipworm, *Bankia sectacea*) will eliminate lost traps in a period of years. However, lost non-wooden gear would continue to provide dens for octopus, essentially enhancing octopus habitat. Enhancement of octopus populations through increased shelter or brooding dens could have significant collateral effects on commercially important crustaceans (crabs and shrimp) which are their primary prey.

6.3. Information Requirements For Assessment and Management

This review revealed critical shortcomings in the amount and the quality of harvest and biological information available for stock assessment or to evaluate potential management strategies. This section outlines assessment and management information requirements, and suggests means of obtaining such information.

Information requirements are determined by the management strategies used to control the fishery. Management of the fishery using size/sex/season restrictions requires collection of biological information to determine which species and portions of octopus populations are vulnerable to various gear types, and general patterns of growth, maturation and reproduction on a seasonal and area basis. This management strategy also requires development of thresholds (*e.g.*, size limits) and critical periods which will provide protection to important life history stages.

Management by quota has more onerous data requirements. Estimates of abundance are complicated by the migratory habits of octopus, requiring multiple gear types to survey the entire size range and bathymetric distribution of the population. Each gear type has inherent sampling bias, both in terms of size selectivity and effectiveness in different habitats. Tag-recovery studies have been used to a limited extent in the past to establish growth characteristics of populations (*e.g.*, Robinson 1983; Robinson and Hartwick 1986) or to examine denning behaviour (Hartwick, Ambrose and Robinson 1984b). Studies of this type could be useful in developing population estimates. The costs of surveying a small area would be considerable. The development of habitat-indexed catch or population density estimates and habitat mapping to produce abundance estimates (*e.g.*, Yamanaka and Richards 1992, 1993) could be explored. They are likely to be time consuming, labour intensive, costly and of questionable accuracy.

The quality of information currently gathered through harvest logbooks and sales slips can be improved, and augmented with the collection of biological data.

6.3.1. Harvest Logbook Information

Fishers' compliance in completing logs requires improvement and enforcement. If improved reporting can be achieved, current logbook formats for the trap and dive fisheries are largely adequate. Improvements can be made in the collection of geo-referenced harvest location data, as well as species, number and weight, sex, and maturity of animals harvested. Other suggested changes include possible extension of logbook requirements to the shrimp trawl fishery.

6.3.2. Biological Information

Biological information required to assess octopus stocks in British Columbia includes species composition, size (weight, DML, TL), sex and state of reproductive maturity.

Two species (*O. dofleini* and *O. rubescens*) may be included in landings from the shrimp trawl and trap fisheries. Any octopus over 500 g can be safely assumed to be *O. dofleini*, and any mature octopus less than 500 g can safely be assumed to be *O. rubescens*. Other characters useful for discerning the two species are provided in Table 16.

Table 16. Traits useful for distinguishing *Octopus dofleini* from *O. rubescens*.

Trait	*O. dofleini*	*O. rubescens*
Typical maximum size	>20 cm DML, >50 kg	5-10 cm DML, 400 g
Size at Maturity	M 10 kg, F 15 kg	30-50 g
Lamellae on primary gill	25-29	22-26
Hectocotylus length	1/5 of arm	1/10 of arm
Enlarged suckers	none	6th pair, arms I-III (male only)
Interorbital space (dead specimens)	granular	smooth
Ink color	dark brown	red or reddish brown
Live color pattern	red to reddish brown with black reticulations, patches elongate and irregular	red to reddish-brown mottled with white, patch-and-groove reticulation with small circular patches on dorsal surface

References: Hochberg and Fields (1980); Hochberg (1997b); Hochberg (pers. comm.).

Mass is an appropriate measure of a living octopus. However, for accurate weights, care must be taken to drain the mantle cavity of water. DML or TL are variable, dependent upon state of mantle contraction and muscular contraction of the limbs. While these measurements are valuable, they can only be taken with any degree of confidence from dead or anaesthetized animals (Nixon 1966, Buchan and Smale 1981).

For commercial size octopus, sex is easily determined externally through examination of the third right arm for a hectocotylus. If the third arm is missing or damaged, sex can be determined by internal examination. The reproductive glands and ducts of the female are paired, while the male develops a spermatic duct, penis and diverticulum on the left side only. In *Octopus vulgaris*, the sexes can be determined internally at hatching (Mangold 1983b). External differentiation of the hectocotylus does not begin to develop on males until they are 50-70 g in weight.

Maturity stages for octopods (Table 17) are relatively easy to determine on gross inspection of males. Hatanaka (1981) and Mangold (1983) considered the presence of spermatophores in Needham's sac indicative of male maturity. Sato (1996) divided immature and mature males based on length of spermatophores present: octopi with spermatophores >70 cm in length were considered mature. Female stages Ia and Ib for females are not discernible macroscopically, though I, II and III are discernible on gross inspection.

Table 17. Maturity stages of octopus.

Males			Females		
Stage		Description	Stage		Description
I	immature	entire gonoduct transparent	Ia	immature	ovary small and white, oocytes not surrounded by follicle cells
			Ib	immature	ovary small and white, oocytes surrounded by flattened follicle cells
II	maturing	vas deferens thickened, creamy white	II	maturing	ovary increases greatly in size, color changes to yellow or orange (vitellogenesis)
III	mature	spermatophores in Needham's sac	III	mature	ovary stretched, appears transparent, loose eggs present in ovisac

Based on Hatanaka (1981); Mangold (1983); Hochberg (pers. comm.)

