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A review of the biology of opal squid (*Loligo opalescens* Berry), and of selected Loliginid squid fisheries

Synthèse sur la biologie du calmar opale (*Loligo opalescens* Berry) et sur certaines pêches aux calmars loliginidés

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ABSTRACT

Opal squid are relatively small, short-lived squids that are found only on the west coast of North America, from Baja California to southeastern Alaska. They are most abundant off California, where they are the basis of a large fishery worth US $20-30 million annually. They live approximately 1 year, are terminal spawners, and the squid are fished while aggregated for mass spawning. The distribution, biology, abundance and ecology of opal squid in British Columbia is not well known, although they have been a minor bait fishery for decades.

Opal squid are particularly difficult to assess and manage because of their short life span. Stock-recruit relationships are weak, and likely driven by environmental conditions. Abundance, distribution and movements are not known, in part because opal squid are small and highly motile, evading sampling gear traditionally used in surveys for other species. Age can be determined using statoliths, but it is a time-consuming, specialized process that makes the use of ages in routine assessments too expensive. Protracted spawning and differing growth rates within an annual cohort make use of length-based methods very difficult. The State of California recently spent millions of dollars over three years to develop recommendations for research and assessment and a proposed management plan for the species.

The opal squid fishery in British Columbia is managed through gear restrictions, hail requirements to open areas for fishing and catch monitoring. Number of licences issued, effort and landings have all declined since the mid-1990s, to the point where coast-wide landings data cannot be released publicly because fewer than three vessels submit records. Primary management concerns are quality of catch monitoring, bycatch and adverse impacts of gear on habitat. Opal squid are the last remaining commercial invertebrate fishery that has unlimited licence issue; there are no proactive controls in place to check expansion of the fishery should market demand change.

Several options are suggested to managers: status quo, active development of the fishery (with associated assessment and management frameworks), effort limitation, or complete closure of the fishery in the absence of assessment and management frameworks. Recommendations presented include: the fishery should not be allowed to expand in the absence of assessment and management frameworks; development of the fishery should be in context of the policy for New and Developing Fisheries; the ecosystem impacts of fisheries development should be considered; and continued monitoring of management systems in other *Loligo* fisheries to guide assessment and management framework development in British Columbia.

RÉSUMÉ

Le calmar opale est un calmar relativement petit, à courte durée de vie et présent seulement le long de la côte ouest de l'Amérique du Nord, de la Basse-Californie jusqu'au sud-est de l'Alaska. Il est plus abondant au large de la Californie, où il fait l'objet d'une importante pêche de 20 à 30 millions de dollars US par année. Cet animal vit environ un an, meurt après s'être reproduit et est pêché lorsqu'il forme des bancs de reproduction. La répartition, la biologie, l'abondance et l'écologie du calmar opale en Colombie-Britannique sont méconnues, bien qu'il fasse l'objet d'une petite pêche pour appâts depuis des décennies.

La courte durée de vie du calmar opale rend l'évaluation et la gestion de ses stocks particulièrement difficiles. Les relations stock-recrutement sont faibles et dépendent sans doute des conditions du milieu. On ignore son abondance, sa répartition et ses déplacements, en partie parce qu'il s'agit d'un petit animal très mobile que l'on ne peut échantillonner au moyen des engins habituellement utilisés dans les relevés d'autres espèces. Son âge peut être déterminé par observation des statolithes, mais il s'agit d'une méthode spécialisée qui demande beaucoup de temps et coûte trop cher pour être utilisée dans les évaluations courantes. La période de fraie prolongée et les taux de croissance variables des individus d'une même cohorte annuelle rendent très difficile l'utilisation de méthodes fondées sur la longueur. L'État de la Californie a récemment dépensé des millions de dollars sur trois ans pour élaborer des recommandations en matière de recherche et d'évaluation ainsi qu'une proposition de plan de gestion du calmar opale.

La pêche du calmar opale en Colombie-Britannique est gérée au moyen de restrictions sur les engins, de l'obligation pour les pêcheurs de faire un rapport radio avant de commencer à pêcher et de la surveillance des prises. Depuis le milieu des années 1990, le nombre de permis délivrés, l'effort de pêche et les débarquements ont tous diminué, à tel point que les données de débarquements à la grandeur de la côte ne peuvent plus être rendues publiques parce que moins de trois bateaux fournissent des données. La qualité de la surveillance des prises, les prises accessoires et les incidences néfastes des engins sur l'habitat constituent les principales préoccupations liées à la gestion. La pêche du calmar opale est la dernière pêche commerciale d'un invertébré pour laquelle le nombre de permis délivrés n'est pas restreint; il n'existe actuellement aucune mesure de réglementation proactive permettant de limiter l'expansion de la pêche si la demande du marché venait à augmenter.

