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Review of Biology, Fisheries and Assessment of Oceanic Squids, particularly Ommastrephes bartrami, Onychoteuthis borealijaponica, = = Gonatopsis borealis and Berrryteuthis magister

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¹ La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

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Abstract

Four species of oceanic squid, neon flying squid (*Ommastrephes bartrami*), boreal clubhook squid (*Onychoteuthis borealijaponica*), eight-armed squid (*Gonatopsis borealis*) and schoolmaster gonate squid (*Berryteuthis magister*) were designated as target species in a pilot fishery to evaluate the potential for development of an automated jig fishery for squid off British Columbia. This paper reviews available literature on the biology, fisheries, assessment and management of oceanic squid species, particularly the four target species.

Assessment and management of squid species are complicated by variable recruitment, oceanographic effects on distribution and availability, extensive migrations, short (usually annual) life cycle, and semelparity. Very little information is available for the proposed target species, and much of it relates to the northwestern Pacific. More information is required regarding life history, population structure and dynamics of these species in the eastern North Pacific.

The paper reviews information requirements for rational assessment and management of fisheries of these species, outlines priorities of an assessment program, and provides management considerations from the literature.

Résumé

Quatre espèces de calmars océaniques, soit l'encornet volant (*Ommastrephes bartrami*), le cornet boréal (*Onychotheutis borealijaponica*), l'encornet boréopacifique (*Gonatopsis borealis*) et l'encornet suçoir (*Berryteuthis magister*), ont été la cible d'une pêche pilote visant à évaluer le potentiel de développement d'une pêche du calmar à la turlutte automatique au large de la Colombie-Britannique. La présente communication est une analyse des documents disponibles sur la biologie, la pêche, l'évaluation et la gestion des espèces de calmars océaniques, en particulier les quatre espèces ciblées.

Le recrutement variable, les effets océanographiques sur la distribution et la disponibilité, les grandes migrations, le cycle vital court (habituellement annuel) et la nature sémelpare des organismes compliquent l'évaluation et la gestion des diverses espèces de calmar. Très peu d'information est disponible sur les espèces ciblées, et la plus grande partie de celle-ci porte sur le Pacifique nord-ouest. De plus amples données sont requises sur le cycle vital, la structure des populations et la dynamique de ces espèces dans le Pacifique nord-est.

La présente communication passe en revue l'information nécessaire à l'évaluation et à la gestion rationnelles de la pêche de ces espèces, fait un survol des priorités d'un programme d'évaluation et établit les points de gestion à considérer tirés de documents publiés.

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1. Introduction

Interest in offshore squid resources has increased in British Columbia over the last two decades, as opportunities in conventional fisheries decrease (due to stock conditions or increased regulation) and market demand for squid increases due to decreased catches in other fisheries. Squid have often been cited as underutilized resources (MacFarlane and Yamamoto 1974; Bernard 1980; Mercer 1981; Fiscus and Mercer 1982; Wilson and Gorham 1982; Wolotira *et al.* 1990; Clayton 1993).

Neon flying squid, *Ommastrephes bartrami*, are found throughout the North Pacific to approximately 53°N latitude. This species has been fished extensively in the western and central North Pacific since the late 1970's, and supported jig and driftnet fisheries conducted by Japan, Korea and Taiwan through the 1980's and early 1990's. Experimental fisheries using drifting gillnets (Bernard 1980, 1981; Robinson and Jamieson 1984; Sloan 1984; Jamieson and Heritage 1987, 1988) and automated jigging technology (Shaw and Smith 1995) indicated that neon flying squid were available within the Canadian 200-mile Fisheries Conservation Zone (FCZ) in the summer and fall.

In 1996 an exploratory commercial jig fishery for neon flying squid was initiated via industry/government partnerships (Gillespie and Shaw 1997). The potential for developing this as a pilot new fishery was addressed by Department of Fisheries and Oceans (DFO) and the British Columbia Ministry of Agriculture, Fisheries, and Food (MAFF) via the signing of a Memorandum of Understanding (MOU) on Fisheries and Seafood Diversification on December 6, 1995. The objective of this MOU was to provide an orderly, precautionary approach to new commercial fishing opportunities in British Columbia. A Federal/Provincial committee was formed under the auspices of the MOU and developed operational guidelines for the implementation of this pilot fishery.

The purpose of the exploratory fishery for neon flying squid was to determine the feasibility of an automatic jig fishery. In particular, the fishery needed to determine the distribution and abundance of this species within and adjacent to Canada's FCZ, assess the effectiveness of the automatic jig technology for harvesting large squid, and collect biological and by-catch information to support sound fisheries management decisions. This exploratory fishery was to proceed from 1996 to 1998. The three year period would provide the necessary time to gain some understanding of the resource and determine whether this would be a viable fishery.

After the 1996 fishing season, industry requested that DFO include three other species in the management plan for the remainder of the pilot. The 1997 management plan reflects this change, including boreal clubhook squid (*Onychoteuthis borealijaponica*), eight-armed squid (*Gonatopsis borealis*) and schoolmaster gonate squid (*Berryteuthis magister*) as target species.

Perry (1996) outlined a framework for the development of assessment and management programs for new and developing fisheries. He presented a phased approach which explicitly endorses a precautionary to fisheries management and research. The first phase (0) was collection of existing information on the biology, abundance, distribution and productivity of the

targets species, potential fishing techniques, and potential responses of the target species to exploitation. The second phase (1) was fishing for information - formal surveys or exploratory fishing to collect information which was identified as insufficient in the phase 0 review. The final phase (2) was fishing for commerce, ideally commencing after collection of biological information, stock characteristics, acceptable indices of abundance and a management plan had been developed.

This paper represents a phase 0 review for oceanic squid proposed as target species of an automated jig fishery off British Columbia, both within and outside of the FCZ. The paper includes:

- a general review of oceanic squid biology, particularly in terms of fisheries biology;
- reviews of available information for the 4 target species in the eastern North Pacific, and elsewhere in their distributions;
- examples of assessment and management of fisheries for similar species;
- a review of exploratory fishing for oceanic squid off western North America; and
- an outline of Canada's responsibilities under United Nations guidelines for fisheries on highly migratory or straddling stocks;
- recommendations for collection of information required to assess the Canadian jig fishery for oceanic squids.

2. Review of Squid Fisheries Biology

Previous reviews of cephalopod biology and fisheries include Bernard (1980), Boyle (1983; 1987; 1990), Caddy (1983a), Rathjen (1983), Voss (1983), Roper *et al.* (1984), Jefferts (1986), Murata (1990) and Sinclair (1991). The following review draws primarily on these sources. Information from other sources will be directly referenced below. Oceanographic zones referred to follow Favorite *et al.* (1976) and Roden (1991).

Squid are one of five orders of living cephalopods: squids (Order Teuthoidea), cuttlefishes (Order Sepiodea), octopuses (Order Octopoda), vampire squid (Order Vampyromorpha) and chambered nautiluses (Order Nautiloidea). Squid have long, tapered bodies, equipped with a pair of posterolateral fins, eight arms arranged in a ring around the mouth and each bearing rows of suckers armed with chitonous rings or hooks, and two longer tentacles bearing clusters of suckers and/or hooks (tentacular clubs) at their distal end.

The Teuthoidea are divided into two suborders: the Myopsida and the Oegopsida. The eyes of myopsids are covered by a corneal membrane and have a minute associated pore, the tentacular club bears suckers only (never hooks), and females have a single oviduct and accessory nidamental glands. This suborder consists of near-shore neretic squids, including the familiar and commercially important loliginids, that lay their eggs in compact masses on the bottom.

The eyes of oegopsids are open to the ocean, they lack an eye pore, their tentacular clubs may have hooks as well as suckers, and females have paired oviducts and lack accessory nidamental glands. This suborder consists of pelagic oceanic squids, including commercially exploited onychoteuthid, gonatid and ommastrephid squids. Some species may be demersal or epibenthic at some stages of their life cycle, but most are pelagic. Their life cycles are generally completed far offshore, and their eggs are laid in large, diffuse, masses (as described for the ommastrephid *Illex illecebrosus* by O'Dor and Balch 1985).

Although myopsid squids are exploited by fisheries using various jig and net gears, their biology and fisheries are very different from the jig fishery for large pelagic squids proposed under this pilot. This review will concentrate on jig fisheries for oegopsid squids.

Distribution

Squids are found in all of the oceans of the world. The oegopsids are generally strong, active forms, which are found in open ocean waters. They generally exhibit diel vertical movements as adults, inhabiting deep water in the daytime, and rising in the water column at night. Species fished by jig gear are phototactic, and catch rates are improved by using lights.

Most temperate water forms undergo extensive migrations from spawning areas to feeding areas, with a return migration beginning with onset of sexual maturity. Many of these temperate migrants are associated with large currents which sweep larvae into productive waters where they can grow at the greatest rate. Many North Pacific species are most abundant in certain water masses: life histories differ to exploit the characteristics of the water mass which they inhabit. Kubodera (1986) discussed the attractiveness of productive Transition and Subarctic waters in the summer. Subtropical waters are less attractive in the summer, and more productive in the winter. The extent of northern migration is determined by the northward advance of specific water masses and the temperature tolerance of the species involved. The observed separation of peak abundances in *Omm. bartrami* and *Ony. borealijaponica* in the western Pacific, even though both migrate north from southern spawning areas, is a function of the temperature preferences of the two species, the latter tolerating colder waters than the former.

Age and Growth

Considerable recent work has been done on age determination of squids using statoliths (e.g., Spratt 1978; Dawe 1981; Dawe *et al.* 1985; Hurley *et al.* 1985; Rodhouse and Hatfield 1990; Nakamura and Sakurai 1991; Dawe and Beck 1992; Bigelow and Landgraf 1993; Natsukari *et al.* 1993; Bigelow 1994; Brodziak and Macy 1994; Jackson 1994; Macy 1995). However, the technique remains labour intensive, as structures must be polished and prepared, and daily growth increments interpreted from their surfaces.

Life span for squids range from less than a year in tropical waters or for small species to 1-2 years (exceptionally 5 years) at maturity (however, see Natsukari *et al.* 1993). Squids are semelparous, suffering extremely high post-spawning mortality rates. There is little evidence of survival through successive breeding seasons. In tropical waters, where there is little seasonal variability, life cycles are generally sub-annual (O'Dor 1992). In temperate waters, annual or longer life cycles dominate.