7. Conclusions

It is difficult to consider which management options may be best suited for these fisheries without a better understanding of octopus population structure and dynamics, and how fisheries may affect them. Indices of abundance and identification of which portions of the octopus population are vulnerable to specific fisheries is required. In the interim, DFO must take actions to prevent adverse impacts from potential rapid significant increases in participation, effort and landings in the octopus fishery. Both fishery-independent and fishery-dependent information is required to develop assessment and management frameworks for octopus fisheries. Better information on catch and effort is required, as well as biological information, and improvement of data systems in which this information resides.

The dive fishery is an unlimited fishery on a stock for which there is limited biological information. Landing and logbook records are marginally reliable. The dive fishery does not exploit deep-living portions of octopus populations due to depth limitations. Therefore, there is inherently less risk of overexploitation associated with this fishery, although local harvest impacts may be important.

The trap fishery is an unlimited fishery on a stock for which there is limited biological information. The trap fishery has the risk of creating significant gear conflicts with existing established high value fisheries. The landing and logbook records are largely unreliable. This is a classic example of an unlimited fishery with significant potential for overexploitation, requiring only minor changes in demand at this point to trigger large scale effort increases with no controls in place.

8. Recommendations

As a result of review of available literature, discussions with fellow managers, with assessment biologists outside of British Columbia, and within the Invertebrate Subcommittee of the Pacific Stock Assessment Review Committee, the following recommendations are presented:

1. Develop an octopus stock assessment program involving estimates or indices of abundance and the collection of information that will permit modeling or analyses to describe recommended yields. Consider if habitat-indexed models may assist in developing biomass estimates.

2. As part of this octopus stock assessment program, critically assess and, where necessary, develop new logbooks that provide geo-referenced information on catch and effort. Separate logbooks may be required to ensure reporting of octopus catch in trawl fisheries. Otherwise, shrimp trawl logbooks require revision and/or special instructions to ensure that octopus catch in this fishery is recorded and coded correctly. Establish means to capture data recorded from groundfish trawl fisheries by service bureau agency personnel (private industry fishery service companies which provide at sea observers and shore based landing validators for commercial fisheries managed with these components). Geo-referencing of locations in the dive fishery needs to be reviewed, as reporting at Statistical Area resolution is likely inadequate to understand the fishery.

3. Commercial catch sampling is required to collect biological data to determine which sexes and sizes of octopus are exploited by various fisheries. DFO's fishery-independent shrimp,

prawn and crab assessments should be utilized to collect biological information on octopus, and to estimate the impact of octopus on crustacean trap fisheries. DFO's shrimp trawl bycatch project will also provide information on catch rates and provide an opportunity to collect species composition and biological information.

4. Management steps should be taken to limit effort and expansion in the fishery until a stock assessment program has yielded sufficient biological information.

9. Management Considerations

1. For the dive fishery, effort is presently uncontrolled. Sustainable fishing levels cannot be estimated or established in advance of continued exploitation. Licence limitation should be pursued as a first step in limiting potential effort in this fishery. Managers are aware that this management measure of itself may not limit increased effort. Octopus dive licences are a personal licence designated to a vessel. As such, they do not limit the number of divers that can fish from each licenced vessel. Accordingly, redefinition of the octopus by dive licence may be required to acheive effort limitation.

2. For the dive fishery, evaluate current fishing patterns. Consider establishing large reserve areas where harvest will not be permitted until such time as additional biological information about octopus stocks becomes available.

3. For the dive fishery, initiate consultation with octopus divers to evaluate alternative irritant solutions other than bleach.

4. For the dive fishery, establish more rigorous obligations for accurate and timely information reporting through the conditions of licence backed up by enforcement. Include data reporting requirements for additional aspects of life history and biological information collection which may be necessary for stock characterization and assessment.

5. For the trap fishery, the available information is insufficient upon which to make a rational assessment of fishers' past participation in the fishery. Accordingly, do not proceed with licence limitation based on historical landings. Allow the octopus by trap fishery to continue as a bycatch fishery within the existing prawn and shrimp trap and crab trap fisheries.

6. For the trap fishery, continue to permit fishing only at those times and locations where prawn and shrimp trap fisheries are open. This will continue the present practice of protecting octopus stocks with significant time and area closures until additional stock assessment information can be collected.

7. For the current octopus trap fishers who have a recent history of active participation in the fishery and who have not held a shrimp or crab trap fishing licence, provide fishing opportunity under scientific licence authority at those times when the prawn and shrimp trap

fisheries are open. Include trap limits within the scientific licence to prevent gear conflict with existing trap fisheries.

8. For the trap fishery, further development of the fishery at those times of year when prawn and shrimp trap fisheries are closed, should be governed by the Pacific Regional Guidelines for New and Developing Fisheries, advocates the phased approach proposed by Perry (1996). Allow a limited number of applicants to fish under the authority of scientific licenses as a Phase 1 fishery designed to provide stock assessment information. Data reporting requirements should be described in a survey protocol to be developed by the Stock Assessment Division. Observers may be required for bycatch and biological data reporting. The scientific licence program should encourage trap testing to develop gear which does not provide a bycatch concern.

9. For the shrimp trawl and groundfish trawl bycatch fisheries, improve data reporting requirements.

10. Develop partnering arrangements with all industry sectors to collect biological information from fishery catches in addition to the standard catch and effort reporting requirements.

11. Estimate additional costs that will result from further development of octopus trap and dive fisheries, and advise stakeholders of the need for cost recovery mechanisms to be established within a projected time frame.

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