Nous suggérons plusieurs options aux gestionnaires : le statu quo, le développement actif de la pêche (avec des cadres de gestion et d'évaluation), la limitation de l'effort de pêche ou la fermeture complète de la pêche en l'absence de cadres de gestion et d'évaluation. Nous faisons les recommandations suivantes : ne pas laisser la pêche prendre de l'expansion en l'absence de cadres de gestion et d'évaluation; développer la pêche dans le cadre de la politique des pêches nouvelles et en développement; tenir compte des impacts du développement de la pêche sur l'écosystème; continuer de surveiller les régimes de gestion d'autres pêches de *Loligo* afin de s'en inspirer dans l'élaboration des cadres de gestion et d'évaluation de la pêche au calmar opale en Colombie-Britannique.

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Introduction

Cephalopods (squids, cuttlefishes and octopuses) continue to increase in importance as fisheries resources. World production of cephalopods increased from approximately 1.5 million t in 1980 to over 3 million t after 1996 (Figure 1). In North America, however, cephalopods have generally remained minor fisheries resources.

In British Columbia, three species are the focus of relatively minor fisheries. Octopus, primarily *Enteroctopus dofleini*, are targeted in a dive fishery and taken incidentally in crustacean trap fisheries and shrimp and groundfish trawl fisheries (Gillespie *et al*. 1998). Neon flying squid, *Ommastrephes bartramii*, are occasionally targeted by vessels using automated jigging machinery (Gillespie 1997), and opal squid, *Loligo opalescens*, are targeted using small seines. Some schoolmaster gonate squid, *Berryteuthis magister*, are taken as bycatch in groundfish trawl fisheries (Gillespie 1997).

This paper is a result of concerns regarding decreasing trends in catch and effort and industry information on British Columbia fisheries for opal squid. Because the opal squid fishery in British Columbia has already been developed, this paper represents a *post facto* phase 0 assessment (*fide* Perry *et al*. 1999). The objectives of the paper are:

1. To gather and synthesize all available published information on the biology, behaviour and ecology of loliginid squids, particularly *L. opalescens*;
2. To critically review available information on British Columbia opal squid fisheries;
3. To review assessment and management of fisheries for loliginid squid in general, and *L. opalescens* in particular, elsewhere in the world;
4. To provide a focus for discussion of current issues relating to British Columbia opal squid fisheries; and
5. To provide recommendations and advice to managers for the rational management of British Columbia fisheries for *L. opalescens*.

Biology of *Loligo opalescens*

Taxonomy and Systematics

Living cephalopods are divided into two subclasses: Nautiloidea (for the chambered nautiluses) and Coleoidea (Figure 2). The Coleoidea are divided into two superorders: Decapodiformes and Octopodiformes. The Decapodiformes contain four orders: Spirulida (containing only one species, *Spirula spirula*), Sepiida (cuttlefishes), Sepiolida (bobtail squids) and Teuthida (squids). The Octopodiformes are divided into two orders: Octopoda (octopuses) and Vampyromorpha (vampire squids).

Squid are characterized by long, tapered bodies equipped with a pair of posterolateral fins, eight arms arranged in a ring around the mouth (each bearing rows of suckers armed with chitinous rings or hooks), and two longer tentacles bearing clusters of suckers and/or hooks (tentacular clubs) at their distal end.

The Teuthida are divided into two suborders: the Myopsina and the Oegopsina. The eyes of myopsids are covered by a corneal membrane and have a minute associated pore, the tentacular club bears suckers only, and females have accessory nidamental glands and only a single oviduct. This suborder has only a single family, the Loliginidae, which contains five genera of near-shore neretic squids which lay their eggs in compact masses on the bottom. The opal squid is one of 30-40 species of squid in the family Loliginidae (Nesis 1982; Boyle and Boletsky 1996)(Figure 3) and one of 21 species of squid known from B.C. waters (Table 1).

Roper *et al*. (1984) listed only a single synonym for *L. opalescens* Berry, 1911 - *Loligo stearnsi* Hemphill, 1892. Although this name pre-dates *opalescens*, it was suppressed by a ruling of International Committee on Zoological Nomenclature (Sweeney and Vecchione 1998). Hochberg (1998) included *Ommstrephes tryoni* Keep, 1904 (no description, not of Gabb) and *Loligo pealii* not LeSueur (cited in Jenkins and Carlson 1903).

The FAO accepted common names are opalescent inshore squid, calmar opale (French) and calamar opalescente (Spanish). Other common names include market squid in the United States, opal squid in Canada and Kariforunia yariika in Japan (Roper *et al*. 1984) common squid, sea arrow, calamary and calamari (Hochberg and Fields 1980).