Growth of squid is variable, and likely responsive to environmental variability (Forsythe 1993), although the critical determinant of growth may be availability of food (Caddy 1983b). Growth is rapid throughout life, but slows dramatically, becomes erratic or even decreases with the onset of sexual maturity. There is currently no agreement regarding which model best describes squid growth. Early growth of paralarvae is exponential (Forsythe and van Heukelem 1987; Bigelow and Landgraf 1993; Bower 1996), post-larval growth is thought to be logarithmic. Sudden departure from the logarithmic growth phase at the end of the life cycle renders asymptotic growth models (e.g. Gompertz or von Bertalanffy curves) inappropriate for squids (Forsythe and van Heukelem 1987). Ehrhardt *et al.* (1983) found that growth of different subcohorts of *Dosidicus gigas* in the Gulf of California were best fit to either linear or von Bertalanffy models. Pauly (1985) proposed a modification of the von Bertalanffy curve with an additional term for seasonal variation. Bigelow (1994) used a four parameter Schnute model (Schnute 1981) to describe growth of *Onychoteuthis borealijaponica*. In the case of data derived from fisheries for migratory squids, the apparent flattening of the growth curve late in life might be a result of emigration of large mature squid out of the sampling area (Rodhouse *et al.* 1995).

Forsythe (1993) demonstrated that small differences in temperature during early paralarval growth can significantly increase growth. *Loligo forbesi* raised at 2°C higher temperature grew to five times the final size of a control group at the end of the 90 day exponential growth period. Thus, there is potential for late-spawned subcohorts to be larger than older portions of the population at maturity. He discussed the ramifications of environmentally determined growth rates on final population structure, and the interpretation of length-based growth models.

Sexual dimorphism in squid is partly a consequence of different growth rates during the logarithmic phase, and partly a consequence of different life spans of the two sexes (Forsythe and van Heukelem 1987). The energetic costs of maturation in males is considerably less than in females (gonad weight of mature males is rarely more than 5% of body weight), and in some species males continue to grow after maturation. In females, ovary weight increases from less than 1% of body weight to 20-30% (exceptionally even 50%) at maturity. Typically, females cease somatic growth at onset of maturity.

Reproduction

Squids are dioescious (sexes are separate) and fertilization is achieved by direct mating (Mangold 1987). Sperm is packaged into spermatophores and stored in a special organ (Needham's sac). When mating occurs, spermatophores are passed from male to female by a modified (hectocotylized) arm. Spermatophores are stored by the female in the buccal membrane or within the mantle until spawning. Females also produce complex envelopes to protect eggs: examples include demersal eggs mops produced by loliginids and diffuse gelatinous egg masses of ommastrephids.

The sexes of migratory oceanic squids often mature at different times of the year, i.e. mating and spawning are distinct events occurring weeks or months from one another. Spawning areas for most oceanic squid are poorly documented (however, see Bigelow and Landgraf 1992, Bower 1996 and references therein).

Fecundity of squids is not well documented. Inshore loliginids have been estimated to produce from a few hundred to 50,000 eggs per female, and offshore ommastrephid squids from 70,000 to several million eggs (Mangold 1987).

Squid do not have a larval stage in the strict sense. The paralarvae hatch with a body that differs very little from the final adult form. Eggs and paralarvae are the least well known of the squid life history stages. Active paralarvae can avoid most plankton sampling gear, and most cephalopod juveniles are difficult to identify to species. Avoidance makes development of juvenile abundance estimates difficult, and taxonomic difficulties make surveys of less well-known species nearly impossible.

Trophic Relations

Squid are active, high-level predators in both coastal and pelagic ecosystems (Amaratunga 1983; Mangold 1983). They utilize a wide variety of prey types, and opportunistically feed on the most abundant types available at any time. Among the oceanic squids, the general pattern is dependence on small crustacean prey as juveniles, with fish and other squid increasing in importance for larger squid. Cephalopod remains are often found in the gut, and cannibalism of conspecifics is commonplace.

O'Dor and Wells (1987) proposed that cannibalism may be an alternative to reducing metabolic rates when other food is scarce. Maturing squid must channel energy into gonad development while completing long-distance migration to the spawning grounds. Squid migrating in schools have easy access to other school members, and cannibalism may provide the energy needed to complete sexual maturation while migrating back to the subtropical waters which provide the best conditions for paralarval survival and growth.

Growth rates can be affected by prey availability when squid become large enough to switch from small invertebrate prey to larger fish prey. If the next prey item in the progression is rare, then squid may "stall" at that size, remain vulnerable to predation longer, or not grow large enough to be able to complete the return migration. Rather than stall growth rates, squid may prey on smaller conspecifics until large enough to utilize other prey.

Food intake in squids may be as high as 50-100% of body weight in early life history stages, reduced to <10-15% in subadult and adult stages (Boucher-Rodoni *et al.* 1987; O'Dor and Wells 1987). The high feeding rates of paralarvae correspond to an exponential growth phase. Large squid cannot maintain the growth rates of early life history phases, in part because no ecosystem could support these feeding rates. High food intake is required for high metabolic rates to support high activity levels: squid are negatively buoyant, and thus expend energy just to maintain position in the water column. Jet propulsive pursuit and escape are less energy efficient than undulatory swimming. Squid require more resources to support a higher metabolic rate than the neutrally buoyant, energy-efficient fishes with which they compete.

Food is detected visually and captured by direct attack. The extensible tentacles are used to trap food and bring it to the arms, which subdue the prey until it is dispatched by the beak. The feeding mode of squids, which involves using the beak and radula to tear pieces from prey held

in the arms, coupled with a rapid rate of digestion make relation of gut contents to the actual diet difficult.

Squids are in turn preyed upon by large fishes (tunas, billfishes and salmon in particular), seabirds, sea mammals and other squid. Deepwater squids are particularly important in sperm whale diets, and Clarke (1983, 1987) discussed the analysis of whale stomach contents to provide information on distribution, abundance and relative importance of squid species. Presence of squid in seabird diets may be due in part to scavenging of dead or moribund post-spawning squid which have risen to the surface (Lipinski 1992).

Parasites and Disease

Hochberg (1983) reviewed parasites of cephalopods. Partial data are available for a number of species, though, in his opinion, only two commercially important species (*Octopus vulgaris* and *Sepia officinalis*) had been studied in detail and their entire parasite fauna documented. Literature regarding cephalopod parasites is particularly confusing, owing both to the taxonomic problems of both host and parasite species and the disjoint geographic sources of material.

Parasite faunas are of particular interest when they either affect human consumers, as in the nematode *Anisakis*, have impact on attempted aquaculture, or prove useful in distinguishing stock structure of exploited species. Hochberg (1983) briefly discussed concerns regarding anisakiasis, transmitted to humans by eating raw or partially cooked squid. Comments relating to stock delineation are included in the review of *Ommastrephes bartrami* below.

Population Structure

Delineation of population structure in migratory squids has been primarily directed at temporal subcohorts (based on time of spawning or appearance of recruits) rather than geographic stock separation (Amaratunga 1987). Most commercially exploited oceanic squids undergo extensive migrations over broad geographic ranges, and return to spawning grounds which are not well known. The degree of mixing on the spawning grounds of squid which migrate to different parts of the North Pacific to feed and grow has not been assessed.

O'Dor (1992) and O'Dor and Coehlo (1993) presented an hypothesis explaining evolution of large species of squid and highly variable, cyclic recruitment of squid populations. They proposed that highly productive coastal upwelling areas associated with large currents that support large populations of squid also exert selective pressure for large individual size.

Spawning is timed to take advantage of high production events, such as spring blooms. Squid which migrate synchronously with seasonal progressions of production (from tropical to temperate waters) grow faster, require more time to complete the return migration, and are more fecund upon their return. Because timing of productive blooms is variable, squids may "hedge their bets" by spreading spawning over a long period of time, to avoid missing the opportunity to maximize growth and reproductive potential entirely. Only large individuals that can complete the return migration to a spawning area which allows paralarvae to drift into the productive zones (i.e., complete the migration loop) will contribute to the gene pool. Squid which do not migrate far do not grow as large, and may "fall prey to returning cannibal hordes" (O'Dor and Coehlo 1993). Intra-annual cannibalism may strengthen selective pressures which favour migration and growth to large size, and semelparity speeds selection because "losers" do not get a chance to reproduce. Under stable environmental conditions, these populations should develop stable migratory subcohorts.

However, semelparity carries increased risk of population collapse. A single year of low productivity, unusual current patterns or overfishing may cause failure of an entire year-class. Population collapse may also occur if the migratory subcohort becomes abundant enough to over-graze its habitat (O'Dor 1992). For annual semelparous species, not buffered against adversity like iteroparous age-structured populations, failure of a large portion of the population to reproduce in a given year means population collapse. If the large, migratory portion of the population is lost, some recovery time is required for this portion to "re-evolve" from the smaller, non-migratory portion. Strong selective pressures, as outlined above, may allow recovery in a relatively short period of time, because of the short generation time.

3. Review of Available Information for Target Species

3.1. Neon Flying Squid (*Ommastrephes bartrami*; Ommastrephidae)

Neon flying squid are large oceanic squid, females growing to mantle lengths of 60 cm and weights of 5.3 kg (Nakamura and Siriroksophon 1992), males somewhat smaller (Roper *et al.* 1984). The mantle is cylindrical, muscular and robust, lacking a pointed tail posteriorly. The fins are muscular and lobed, length 0.40-0.45 of mantle length, width approximately 0.60 of mantle length. The upper surface of the body is mauve, the ventral surface of the mantle marked by a golden or silvery stripe from the mantle opening posterior to the point of fin insertion. Similar luminescent tissue present on the ventral surface of the head and fourth arms. Arms with two rows of large suckers, tentacular club has four rows of suckers, all with toothed rings. The name flying squid refers to the flying behaviour exhibited by small *Omm. bartrami* as an escape mechanism from predators (Murata 1988).

Distribution

Neon flying squid are found in the Pacific, Atlantic and Indian Oceans (Roper *et al.* 1984). In the north Pacific Ocean, *Omm. bartrami* are found from 21-53°N (Sinclair 1991; Murata and Hayase 1993). Distribution changes seasonally, as flying squid migrate northward to feed in the summer and fall, and return to southern waters to breed in the fall and winter. These migrations are associated with seasonal shifts in oceanographic conditions.

Omm. bartrami paralarvae are known from waters southeast of Honshu (approx. 35° N, 140°W) and near the Hawaiian Archipelago (Biglow and Landgraf 1993; Bower 1996). Paralarvae were taken off Japan in January and March through May, and near Hawaii from February to May (Bigelow and Landgraf 1993) or January to April (Bower 1996).

Omm. bartrami are found in the Subtropical and Transition Domains in summer, with the greatest concentrations in the northern end of their distribution (Kubodera 1986). Yatsu *et al.* (1993) found neon flying squid in research nets set at sea surface temperatures (SST) greater than 9°C, with higher CPUE's associated with 15-22°C SST. Abundance was high in the Transition Domain and near the Subarctic Boundary, but was very low in the Subarctic Domain. Off Washington and Oregon, Nakamura and Siriraksophon (1992) had highest CPUE's associated with a warm front near an upwelled cold area, at SST of 12.8-19.4°C, and temperatures at 120 m depth of 7.5-8.3°C.

Male *Omm. bartrami* are rare in northern catches, accounting for <1% of the catch off British Columbia (Shaw and Smith 1995) and between 2.4% (Nakamura and Siriraksophon 1992) and 7% (June and Wilkins 1991) of the catch off Oregon and Washington.

Adult flying squid are found from surface waters to approximately 1,500 m depth (Roper *et al.* 1984). They undergo diurnal vertical migrations from nearsurface waters at night to >300 m during the day (Yatsu *et al.* 1995). Paralarvae are found from the surface to 40 m during both day and night (Bower 1996).

Reproduction

As in most other squid species, mating and spawning are separate acts. Spermatophores are stored in the mantle cavity until the female ripens and spawns. Murata and Hayase (1993) examined timing of maturity in the north Pacific Ocean. Proportion of mature females was low (<9%) until December, then rose to more than 50% in March and April. Proportion of mature males was low (<9%) until September, increased rapidly after November and was 70-100% from December to April. Mantle lengths of mature females were 39-50 cm, for males were 26-38 cm.

Fecundity estimates for neon flying squid have been as high as 3.16 million eggs (Reznik and Bessmertnaya 1993), or ca. 360,000 (Boyle 1990).

Spawning areas are not well documented, but may be associated with shallow reefs, islands, seamounts and ocean ridges and basins (Osako and Murata 1983). Proposed hatching dates from statolith analysis of paralarvae collected near the Hawaiian Archipelago indicated that North Pacific *Omm. bartrami* spawn from at least January to April (Bigelow and Landgraf 1993). No gradient of paralarval size with distance from shore was observed, and spawning is postulated to be oceanic (Bower 1996).

Egg masses are likely spawned in midwater (Osako and Murata 1983), similar to *Illex illecebrosus* (O'Dor and Balch 1985). Egg masses are neutrally buoyant, and may be retained in the spawning area if they become suspended in the mesopelagic water layers where current speeds are reduced (Bower 1996).

Age and Growth

Flying squid live approximately one year (Ishii 1977; Murata and Ishii 1977; Welch and Morris 1993; Yatsu *et al.* 1997). Sinclair (1991) reported that the LL size class represented females which did not spawn until two years of age, but other authors do not agree (Yatsu *et al.* 1997)

Murata and Hayase (1993) examined monthly length frequencies in the north Pacific Ocean. Modal mantle length increased from 16-22 cm in May and June (both sexes) to 32-35 cm for males and 43 cm for females the following April. Monthly growth from June to October was 2.7 cm for males and 4.0 cm for females. Yatsu *et al.* (1997) estimated individual growth rates through statolith analysis. Daily growth rates ranged from 1.1-2.1 mm for males and 1.1-2.5 mm for females.

Population Structure

Murata and Hayase (1993) proposed that the north Pacific population was composed of two subcohorts: a "spring-breeding group" and a "fall-breeding group". The spring subcohort is thought to spawn and breed in Subtropical waters from Japan to North America from 21-35°N. The subcohort moves north in spring and summer and is distributed from the Subarctic Boundary to the Transition Domain in summer and fall. Females move northward more quickly than males, and migrate further north. Southward migration is in October-November for males and November-December for females. Life span for the spring subcohort is approximately one year.

The fall subcohort is thought to breed between 25-32°N, east of 160°E (Murata and Hayase 1993, Fig. 15). This subcohort moves north in the summer and south in the winter following the Subtropical Domain. Some females are distributed as far north as the Transition Domain in summer, males do not travel as far north. Southward migration begins in July for males and in September for females.

Some authors (Murata 1990; Murata and Hayase 1993) have described up to four putative seasonal subcohorts, labelled SS (extra small), S (small), L (large) and LL (extra large). The LL group is composed only of large female squid, and some authors (Kubodera *et al.* 1983; Murata 1990; Murata and Hayase 1993) believe that the LL and SS groups represent a common cohort with females living for more than one year (however, see Yatsu *et al.* 1997).

Murata (1990) proposed that two geographic stocks of *Omm. bartrami* exist in the North Pacific, with the division between them being approximately 160-170°E latitude. This division was based on size composition from commercial catches and low abundance in the area of the proposed stock boundary.

Trophic Relations

Flying squid eat primarily fishes, including lanternfishes (Myctophidae: Diaphus, Myctophum, Hygophum, Symbolophorus, Lampanyctus, Nanensia, Scopelosarus and Centrobranchus sp.), stomiiform fishes, sardines (Sardinops melanosticta), anchovies (Engraulis japonica), mackerel (Scomber japonicus) and sauries (Cololabis saira) (Wormuth 1976; Bernard 1981; Araya 1983;

Kubodera 1986; Seki 1993a,b). Filipova (1974, cited in Nixon 1987) listed fishes of the families Myctophidae, Exocetidae and Gempylidae, the genera *Tetragonurus* and *Acanthocybium*, and *Scomberesox saurus*.

A major component of their diet is other squid, including a high rate of cannibalism. Other squids include the families Enoploteuthidae, Ommastrephidae, Onychoteuthidae and Histioteuhidae (Nixon 1987), and *Watasenia scintillans*, *Onychoteuthis borealijaponica*, *Berryteuthis anonychus* and *Abraliopsis* sp. (Bernard 1981; Pearcy 1991; Seki 1993a, b). Remains of heteropod molluscs and other crustacea (Decapoda, Phronimidae and Cirripedia) were also noted. Small flying squid eat pelagic crustaceans (*Parathemisto* sp., other euphausiids and hyperiid amphipods), but these are less important to adult squid, and fish become most important at sizes greater than 80 mm ML (Kubodera 1986; Nixon 1987).

Flying squid are eaten by swordfish (Xiphias gladius) and blue sharks (Prionace glauca) (Seki 1993a, b). Predation by sperm whale (Physeter macrocephalus) and northern elephant seal (Mirounga angustrostris) have been reported. Other potential predators include blue and striped marlin (Makaira mazara and Tetrapturus audax, respectively), shortnose spearfish (Tetrapturus angustirostris), yellowfin (Thunnus albacares), bigeye (Thunnus obesus), bluefin (Thunnus thynnus) and skipjack (Katsuwonus pelamis) tunas, short-finned pilot whale (Globiocephala macrorhynchus), Dall's porpoise (Phocoenoides dalli), Pacific white-sided dolphin (Lagenorhynchus obliquidens), Risso's dolphin (Grampus griseus), northern right whale dolphin (Lissodelphis borealis), Baird's beaked whale (Berardius bairdi), Cuvier's beaked whale (Ziphius cavirostris), dwarf sperm whale (Kogia simus), common dolphin (Delphinus delphis), striped dolphin (Stenella coeruleoalba) and northern fur seal (Callorhinus ursinus). Juvenile flying squid are eaten by red-footed boobies (Sula sula) and likely are preyed upon by other subtropical seabird species.

Parasites and Disease

Bower et al. (1990) and Bower and Margolis (1991) described the helminth parasites found in Omm. bartrami in the northeastern Pacific. These included juvenile nematodes (Hysterothylacium sp. and Anisakis simplex) and cestodes (Phyllobothrium sp. and Tentacularia sp.) and adult acanthocephalans (Rhadinorhynchus sp.). This differs from the reported parasite faunas of Ommastrephes in the western Pacific, indicating that populations from the two regions to not mix. They proposed that differences in the parasite faunas of eastern and western North Pacific Ommastrephes might be used to determine whether squids feeding in the two areas intermingle in spawning areas.

Fisheries

The North Pacific fishery for *Ommastrephes bartrami* was begun by the Japanese in 1974, following declines in the Pacific stock of the Japanese common squid, *Todarodes pacificus* (Araya 1983; Ignell 1991). The jig fishery developed rapidly, primarily through exploration of new fishing grounds, increased fleet size and improved fishing technology. In 1978, drift gillnet fishing was initiated, further increasing the fishing pressure on flying squid. In 1981, a driftnet

fishing season of June 1-December 31 was established, and a fishing area stabilized (Yatsu *et al.* 1993). The driftnet fishing area included waters between 170°E and 145°W longitude and from 20°N to 40-46°N latitude, excluding the FCZ around the Hawaiian Islands. The northern boundary varied monthly (from 40°N in June to 46°N in August-September, returning to 40°N in December) to minimize bycatch of salmonids, and most of the effort in any year was expended within 3° of the northern boundary.

In response to global concerns over the levels of bycatch of marine mammals, birds, reptiles, other cephalopods and fishes, the United Nations General Assembly imposed a 50% reduction in driftnet fishing effort in June of 1992, and a complete moratorium on large-scale pelagic driftnet fishing effective December 31, 1992 (Waddell and McKinnell 1994).

Assessment and Management

Trends in stock size were examined using CPUE data, calculating indices of stock size (P = total of mean catch/day/vessel in one degree blocks) and stock density (D = P/number of one degree blocks) (Murata 1990). Assessments are viewed cautiously because of shifts in gear type and effort patterns in both jig and driftnet fisheries. However, Murata (1990) indicated that *Omm.* bartrami stocks exploited by the jig fishery west of 170°E had declined from 1978 to 1985, but was unclear whether stock declines were due to the jig fishery (jig effort had declined during the period), catches of Korean and Taiwanese driftnet fisheries, or natural causes. The driftnet fishery east of 170°E likewise showed evidence of declines in 1984 and 1985.

Both fisheries exhibited decreases in mean size of animals caught, the jig fishery from 1977-79 (Araya 1983) and the driftnet fishery from 1984-86 (Murata 1990), indicating removal of the largest, fastest-growing subcohort of the population (Osako and Murata 1983; Murata 1990, Sinclair 1991). Similar to the *Todarodes* fishery described later, management actions were designed primarily to separate industry sectors, and to some extent to reduce salmonid bycatch, and not in response to conservation concerns for the squid themselves (Ingell 1991).

Total catch from the jig and gillnet fisheries remained relatively stable throughout the 1980's and early 1990's (Table 1). Changes in effort patterns in the last two years of the driftnet fishery make it difficult to attribute decreased catches to stock abundance. Annual CPUE in the Korean driftnet fishery (measured in kg/pok) from 1983 to 1990 varied from 3.36 (1986) to 6.70 (1983), with no obvious trend (Gong *et al.* 1993). Variation in catches and CPUE, while reflecting annual variation in abundance, may not indicate decreasing stock abundance at these levels of exploitation.