Description

A slender mantle, compact head, eight short, compact arms and two feeding tentacles characterize the relatively small opal squid (Figure 4). The tentacular clubs are narrow and unexpanded and the tentacular suckers are equipped with rings, each armed with approximately 30 blunt teeth. The arm sucker rings have 9-12 blunt teeth. In males, the fourth left arm is hectacotylized on the distal third, with suckers greatly reduced in size and the stalks enlarged into papillae (Roper *et al*. 1984). The mantle also has an internal shell, called a pen or gladius. A pair of fins, about half as long as the mantle (Berry 1911), along with a siphon, propel the squid as it darts through the water. For a more detailed morphological description, please see Berry (1912) and Hochberg (1998).

Maximum size is approximately 19 cm dorsal mantle length (DML) and 130 g for males, 17 cm DML and 90 g for females. Average total length (TL) is approximately 30 cm. Minimum size at spawning is 8-12 cm DML for females, and 7-11 cm DML in males (Roper *et al*. 1984). In general, females will have smaller head, arm and tentacle measurements than males of the same mantle length (Fields 1965)(Figure 5).

The coloration of living animals when undisturbed is at most times pale, milky and translucent, with a faint bluish tone due to the haemocyanin of the blood. Deeply embedded in the skin are iridophores, which produce scattered areas of brilliant blue-green opalescence and allow for instant camouflage. Intense and varied color patterns are exhibited during activity and excitement, with waves of color running over the whole animal when it is catching its prey. After pursuit when the animal is eating there is a general darkening of color (Fields 1965).

Distribution

Opal squid inhabit continental shelf waters off the west coast of North America from approximately 25-50ºN, and occasionally occur as far north as Southeastern Alaska (Wing and Mercer 1990). They are particularly abundant in the California Current system (Roper *et al*. 1984) and occur most commonly in the nearshore and inshore waters. In B.C., they have been found throughout coastal waters. However, fishable concentrations are less common north of Vancouver Island, though abundance in more northern regions is believed to increase during and just after El Niño years (Wolotira *et al*. 1990). Although widely dispersed along most of coastal North America, the areas of greatest spawning abundance appear to be off central and southern California (Fields 1965; Kato and Hardwick 1975; Vojkovich 1998).

Schools occur primarily in waters where temperatures range from 10-16ºC (Roper *et al*. 1984). Before reproducing, opal squid appear more dispersed, with some individuals in deeper water. However, for spawning they generally form dense schools and migrate to near shore areas of 20-55 m in depth. While these depths are typical, spawning *L. opalescens* adults have also been found depositing eggs in depths as shallow as 3 m and occasionally eggs have been observed at depths of 200 m (Hixon 1983; Maupin 1988), on salmon net pens at depths of 5-10 m (J. Morrison, DFO Fish Management, pers. comm.) and in the intertidal zone (J. Cosgrove, Royal B.C. Museum, pers. comm.).

Life History

Short-lived and known to complete its entire life cycle in 9-18 months, the opal squid appears to be a true terminal spawner, with death following soon after spawning. Laboratory studies indicate that this species can spawn successfully 8-9 months after hatching (Yang *et al*. 1983b). Analysis of statoliths indicated that for both male and female opal squid in southern California, maturity (during an El Niño year) was sometimes as early as 6 months after hatching (Butler *et al*. 1999). At maturity they tend to form large spawning aggregations usually in relatively shallow waters, where the eggs are commonly deposited on sandy substrate, often at the edges of canyons or rocky outcroppings (McGowan 1954).

Eggs are 2.0-2.5 mm in length and from 1.3-1.6 mm in width (Fields 1965; Jefferts 1983). The female will extrude 20 to 30 gelatinous egg capsules, each containing 200 to 300 eggs (Fields 1965). Each capsule measures 5-20 cm. The females anchor the egg capsules, by means of a thin transparent, eggless stalk, to previously laid egg capsules or to the substrate. The preferred substrate typically being mud, sand or gravel. Several hundred egg capsules may be attached to the same spot to form a large cluster. Benthic egg masses can be up to 12 m in diameter and over a meter in depth (Hixon 1983), with masses sometimes scattered over several acres of inshore sea floor (Frey and Recksiek 1978).

Rate of embryonic development is dependent on water temperature. Eggs hatch in approximately 90 days at 8ºC, 60 days at 10ºC, 30 days at 13.6ºC, and 15-23 days at 16ºC (McGowan 1954; Fields 1965; Bernard 1980; Jefferts 1983). In laboratory experiments, eggs developed in 30 days at 15ºC (Yang *et al*. 1983b).