Year	Jigging	Driftnet	Total
1974	17,000	0	17,000
1975	41,164	0	41,164
1976	81,736	0	81,736
1977	124,917	0	124,917
1978	107,505	45,000	152,505
1979	78,385	45,120	123,505
1980	75,274	125,510	200,784
1981	61,489	119,944	181,433
1982	63,037	185,362	248,399
1983	54,223	232,710	286,933
1984	29,061	180,764	209,825
1985	51,010	239,378	290,388
1986	23,015	204,279	227,294
1987	21,034	301,378	322,412
1988	15,610	246,592	262,202
1989	15,694	341,128	356,822
1990	15,000	320,386	335,386
1991	13,434	106,672	120,106
1992	2,272	114,047	116,319

Table 1. Annual catch (t) of neon flying squid (*Ommastrephes bartrami*) by Japan, Korea and Taiwan in the North Pacific by gear type. 1974-1990 from Gong *et al.* (1993), 1991 and 1992 (W. Shaw, DFO Nanaimo, pers. comm.) include only catches by Japan.

3.2. Boreal Clubhook Squid (*Onychoteuthis borealijaponica*; Onychoteuthidae)

Boreal clubhook squid are one of 5 perportive species of *Onychoteuthis* found in the North Pacific (Bigelow 1994). The mantle is long, slender and muscular, the fins broad and muscular, fin length 0.55-0.60 of ML (Roper *et al.* 1984). Tentacular club is large, with 25-29 hooks in two rows. Arms of males are not hectocotylized. There are two small oval photophores associated with the intestinal tract. Maximum size is 36-37 cm ML in females, 28-30 cm ML in males. *Ony. borealijaponica* is replaced by an undescribed species in the Transition Domain, and three species of the *O. banksi* complex are found in subtropical waters (Young and Harman 1987; Bigelow 1994).

Because of taxonomic confusion surrounding this species complex, much of the information reported here might apply to more than one species. Determination of true distributions and life histories for each of the species awaits resolution of their status and relations to one another.

Distribution

Clubhook squid are found from 28-58°N in the northeastern Pacific (Jefferts 1988), from the west coast of the U.S. and Canada to the Kurile Islands and Hokkaido (Bigelow 1994). They are not

found in the Okhotsk or Bering Seas. Yatsu *et al.* (1993) found clubhook squid north of the Subarctic Boundary, generally at SST less than 19°C. In the northwestern Pacific, clubhook squid are found primarily in the Subarctic Transition Domain in summer, where adult squid feed, grow and mature (Kubodera *et al.* 1983; Okutani and Murata 1983; Kubodera 1986; Yatsu *et al.* 1993).

Okutani and Murata (1983) described seasonal distribution off Japan, based on fishery catches. Clubhook squid appear east of Hokkaido in April, and by June are found in Subarctic waters and the Transitional Domain between 39-50°N. In August and September the squid were concentrated along the Subarctic Boundary between 42-45°N. In warm water years the squid migrate further north, but not into the Okhotsk or Bering Seas. The squid then disappear from the fishing grounds, suggesting a southward spawning migration.

Japanese catches indicate that clubhook squid prefer 10-15°C SST, lower than those preferred by flying squid (generally 15-22°C SST) but higher than those preferred by eight-armed squid (generally <10°C SST) (Okutani and Murata 1983). The driftnet fishery generally occurred in waters of <20°C SST, and Eastern Pacific catches were primarily between 10-16°C (Mercer and Bucy 1983).

Reproduction

Spawning in the northwestern Pacific is thought to occur in the countercurrent waters of the Kurushio Current in autumn and winter (Yatsu *et al.* 1993). Okutani and Murata (1983) suggested that clubhook squid spawn at moderate depths, not in the surface layer, based on depths of recovery of juveniles in the Kuroshio current and countercurrent areas off Japan. By back calculating hatching dates from statolith analyses, Bigelow (1994) demonstrated a peak of spawning in October-November in the northwestern Pacific and September-November in the northwestern Pacific. He suggested that spawning occurs in the Transition Domain between 30-42°N.

Males mature from June-October off Japan (Murata and Ishii 1977; Okutani and Murata 1983). Some maturing males were taken in August off Washington and Oregon (Mercer and Bucy 1983). Smallest size at maturity is approximately 20 cm ML. Number of spermatophores carried by an individual male varied from 10-80.

Females mature after August, based on increased nidamental gland length and ovary weight (Okutani and Murata 1983). One female taken in September 1981 off Washington appeared to be maturing (Mercer and Bucy 1983). Minimum size at maturity is approximately 27-28 cm ML. Females exhibit a secondary sexual characteristic at onset of maturity: the reproductive organs and inner surface of the mantle turn orange in color (Murata and Ishii 1977; Okutani and Murata 1983). Fecundity has not been estimated.

Male onychoteuthid squids do not have hectocotylized arms to pass spermatophores to females, and it is hypothesized that males use the hooks on the tentacular clubs to cut the mantles of females to implant spermatophores (Okutani and Murata 1983).

Age and Growth

Clubhook squid are an annual species (Murata and Ishii 1977; Bigelow 1994). Maximum size is approximately 36 cm ML for females and 28 cm ML for males (Okutani and Murata 1983).

Bigelow used back calculated ages from statolith analyses to calculate growth rates of 0.80% of mantle length/day for both males and females. Females increased in weight more rapidly (1.90%/day) than males (1.40%/day). Mercer and Bucy (1983) reported similar growth rates from modal length analyses off the Washington and Oregon coasts.

Population Structure

Murata and Ishii (1977) reported a broad range of mantle lengths of *O. borealijaponica* taken over several years off Japan. They interpreted this as a single year-class which spawned in different seasons (however, there may be more than one species included in the data).

Trophic Relations

Little information is available regarding the diet of clubhook squid. Okutani and Murata (1983) reported mostly empty stomachs, with some incidence of small fish and cannibalism of other clubhook squid. Naito *et al.* (1976, cited in Kubodera 1986) reported over 90% empty stomachs (n=308). When food was present, it was mostly small fishes with fewer small squid.

Fisheries

Ony. borealijaponica was taken incidentally in fisheries for other squids (primarily Omm. bartrami and T. pacificus) off Japan (Okutani and Murata 1983; Osako and Murata 1983; Murata 1990) and incidentally in the midwater trawl fishery for pollock in the Aleutian Islands (Fritz 1996).

Catches off Hokkaido from 1971 to 1979 varied from 0 to 5,060 t, averaging 1,172 t (Table 2). Squid catches in the Bering Sea and Aleutian Islands (Table 3) are reported in aggregate, not by species (Fritz 1996). Recent domestic catches in the eastern Bering Sea are predominantly *B. magister*, those in the Aleutian Islands are predominantly *Ony. borealijaponica*, and this is likely true for historic fisheries as well (L. Fritz, NMFS, Seattle, pers. comm.). Aleutian Island domestic catches from 1990 to 1995 averaged 72 t. Catches from the foreign fishery from 1977 to 1982, before development of joint venture fisheries, averaged 1,950 t. The decline in catches from 1980-82 is likely related to decreased interest in the resource, so inferences regarding stock production are not possible.

Year	Catch (t)	
1971	2,232	
1972	750	
1973	60	
1974	5,060	
1975	0	
1976	2,225	
1977	54	
1978	77	
1979	89	

Table 2. Annual catch (t) of *Onychoteuthis borealijaponica* landed in northeastern Honshu and Hokkaido (Okutani and Murata 1983).

Table 3.	Annual	catch	of	squid	(t)	in	the	eastern	Bering	Sea	and	Aleutian	Islands	by	trawl
	fisheries	s (Fritz	: 19	96).											

		Eastern	Bering Sea			Aleuti	an Islands		Grand
Year	Foreign	JV	Domestic	Total	Foreign	JV	Domestic	Total	Total
1977	4,926			4,926	1,808			1,808	6,734
1978	6,886			6,886	2,085			2,085	8,971
1979	4,286			4,286	2,252			2,252	6,538
1980	4,040			4,040	2,332			2,332	6,372
1981	4,178	4		4,182	1,763			1,763	5,945
1982	3,883	5		3,838	1,201			1,201	5,039
1983	3,461	9		3,470	509	1		510	3,980
1984	2,797	27		2,824	336	7		343	3,167
1985	1,583	28		1,611	5	4		9	1,620
1986	829	19		848	1	19		20	868
1987	96	12	<1	108		23	<1	23	131
1988		168	246	414		3		3	417
1989		106	194	300		1	5	6	306
1990			532	532			94	94	626
1991			544	544			88	88	632
1992			819	819			61	61	880
1993			611	611			72	72	683
1994			517	517			87	87	604
1995			364	364			95	95	459

Assessment and Management

Japanese fisheries for *Ony. borealijaponica* are not actively assessed or managed, as they are caught incidentally in fisheries for other species, and the information required to produce stock forecasts is lacking (Osako and Murata 1983).

The fishery in the Aleutian Islands-Bering Sea is managed under an annual TAC (Fritz 1996). Because assessment survey data and information on distribution, abundance and biology of squids is generally lacking, the overfishing harvest level is the mean annual catch from 1978-1995. The allowable biological catch is 75% of the overfishing level. Thus the TAC for all squid species in the Bering Sea and Aleutian Islands for 1997 is 0.75*2,624, or 1,970 t.

3.3. Eight-armed Squid (*Gonatopsis borealis*; Gonatidae)

As the name suggests, eight-armed squid lack tentacles as adults (Roper *et al.* 1984). Tentacles are present in juveniles and atrophy with development. The mantle is stout, thick and muscular, the fins are muscular, fin length 0.40-0.45 of mantle length, fin width 0.65-0.70 of mantle length. The arms are thick and muscular, arms I-III with a median row of hooks and two marginal rows of suckers, arms IV lack hooks and have 4 rows of suckers. Maximum size is 30 cm ML.

Distribution

Eight-armed squid are found in the northwestern Pacific from approximately 37-55°N, generally north of 40°N in the central north Pacific, in the Okhotsk Sea, in the Bering Sea to approximately 60°N, throughout the Gulf of Alaska and south to approximately 25°N off Baja California (Roper *et al.* 1984; Okutani *et al.* 1988). *G. borealis* are found in the Transition and Subarctic Domains and prefer SST less than 14°C (Kubodera *et al.* 1983; Kubodera 1986; Yatsu *et al.* 1993). Kubodera and Jefferts (1984b) found early life history stages throughout the Subarctic Pacific, except in the Okhotsk Sea. Kubodera (1986) found greatest abundance in the western Subarctic Pacific.

Eight-armed squid are found between 400-800 m depth during the daytime, and migrate vertically to 0-400 m at night (Okutani *et al.* 1988).

Reproduction

Kubodera and Jefferts (1984b) speculated that *G. borealis* have broad offshore spawning/hatching areas in the Subarctic Pacific, with the exception of the shelf areas of the Bering Sea and the Okhotsk Sea. Early life history stages were found year-round in the northeastern Pacific, with peak abundance of subadults in mid to late summer and late winter. They felt there was little evidence for seasonal or synchronous spawning in *G. borealis*. Peak spawning times may be correlated with increasing abundance of crustacean larvae following the spring phytoplankton bloom.

Age and Growth

G. borealis live approximately 1 or 2 years (Kubodera 1986). No other information on age and growth of eight-armed squid was found.

Population Structure

Little information was available on geographic stock distinction of eight-armed squid. Kubodera (1986) reported two size classes (>20 cm DML and <20 cm DML) which had different geographic distributions. He postulated that the larger size class might be survivors of the small size class that did not mature in the previous year.

Trophic Relations

Most stomachs examined by Naito *et al.* (1977, cited in Kubodera 1986) were empty. When food was present, it consisted of small fishes.

Fisheries

G. borealis was fished in northern Japan, using jigs, and taken incidentally in fisheries for other species (Osako and Murata 1983). Catches, though not documented, were reported to be small relative to *Todarodes* and *Ommastrephes*.

Assessment and Management

Because catches were small, and generally undirected, no assessment or management has been directed at this species (Osako and Murata 1983).

3.4. Schoolmaster Gonate Squid (*Berryteuthis magister*; Gonatidae)

Schoolmaster gonate squid are relatively large, soft squids. The mantle is robust, the fins large and thick, fin length 0.55 of mantle length, fin width 0.70 of mantle length. The tentacles are long, possessing numerous small suckers, but lacking hooks. In contrast to pelagic oceanic squids, their tissues are flabby, with a higher water content and less well -developed musculature (Okutani *et al.* 1988). Coloration is brown to violet, with no iridescent tissues. Maximum size (sex not specified) is 32 cm ML (Okutani *et al.* 1988).

Distribution

Schoolmaster gonate squid are found from southern Japan (approximately 32°N) through the Okhotsk and Bering Seas, Gulf of Alaska, and coastal North America to approximately 40°N (Roper *et al.* 1984). Kubodera and Jefferts (1984b) classified them as pan-Subarctic Pacific species.

Paralarvae and postlarvae of *B. magister* have been collected from California to Japan, with centers of abundance in the south-central Bering Sea and southeastern Okhotsk Sea (Kubodera and Jefferts 1984a,b). Early life history stages were present from late March to early September in the northeastern Pacific, but were more abundant in summer. *B. magister* larvae were typically found in near-shore oceanic waters. Kubodera and Jefferts (1984b) felt that a lack of subadults in their collections may have been due to taxonomic problems (i.e. larger individuals were attributed to other species) or to increased net avoidance by larger animals. They also suggest that subadults are not taken in the upper midwater because they move to a epibenthic habitat as they grow.

Schoolmaster gonate squid are nectobenthic: as adults they are associated with the bottom, and are rarely taken in surface waters (Okutani *et al.* 1988). In the western Pacific, they are found at

greater depths, on the contintental slope between 200 and 500 m, in the southern part of their range. Juveniles are neretic to ocean pelagic (Roper *et al.* 1984).

Reproduction

Schoolmaster gonate squid spawn January to July in the North Pacific, February to April in the Bering Sea, March to June with a peak in April in the Okhotsk Sea and December to May with a peak in February and March in the Sea of Japan (Yuuki and Kitazawa 1986; Okutani 1988). The south-central Bering Sea and southeastern Okhotsk Sea may be important spawning areas (Kubodera and Jefferts 1984b). Okutani (1983) reported newly hatched schoolmaster gonate squid collected in the Strait of Georgia February-April 1981, and documented oceanic collections of advanced larvae throughout the Gulf of Alaska and Aleutian Islands areas.

Male *B. magister* develop a subtle hectocoylus on either the right or left fourth arm at maturity (Voight 1996). The males pass spermatophores to females during mating. The spermatophores are inserted into the mantle cavity and attached to the inner wall of the mantle slightly anterior to the base of each gill and near the opening of the distal oviductal gland.

Fecundity was estimated at 4,000-5,000 eggs per female in the Sea of Japan. These females had between 56 and 115 sperm ropes implanted in the mantle cavity near the base of the left or right gill. Females examined by Voight (1996) carried as many as 170 spermatophores. Wolotira *et al.* (1990) estimated fecundity at 10,000 eggs/female. Yuuki and Kitazawa (1986) estimated total fecundity at 6,000-10,000 eggs/female, and suggested multiple spawnings of approximately 400 eggs at a time. Schoolmaster gonate squid are benthic spawners, as indicated by the capture of gravid females and early juvenile stages in bottom trawls.

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Age and Growth

B. magister differs from other species reviewed in that they regularly live for more than one year. One proposed life history for the species (Okutani 1988) includes spawning in the late winterearly spring. Paralarval (5-10 mm DML) and postlarval (10-17 mm DML) stages are pelagic through the first summer, with an ontogenic descent to a benthic existence (approximately 50-70 mm DML). Subadults grow to 150-180 mm DML by the second summer, and move to the spawning grounds at lengths of 250-280 mm DML and 2 years of age. Females mature at approximately 180 mm ML and males at approximate 130 mm ML (Yuuki and Kitazawa 1986). However, Natsukari *et al.* (1993) estimated life span for *B. magister* to be four years, using statolith analyses.

Population Structure

Katugin (1995) provided electrophoretic and morphometric evidence of stock distinction in *B. magister*. He proposed three distinct stocks: one in the sea of Japan, one ranging from the Kuriles to Navarin Bay in the western Bering Sea, and a third in the Gulf of Alaska. His samples do not closely examine relationships in the eastern Bering Sea-Aleutian Islands area or within or south of the Gulf of Alaska.

Trophic Relations

Yuuki and Kitazawa (1986) and Okutani et al. (1988) listed prey of schoolmaster gonate squid in the northwestern Pacific. Included were pelagic crustaceans (*Calanus* sp., *Parathemisto* sp. and euphausiids), squids (*Watasenia scintillans*, *Enoploteuthis chunii* and *B. magister*), and small fish (*Maurolicus japonicus* and *Maurolicus muelleri*).

Reported predators of schoolmaster gonate squid include: chinook (Oncorhynchus tshawytscha), sockeye (O. nerka), chum (O. keta), coho (O. kisutch) and pink (O. gorbuscha) salmon, grenadiers (Albatrossia pectoralis, Coryphaenoides armatus and C. filifer), thick-billed murre (Uria lomvia), northern fur seals (Callorhinus ursinus), Dall's porpoise (Phocoenoides dalli) and sperm whales (Physeter macrocephalus) (Osako and Murata 1983; Okutani et al. 1988).

Fisheries

B. magister was fished in the Japan Sea, Kurile Islands and Aleutian Islands by Japanese trawlers (Osako and Murata 1983). Interest in fisheries for *B. magister* declined after the establishment of FCZ's in the 1980's, and there is currently not a directed fishery for *B. magister* in the American Bering Sea or Aleutian Islands. Present landings are bycatch in the eastern Bering Sea midwater trawl fishery for pollock, and discard rates are estimated to be more than 90% (Fritz 1996).

Squid catches in the Bering Sea and Aleutian Islands (Table 3) are reported in aggregate, not by species (Fritz 1996). Recent domestic catches in the eastern Bering Sea are predominantly *B. magister*, those in the Aleutian Islands are predominantly *Ony. borealijaponica*. Eastern Bering Sea domestic catches from 1990 to 1995 averaged 483 t, approximately 1/10 of the mean annual foreign landings from 1977-84 (4,307 t). It is assumed that decreased catches are largely due to lack of directed effort for squid, and large discard rate, not to depletion of the stocks.

Exploratory jig fishing off the west coast of North America has not been successful in capturing significant quantities of schoolmaster gonate squid (Bernard 1980; Mercer and Bucy 1983; Robinson and Jamieson 1984; Jamieson and Heritage 1988; June and Wilkins 1991; Shaw and Smith 1995; Gillespie and Shaw 1997). Since the adult stages are epibenthic and more solitary than other squid species, they are primarily available to trawl gear, rather than jigging.

Assessment and Management

Fisheries in Japan were reported to be largely unassessed and unregulated (Osako and Murata 1983). The fishery in the Aleutian Islands-Bering Sea is managed under an annual TAC (Fritz 1996). Because assessment survey data and information on distribution, abundance and biology of squids is generally lacking, the overfishing harvest level is the mean annual catch from 1978-1995. The allowable biological catch is 75% of the overfishing level. Thus the TAC for all squid species in the Bering Sea and Aleutian Islands for 1997 is 0.75*2,624, or 1,970 t.

4. Fisheries, Assessment and Management of Other Selected – Oceanic Squids

4.1. Assessment of Squids

This section is drawn from information presented in recent reviews of assessment and management of annual squid species, particularly Okutani (1977), Caddy (1983a), Pauly (1985), Saville (1987), Rosenberg *et al.* (1990), Basson and Beddington (1993) and Pierce and Guerra (1994). Other sources will be individually referenced below.

Critical parameters for assessment of squid fishery resources include biomass, recruitment, growth rates, age, natural and fishing mortalities, and fecundity. It is also important to determine how these parameters interact with one another, and what effect environmental variation has on each parameter. However, the biological differences between squid and finfish make assessment and management of squid using models developed for finfish particularly difficult.

Of primary concern is the poor state of knowledge for most squid species. Life cycles are poorly understood relative to commercially exploited finfish species: fecundity is not well documented; location and details of spawning are relatively unknown; age, growth and mortality rates are poorly understood; and stock discrimination is still difficult. Even when information has been developed, it is often for only a portion of a stock. Most of what is known about *Omm. bartrami* relates to the central and western North Pacific portion of its distribution, whether this information is accurate for the eastern Pacific portion (stock?) of the population is unknown.

Fishable biomass is likely composed of a single year class, and is linked to the previous-year's biomass only via a stock-recruitment relationship. These relationships are generally weak, and may be greatly influenced by variation in environmental conditions. In most cases, indications of stock size in any year are not available until fishing commences, and assessments start from scratch each year. Forecasting of biomass may be achieved through a well-defined stock-recruit relationship, indices of paralarval abundance, early-season indices of fishery performance, modeling of environmental correlates, or a combination of the above. Development of forecasting ability requires time series of not only biomass estimates, but also of the indices or environmental correlates that might be used to predict biomass.

Determination of annual biomass estimates or indices may be direct (surveys), acoustic estimates or post-season estimates utilizing fisheries-dependent data. Acoustic methods of estimating cephalopod biomass are being developed (e.g., Jefferts *et al.* 1987), but are hampered by target strength calibration and identification of acoustic signatures to species (Pierce and Guerra 1994). Unpredictable migration patterns of oceanic squid affect their availability to the fishery, and will cause errors in estimation of recruitment and biomass if fishery-dependent indices are used. Direct surveys of paralarvae and subadults are hampered by the ability of these active, mobile animals to avoid sampling gear, and also by difficulties in identification of early life history stages to species.

The use of age data in assessment models is still too expensive and labour intensive to be a regular part of routine assessments. Although length data is more easily obtained, and methods have been developed to interpret length frequency modes (see Pauly 1985 for a detailed

discussion), these data can be biased by immigration or sampling bias inherent in the fishing gear used to collect the samples. Extended spawning season (or multiple peaks in spawning intensity) and variable growth rates exhibited by subcohorts within a year class make assessment of recruitment and growth difficult. Estimation of natural and fishing mortalities are also highly dependent upon a sound ageing technique, and thus susceptible to the errors mentioned above. The influence of cannibalism on estimation of mortality is also uncertain.

Estimation of fecundity is hampered by a lack of knowledge of spawning behaviour. We require an understanding of whether or not the eggs which have matured in the ovary represent the total reproductive output of the individual, or only a part, if the species exhibits multiple or protracted spawnings. These estimates may require collection of mature females late in the return migration, or on the spawning grounds.

With all of these potential problems, what sort of assessment and management is possible for squid fisheries? Review of existing assessment and management programs can provide guidance on the development of these programs in new fisheries. The following examples of assessment and management frameworks for oegopsid squid are presented in this light.

4.2. Japanese Common Squid

The Japanese common squid, *Todarodes pacificus*, is thought to consist of three "stocks" in the waters around Japan, based on time and location of spawning (Osako and Murata 1983; Murata 1990). The winter stock is widely distributed around Japan, but forms the majority of the population on the Pacific coast. They spawn from January-March in the East China Sea, and adults are commonly found in coastal waters. The autumn stock is found primarily offshore in the Sea of Japan, and spawns September-November. The summer stock is small relative to the others, occurs in the coastal waters of the Sea of Japan, and spawns in the southern Sea of Japan and East China Sea where paralarvae are found May-July.

Harvest of *T. pacificus* in Japan dates back centuries (Osako and Murata 1983). Jigging accounts for the largest portion of the recent catch, with some bycatch from trapnet and trawl fisheries for finfish. The fishery was historically based off northern Japan, on both the Pacific coast and the Sea of Japan. The history of the fishery is one of greatly increased effort and fishing power after 1945, with development of larger vessels and automated jigging gear and exploitation of fishing grounds further offshore.

- Catches from the Pacific stock (Table 4), which had previously accounted for 70-90% of the catch, declined precipitously after 1970, and mean annual catch for 1973-84 (21,000 t) was only 6% of the mean annual catch for 1960-69 (352,000 t) (Murata 1990). Catches in the Sea of Japan likewise peaked in 1972, and declined thereafter (Murata 1990, his Fig. 8). Recently, catches have improved (Table 5).
 - Assessments are based on depletion analyses of catch and effort statistics to estimate initial biomass, and surveys to index larval density (recruitment) and adult density prior to opening the fishing season (Okutani 1977; Murata 1990).

Year	Pacific Coast	Sea of Japan	Total
1960	371	56	480
1961	291	56	384
1962	458	47	536
1963	434	85	590
1964	161	71	238
1965	322	80	397
1966	265	82	383
1967	395	85	477
1968	493	121	668
1969	337	90	483
1970	179	196	412
1971	112	186	364
1972	172	296	464
1973	38	276	348
1974	48	248	335
1975	77	238	378
1976	10	231	304
1977	7	153	234
1978	4	148	199
1979	3	154	213

Table 4. Annual catch ('000 t) of Japanese common squid, *Todarodes pacificus*, off northern Japan (Osako and Murata 1983).

Table 5.	Annual catch	(t) of Jap	anese comr	non squid	(Todarodes	pacificus)	1973-1995	(FAO
	1976, 1978, 19	81, 1984,	1993, 1995). Catches	s marked with	h '*' are be	est estimates	only.

Year	Catch (t)	Year	Catch(t)
1973	379,300	1985	192,466
1974	341,544	1986	141,457
1975	398,660	1987	262,025
1976	325,740	1988	227,786
1977	225,932	1989	319,790
1978	234,344	1990	321,459
1979	238,978	1991	402,976
1980	378,954	1992	545,210
1981	259,233	1993	548,635*
1982	247,922	1994	504,408
1983	230,876	1995	513,407
1984	219,529		

Murata (1990) postulated that the collapse of the fishery was a result of overfishing during naturally-occurring declines in stock, first for the winter stock in the Pacific, and then for the

autumn stock in the Sea of Japan. He indicated that management restrictions were enacted primarily to prevent disputes within industry sectors, and that there had been "little or no effort to conserve or improve the use of resources by controlling fishing effort and catch sizes". He recommended drastic reduction in effort, total closure of the Pacific fishery for one to two years, and shortened fishing seasons as means to allow recovery of *Todarodes* stocks. Stocks have only begun to show indications of recovery in the 1990's (Table 5).

4.3. Short-fin Squid off the Falkland Islands

The jig fishery for short-fin squid, *Illex argentinus*, in the Falkland Islands (Beddington *et al.* 1990; Rosenberg *et al.* 1990; Basson and Beddington 1993; Rodhouse *et al.* 1995) has been touted as "the most closely and successfully regulated cephalopod fishery in the world" (Pierce and Guerra 1994).

Short-fin squid spawn on the edge of the Patagonian shelf, and recruits migrate south into the Falklands Interim Conservation and Management Zone (FICZ) in March to feed. Maturing squid begin emigrating from the FICZ in late May and June and return to the northern spawning grounds in July, to spawn and die. The jig fishery occurs between March and May. Total annual landings (from both inside and outside the FICZ) increased from under 100,000 mt in the late 1970's to over 300,000 mt in 1993-1995 (Table 6).

The FICZ was declared and regulations imposed in 1987 (Beddington *et al.* 1990). The fishery is managed on a proportional escapement target (40%) and the catchability coefficient from the previous year is used to determine effort levels (number of vessels participating) required to attain a fishing mortality of 0.40. Catch and effort data are used post-season to estimate initial stock size, harvest rate, escapement and catchability. The target effort (number of vessels licenced) in the following year is adjusted to reflect the revised catchability coefficient.

The fishery involves far-seas vessels from 12 countries. Fishers report their catches and effort daily. Failure to accurately report can result in fines or loss of licence privileges. Cooperation is excellent, however, as a licence allows a vessel to catch as much as it is able to within the season, without quotas on either individual vessels or a total quota on the fishery. There is no benefit to falsifying fishery records, and the penalties for mis-reporting are significant.

The target rate of 40% is somewhat conservative, and must be as the stock is also fished outside the FICZ and changes in fishing power can and have occurred in the fishery (Beddington *et al.* 1990; Basson and Beddington 1993). The harvest rate likely leads to overfishing in years of poor recruitment, and may result in unnecessarily large escapement (in absolute numbers) in years when stock levels are very high (Pierce and Guerra 1994). Mid-season monitoring and adjustments are necessary to compensate for changes in fishing power of the fleet (which cause departures from the estimated catchability coefficient) and may require an increase in the proportional escapement target in years when abundance is particularly low. Table 6. Annual catch (t) of short-fin squid (*Illex argentinus*) in the southwestern Atlantic Ocean, including catches within the Falklands Interim Conservation and Management Zone (FAO 1981, 1984, 1993, 1995). Landings marked with an '*' are best estimates only.

Year	Landings (mt)	Year	Landings (mt)
1978	61,846	1987	265,390
1979	92,252	1988	236,489
1980	9,827	1989	224,635
1981	13,707	1990	156,965
1982	42,947	1991	207,406
1983	32,388	1992	222,949*
1984	43,343	1993	330,300*
1985	126,981	1994	310,075*
1986	149,238	1995	310,000*

5. Exploratory Fishing off Western North America

Experimental fishing for oceanic squid has taken place off British Columbia since 1980, and off the western U.S. since 1982.

Canadian Experimental Fishing

Bernard (1980) first suggested that commercial catches of *Omm. bartrami* and *Ony. borealijaponica* might be achieved in Canadian waters in June and July. He also speculated that a trawl fishery for *B. magister* might possibly be developed.

Early exploratory fishing primarily employed driftnets (Bernard 1980, 1981; Robinson and Jamieson 1984; Sloan 1984; Jamieson and Heritage 1987, 1988). Limited jig fishing was conducted in 1983 (Sloan 1984) and 1987 (Jamieson and Heritage 1988), but jigging was not extensively explored until 1990 and 1991 (Shaw and Smith 1995). An attempt to capture squid with a two-vessel pair trawl in 1995 was ineffective (Archipelago Marine Research 1995). A pilot commercial jig fishery was conducted in 1996 (Gillespie and Shaw 1997).

Experimental fishing with driftnets indicated that flying squid appeared in commercially exploitable abundance off the west coast of North America, particularly in 1986 and 1987 (Table 7 and Table 8). Highest catches and CPUE values were attained in years when the fishery started in June or July (Table 8).

			C	atch
Year	Gear	Species	Numbers	Weight (kg)
Sep 1979 ¹	Net	NFS	n/a	10,599
•		BCS	n/a	9
	Jig	NFS	n/a	414
	· ·	BCS	n/a	111
		OS	n/a	1
Jul-Aug 1980 ²	Net	NFS	n/a	130, 045
May-Sep 1981 ³	Jig	NFS	2	n/a
2 x	Ū	BCS	1,259	n/a
Jul-Aug 1983 ⁴	Net	NFS	14,133	32,986
U	Jig	NFS	26	64
Jul-Aug 1983 ⁵	Net	NFS	n/a	329,561
U	Jig	NFS	n/a	1,475
	U	BCS	n/a	18
Jul-Sep 1985 ⁶	Net	NFS	338,188*	771,130
Jun-Sep 1986 ⁶	Net	NFS	488,738	1,110,527
		BCS	5	6
Jun-Aug 1987 ⁷	Net	NFS	655,603	1,527,476
	Jig	NFS	40	71
Jun-Sep 1990 ⁸	Jig	NFS	161.415	320,274
	8	BCS	99	92
		EAS	113	103
		SGS	1	1
Aug-Sep 1990 ⁹	Jig	NFS	8,395	18.587
	0	BCS	1,450	961
		EAS	117	83
		RCS	18	68
		OS	6	1
		SGS	1	1
Jul-Aug 1991 ⁸	Jig	NFS	1,746	3,820
õ	U	BCS	29	17
		EAS	54	41
Aug 1996 ¹⁰	Jig	NFS	4,433	7,434'
Ų	5	BCS	46	n/a
		EAS	14	n/a
		SGS	35**	n/a
		PFS	36	n/a

Table 7. Exploratory fishing catches of oceanic squid off the west coast of North America.

Notes: Species are neon flying squid, Ommastrephes bartrami (NFS); boreal clubhook squid, Onychoteuthis borealijaponica (BCS); eight-armed squid, Gonatopsis borealis (EAS); schoolmaster gonate squid, Berryteuthis magister (SGS); opalescent squid, Loligo opalescens (OS); robust clubhook squid, Moroteuthis robusta (RCS); and purpleback flying squid, Symplectoteuthis oualaniensis (PFS). Catches with an asterisk "*" are estimated, those with a double asterisk "**" are incomplete.

Sources: 1) Bernard (1980), 2) Bernard (1981), 3) Mercer and Bucy (1983) 4) Robinson and Jamieson (1984), 5) Sloan (1984), 6) Jamieson and Heritage (1987), 7) Jamieson and Heritage (1988), 8) Shaw and Smith (1995), 9) June and Wilkins (1991), 10) Gillespie and Shaw (1997).

Jig catches were considerably lower than driftnet catches in the 1970's and 1980's (Table 7). The largest jig landings came in 1990, when 5 Japanese vessels participated in cooperative exploratory fishing off the west coast of British Columbia (Shaw and Smith 1995). Different

units of CPUE (Table 9) were presented in each of the studies (kg/machine*h or kg/jig*h). The use of combinations of single- and double-spooled machines, variable numbers of jigs per line and hand jigs precluded the calculation and comparison of standardized CPUE for all studies.

Boreal clubhook squid were the most common bycatch in Canadian exploratory jig fishing (Table 7). From the catches recorded, they appear to be more vulnerable to jig gear than to driftnets, as they are likely too small to be caught effectively by the mesh size used for flying squid. Eight-armed squid, schoolmaster gonate squid and purpleback flying squid each accounted for less than 1% of the total squid catch in 1996.

U.S. Experimental Fishing

Exploratory jig fishing for oceanic squid was carried out by the National Marine Fisheries Service, Northwest and Alaska Fisheries Center, in the summer of 1981 (Mercer and Bucy 1983) and the summer of 1990 (June and Wilkins 1991; Nakamura and Siriroksophon 1992). In 1981, squid jigging machines were mounted on an American charter vessel. In 1990, four Japanese vessels participated in cooperative exploratory fishing off the coasts of Washington and Oregon.

Table 8. Comparison of driftnet CPUE (kg/km) of neon flying squid (Ommastrephes bartrami)from vessels participating in exploratory fishing off the west coast of North America.

Vessel	Vessel Date		Source
		(kg/km)	
KOHOKU MARU 18	Sep-Oct 1979	112.4	Bernard (1980)
TENYO MARU 37	Sep 1979	61.5	Bernard (1980)
TOMI MARU 88	Aug 1980	165.8	Bernard (1981)
TENYO MARU 37	Jul-Aug 1980	332.0	Bernard (1981)
TOMI MARU 88	Jul-Aug 1983	232.3	Sloan (1984)
SIMSTAR	Jul-Aug 1983	339.2	Robinson and Jamieson (1984)
TOMI MARU 88	Jul-Sep 1985	311.5	Jamieson and Heritage (1987)
LA PORSCHE	Aug-Sep 1986	153.8	Jamieson and Heritage (1987)
OCEAN PEARL	Jul-Aug 1986	270.5	Jamieson and Heritage (1987)
TOMI MARU 88	Jun-Sep 1986	266.3	Jamieson and Heritage (1987)
OCEAN PEARL	Jun-Aug 1987	259.8	Jamieson and Heritage (1988)
TOMI MARU 88	Jun-Aug 1987	383.1	Jamieson and Heritage (1988)

Boreal clubhook squid dominated the catch in 1980, with only 2 flying squid captured. Jigging was not particularly successful, as only 47% of the recorded catch were jigged, the remainder were scooped with dipnets. Neon flying squid accounted for more than 90% of the catch in 1990. Boreal clubhook squid were the highest bycatch species (5.37%), and eight-armed, robust clubhook, opal and schoolmaster gonate squids each accounted for less than 1% of the total catch. All of the effort in 1981 was expended east of 126°W latitude. Most of the significant catches of neon flying squid were taken west of 126°W in 1990.

Vessel	Date	CPUE (kg/jig*h)	CPUE (kg/mach.*h)	Source
SIMSTAR	Jul-Aug 1982	n/a	1.33	Robinson and Jamieson (1984)
TOMI	Jul-Aug 1983	n/a	2.20	Robinson and Jamieson (1984)
MARU 88				
TOMI	Jun-Aug 1987	0.01	n/a	Jamieson and Heritage (1988)
MARU 88				
5 vessels	Jun-Sep 1990	0.09	n/a	Shaw and Smith (1995)
SANKO	Jul-Aug 1991	0.06	n/a	Shaw and Smith (1995)
MARU 18				
6 vessels	Jul-Sep 1996	0.04	n/a	Gillespie and Shaw (1997)

Table 9. Comparison of jig CPUE (kg/jig*h or kg/machine*h) of neon flying squid (*Ommastrephes bartrami*) from vessels participating in exploratory fishing off the west coast of North America.

6. Canadian Responsibilities under the U.N. Law of the Sea

The fishery for *Omm. bartrami* will occur in International waters for the most part. During warm-water years a portion of the stock will be available within the Canadian FCZ, where it can be managed exclusively by DFO. However, there will be removals outside of the FCZ by Canadian and international vessels, and management gains within Canadian waters might be undermined as the stock is fished on southward migration. Ultimately, all nations participating in the fishery will have to exchange information and develop a single assessment and management framework if the stock is to be fished optimally and rationally.

Canada is signatory to the United Nations agreement on implimentation of the 1982 Law of the Sea to highly migratory and straddling fish stocks (United Nations General Assembly 1995). This agreement imposes a number of obligations relating to data collection and exchange, assessment of stocks, and management and enforcement of the fishery.

The basic fishery data required under these obligations include: time series of catch and effort statistics, total catch in number and/or nominal weight, effort statistics, discard statistics, description of fishing operations (date, locations and time fished). Additional biological data required include: length, weight and sex composition of the catch; information on age, growth, recruitment, distribution and stock identity; and other relevant research, including surveys of abundance or biomass, hydroacoustic surveys, research on environmental factors affecting abundance, and oceanographic and ecological studies.

There is currently no established forum for exchange of statistics and results of research on oceanic squids in the North Pacific. I recommend development of an appropriate forum for data exchange and collaborative research involving Canada, and other nations participating in offshore squid fisheries. This may be acheived as a wroking group of an existing organization,

such as North Pacific Marine Science Organization (PICES), or through direct exchange between nations participating in the fishery.

7. Discussion

The assessment program for Canadian oceanic squid fisheries must concentrate on *Omm.* bartrami. Landings of the fleet in the first year of the pilot fishery (Gillespie and Shaw 1997) indicate that this is the preferred species in the fishery: flying squid accounts for over 97% of the landed catch (by piece count). The Japanese market demand which drives the fishery prefers flying squid to other species available in the Eastern Pacific.

B. magister may not be a suitable species for a jig fishery. They are epibenthic as subadults and adults, and are more solitary in nature than pelagic squid. Catches elsewhere in the North Pacific and Bering Sea have been by bottom trawl or as incidental catches of midwater trawl fisheries for other finfish species. If they are fished on the continental shelf, where they are known from incidental catches in other fisheries, bycatch rates of finfish will likely become a problem.

In cold-water years, Subarctic species assemblages may be more common off British Columbia (Pearcy 1991; Pearcy *et al.* 1996). Whether a Canadian jig fishery can be supported by a shift in target species, from *Omm. bartrami* to *Ony. borealijaponica* and/or *G. borealis*, will be dependent on the availability of these species, their susceptibility to jig fishing, and their value. Based on previous exploratory fishing, it is doubtful whether they can be caught in sufficient quantities to support large-scale fisheries, due to low demand and lower prices relative to *Omm. bartrami*.

Availability of flying squid to fisheries is a function of both variation in absolute population size and variation of oceanographic conditions, in particular, the distribution of the water masses that species prefer. Variability of population size is extreme, and at times may be cyclic (e.g. Murata 1990). Brodeur and Ware (1995) compared abundance and distribution of oceanic squids and fishes in the Central Subarctic Pacific for the periods 1955-58 and 1980-89, based on catch rates from research surveys. They showed that catch rates of *Omm. bartrami, Ony. borealijaponica* and *G. borealis* were considerably less in the 1950's than in the 1980's, even though they were not the target of active commercial fishing in the former period. While a highly capitalized fishery may be viable now, in a period of relatively high abundance, a downward fluctuation in stock size could render the fishery economically unviable. Large-sized migratory subcohorts within a population are most attractive to fisheries, and also the portion of the population most vulnerable to collapse (O'Dor 1992; O'Dor and Coehlo 1993). The northernmost portion of the stock (which includes that portion which might be available in or near the Canadian FCZ) may, due to overfishing or natural causes, decline or disappear. Given these considerations, a highly capitalized fishery for oceanic squids off Canada will be a risky venture.

I recommend that assessment and management of Canadian oceanic squid fisheries be directed towards *Omm. bartrami*, until landings indicate that other species have become significant contributors to the fishery. However, assessment information for other species should be

gathered opportunistically, to avoid starting from a position of total ignorance should they require assessment attention in the future.

Flying Squid Fisheries Assessment

Many ommastrephid fisheries that have developed assessment frameworks (*Illex argentinus* in the Falkland Islands, *I. illecebrosus* in the northwest Atlantic, *Todarodes* in the western Pacific) involve species which are fished when stocks are feeding and growing over the continental shelf. These species may have more predictable distribution and migrations, and are certainly more accessible to fisheries than squids that do not venture over the continental shelf. The distribution of truly oceanic species, like *Omm. bartrami* are more related to current structure, temperature, etc., and locating stocks over a larger area in response to subtle oceanographic cues will be difficult (or has at least proven to be difficult so far). Assessment of fishery-dependent data must include consideration of oceanographic conditions and biological information (particularly size and growth characteristcs) to determine whether inferred stock trends represent changes in availability or stock decline.

An assessment program for flying squid in the eastern North Pacific requires information on stock discrimination, annual variation in distribution and abundance, basic life history (spawning grounds, migrations, growth and mortalities), stock-recruitment relationships, and the effects of environmental variation on these parameters. Depletion estimators of stock size (Leslie-DeLury analyses) can only be used within a well-defined fishing zone (such as the Canadian FCZ), and only once the fishery has developed to the point where it removes significant portions of the available biomass. After information has been gathered for a number of years, more sophisticated production models, cohort or yield-per-recruit analyses can be examined. In the short term, accurate records of catch, effort and associated information (geo-referenced location, SST and other oceanographic information, weather conditions and sea state, phase of the moon, etc.) are required to develop standardized measures of CPUE. A biological sampling program to collect information on changes in species composition, sex ratio, size and age distribution and maturity state of the catch throughout the season and over the geographic extent of the fishery is also very important.

Management Considerations

In many ways, flying squid present challenges which will not be easily overcome by applying models developed for traditional finfish species. Their short life span renders this species particularly vulnerable to overfishing. Because the species is annual, biomass in any given year is dependent entirely on recruitment. If conditions in that year are poor (either environmentally or through overfishing) then major portions of the population can collapse. Traditional finfish resources are buffered against annual variation in recruitment by iteroparity (the survivors have a second chance to contribute to subsequent recruitment), age-structured stocks (the present biomass is dependent on recruitment and the survivors from the previous year's stock), and by having year classes which are not recruited to the fishery (are protected from overharvesting). Delayed age of recruitment to the fishable population makes possible the use of surveys for pre-recruits to provide information on recruitment strength before the animals are fully vulnerable to the fishery, and an opportunity to manage the fishery accordingly (Rosenberg *et al.* 1990).

Except for predictions based on stock-recruitment relations, assessment of annual squid species begins from scratch every year. The short life cycle of squid stocks do not allow much time to react to detected low abundance levels. Long-term management actions must be conservative enough to protect spawning biomass in 'poor' years, and supplementary actions, when required, must be instituted in-season to protect the existing year-class (and thus the following year's recruitment). In particular, when information regarding stock-recruitment relationships or stock size are poor, management must be conservative, to ensure sufficient escapement "so as not to reduce appreciably the probability of good recruitment in the following season" (Pierce and Guerra 1994).

On the positive side, flying squid have several characteristics which make them excellent candidates for rapid recovery after a collapse. Squid are rapid-growing species with fairly general trophic requirements, and are considered 'epidemic' species (Caddy 1983b) capable of quickly exploiting ecological niches vacated or underutilized by other species. If O'Dor and Coehlo (1993) are correct in their assumptions that migratory subcohorts evolve from the non-migratory subcohorts in a population and that selection for large, migratory squid is strong, then populations should recovery relatively rapidly. However, the ecosystems in which squid reside and function may have multiple stable states, and stocks could "recover" to a different, possibly lower, equilibrium stock size (Pierce and Guerra 1994).

The objectives under which the fishery is managed determine the role of assessments in the management framework. If the primary management objective is orderly conduct of fisheries and protection of historic stake in the fishery, as in the Japanese examples, then assessments are used primarily to allocate resources between competing sectors, and to facilitate industry planning by providing some expectation of resource performance in the upcoming fishery. If the primary management objective is resource conservation, as in the Falklands example, assessments provide information on stock condition and characteristics of the fishery which can be used to achieve targets or ensure that catches do not exceed maximum thresholds.

Long-term management (measures which do not require decisions on an annual or in-season basis) may be most efficient for squid fisheries (Caddy 1983b; Rosenberg *et al.* 1990; Augustyn *et al.* 1992). These might include effort limitation sufficient to avoid overfishing in years of poor recruitment, or pre-arranged and constant time or area closures.

Rosenberg *et al.* (1990) advocate the use of effort limitation in annual species simply because stock size is generally unknown before fishing commences. Limited effort reduces the risk of recruitment overfishing by allowing annual catch to vary in proportion to annual stock size. Effort limitation is desirable during the development of a new fishery, as it allows a cautious approach to sustainable yield (Hilborn and Walters 1994). Effort limitation is particularly important in the development of a Canadian fishery until fishers have learned to effectively locate and capture squid, lest the available effort in the fishery become unmanageable as the fishing power of the fleet increases with experience.

Time and area closures protect immigrant portions of the stock from growth overfishing, and provide refuge for mature or spawning squid late in the year. For these closures to be effective for *Omm. bartrami*, however, they would be required at times when the stock to be protected is

in international waters, vulnerable to exploitation by vessels not controlled by DFO. Canadian fishers might be allowed to travel south and attempt to detect squid during the immigration phase (under the right conditions, and only after sufficient time series are available, this might provide an index of recruitment and thus fishable biomass), but should be discouraged from following emigrating squid south close to or onto the spawning grounds.

Short-term (or supplementary) management actions which further limit harvests in 'poor' years should be considered. For example, if weekly catch or CPUE are considered indices of abundance, a closure of the fishery might be instituted if a minimum threshold of catch or CPUE is not achieved. Annual quotas might be used once predictive indices of abundance are developed, either through a stock-recruitment relationship or an early season index of abundance from the fishery (e.g., catch or CPUE in June between specific latitudes).

At least two commercially important species (*Todarodes pacificus* in the northwestern Pacific and *Illex illecebrosus* in the northwestern Atlantic) have suffered collapses in recent times (Osako and Murata 1983; O'Dor 1992; O'Dor and Coehlo 1993) and some authors attribute these collapses to overharvest at times when stocks are at low abundance naturally (Murata 1990). However, most information on population dynamics of squid comes from fisheries data. Thus, it is unclear whether stock declines occur naturally, or are a result of overharvest. It is inadvisable to ignore conservation principles and precautionary approaches because stock collapse is perceived to be inevitable. If a fishery continues during the collapse and recovery stages, and the fleet moves to fish the non-migratory subcohorts, as may have happened in the *Todarodes* fishery, recovery can be greatly delayed.

O'Dor and Coehlo (1993) believed that the Japanese far seas fisheries were the most effective means of harvesting squid on an industrial scale. Far seas fleets can advantageously fish species or stocks while they are at peak abundance, and, when these stocks show indications of decline, switch to other stocks or species, allowing the first to recover before returning to fish them again. Domestic fleets become dependent upon the closest stocks, and may be forced by economic concerns to continue fishing a population in decline.

Meeting Information Requirements

Application of the phase 0 review of Perry (1995) to developing squid fisheries has provided a summary of information available regarding the target species, and details of assessment and management programs for similar species. The review details the lack of information available for flying squid in the eastern North Pacific. The next step in the approach is to develop an assessment program that provides the information required to properly assess stock condition and fishery effects, for the provision of scientifically defensible advice to managers. These information requirements include:

1. Examination of stock structure in *Omm. bartrami*. If the squid fished by Canadian vessels in the eastern Pacific are only a part of a larger trans-Pacific stock, then the fishery will likely have little effect on the stock, particularly considering the greater effectiveness of driftnet fishing and the Central Pacific stock's response to high effort levels in the driftnet fishery of the 1980's and early 1990's. However, a Canadian jig

fishery would require more stringent assessment and management to avoid deliterious impacts on a small eastern Pacific stock. The Canadian fishery in isolation will not be able to shed light on the stock structure of flying squid in the North Pacific. However, it will provide opportunities for the collection of morphometric data, ageing structures and genetic samples required as part of the cooperative international research required to examine stock structure throughout the entire North Pacific.

- 2. A detailed harvest logbook program to accurately record vessel configuration, catch, effort and associated environmental conditions. Canada is required to collect accurate information on catch and effort in this fishery under the international agreements they are signatory to. Additionally, because most squid assessments are based on CPUE data, measures of effort must be standardized to account for performance differences due to machine type, configuration, effects of weather, etc.
- 3. Biological monitoring of the catch to detect shifts in population structure, and determine whether these are due to the fishery, or to natural causes. Catch and effort alone cannot reasonably be used as indicators of stock health. Population characteristics such as size, age, sex and reproductive state are required to monitor performance of the stock under fisheries pressure. The overall reduction of mean size observed in driftnet and gillnet fisheries in the Central Pacific may indicate that the LL subcohort (that portion of the stock which is available in the Canadian FCZ in most years) is vulnerable to overfishing (Ignell 1991). A program of biological sampling is required to collect this information. This might be best accomplished by on-board observers, but the duration of trips and the per-day cost of trained observers makes this option unpopular with the fishers. A more practical solution might be fishers returning frozen samples from sea to be processed after the trip, at least until the fishery becomes economically viable (and the issue of observer cost is less urgent).

8. Recommendations

The following is a summary of the recommendations detailed in previous sections:

- 1. Managers are advised to continue their policy of limited entry to the fishery. Other fisheries (e.g., the Falklands shortfin squid fishery) use effort limitation extensively to acheive management objectives. It is particularly important in the developing Canadian fishery to approach final allowable effort levels very cautiously until the fishing power of the fleet is fully developed. Allowing new entrants to the fishery based on unrealized fishing potential during development of the fishery should be avoided.
- 2. Assessment and management programs must be directed at neon flying squid until one or more of the incidental species contributes significantly to landings. However, assessment data on incidental species should be should be collected if the opportunity arises, so that future assessments will not begin from scratch.
- 3. The information gathering tools implemented in the initial year of the pilot (harvest logbook and biological sampling) should be maintained, and expanded as the fishery achieves economic viability. As the value of the fishery increases, fishers will be less resistant to observer programs, or more willing to forego a portion of the catch to provide biological

samples. As sampling opportunities increase, a structured biological sampling program must be developed.

4. Canada should take a lead role in the development of a forum of information exchange between nations fishing for flying squid and other oceanic species in the North Pacific.

Under the current DFO policy for cost-recovery in development of new fisheries, the sole source of information on squid in the eastern Pacific is the fishing industry. However, the industry is presently concerned with their own economic matters, not least of which is recovering the capital costs incurred acquiring squid jigging technology. Funding stock assessment activities is unpopular with industry as they see little potential benefit in assessments which limit their access to the resource. The Department is now faced with the delicate task of developing an economically viable fishery (and collaborative information gathering), while not seriously depleting the stock in the course of collecting the information required to develop assessment and management policies.

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