Squid do not go through metamorphic changes, as do other mollusks, hence, *L. opalescens* does not have a true larval stage. Eggs subsequently hatch as miniature adults with disproportionate small fins and are called hatchlings (Yang *et al*. 1983a) or paralarvae. Fields (1965) observed that hatching occurs most profusely in darkness or at night and new hatchlings are often observed swimming upward toward the surface, attacted to lights. It is felt they are widely dispersed by coastal currents from the spawning grounds. Young opal squid 3.5 to 7 mm ML are known from plankton samples to be primarily neritic in occurrence (Okutani and McGowan 1969). They are distributed throughout the year in near-shore waters, where they occur in the water column primarily at depths between 25-40 m and in water temperatures between approximately 12.5-21.0ºC (Okutani and McGowan 1969; Hixon 1983).

Age and Growth

Age and growth estimates for *L. opalescens* have been gathered from a number of sources and methods, including culture data, field data, length-frequency analysis and statolith assessments. The information obtained from these efforts has in some cases been uncertain (*see* Hixon 1983). The work that Fields (1965) began on opal squid during the 1950s and 1960s has defined much of our current knowledge on this species and his initial attempt at understanding growth was derived from field sampling and the use of length-frequency analysis. These earliest estimates suggested a growth rate of 4 mm/month and a life span of approximately 2-3 years (Fields 1965; Jackson 1998). Since these earliest efforts the ageing of squid has progressed with the use of daily statolith increments for defining growth and life spans. Spratt (1978, 1979) originally identified the importance of increments within the statolith and using daily and monthly increments derived a maximum life span for opal squid of 2 years. Age assessments since Spratt's preliminary work by Yang *et al*. (1986), Jackson (1994) and Butler *et al*. (1999) interpreted all statolith increments as daily and suggested that central and southern Californian opal squid may complete an entire life cycle in less than a year.

While gaps still exist in our knowledge of opal squid growth much of the information gathered to date suggests it is strongly seasonal and correlated with water temperature. Typically, squids that hatch during warmer seasons appear to have faster growth rates and shorter lives (Jackson 1998). Spratt (1978) also observed that opal squid hatched in early summer will grow rapidly and reach adult size more quickly than late broods which are subjected initially to low winter temperatures (and hence having low initial grow rates). For example, in central California, upwelling begins in March-April, which brings added nutrients to nearshore areas causing plankton blooms during the summer. Squid spawned in this region in April-May will grow rapidly during the summer season and will tend to reach adult size in less than 1 year.

As well, seasonal differences in growth rate have been documented for other loliginids including *Loligo gahi* (Hatfield 1991, 1998) and *L. pealei* (Brodziak and Macy 1996). Jackson *et al*. (1997) reported that small, shallow-water loliginids (*Loliguncula brevis*) can exhibit marked seasonal differences in growth as a result of pronounced seasonal temperature fluctuations. For example, the age of this species ranges from 81-172 days depending on the prevailing temperatures during growth, with temperature appearing to be especially important during the early growth period (Jackson 1998). As well, Hatfield (1998) during her study of *L. gahi* provided evidence that increased temperature during the early growth period could markedly accelerate growth giving rise to significant differences in length at age for adult squid hatched at different temperatures.

Results of ageing work on various species of squid suggest that growth is continuous, nonasymptotic, and exponential or linear in form. Additionally, other authors have indicated that size may not be a reliable indicator of age in field-caught cephalopods and final size may vary greatly within a species depending upon factors such as food and temperature (*e.g.*, Forsythe and Van Heukelem 1987; Hatfield 1998). While growth of *L. opalescens* is still poorly understood it is apparent that their wide latitudinal distribution influences various growth and life span patterns, mostly due to the considerable temperature differences encountered throughout its range. Opal squid are thus believed to exhibit a marked plasticity in growth depending on the season of hatching, the region and/or other physical phenomena such as El Niño events (Jackson 1998).

Laboratory experiments by Yang *et al*. (1980, 1983a, 1983b, 1986) demonstrated that growth in a 'cultured' environment was initially fast, increased exponentially in the first 2 months, then slowed to a logarithmic rate (8.35% and 5.6-1.6% respectively). Spratt (1978) combined age (statolith ring counts) with DML data to calculate the mean, range and standard deviation value for 3-month intervals throughout the life cycle. Mean size for each 3-month interval from 3 to 24 months was approximately 25, 60, 70, 88, 120, 137, 138, and 167 mm (adapted from Spratt 1978 and Maupin 1988). However, Spratt's (1978) interpretation of monthly growth rings is disputed (Hixon 1983; Jackson 1998), suggesting that his methods underestimated growth and overestimated longevity. In 1998 Butler *et al*. (1999) derived growth rates from size-at-age information for opal squid catches in southern California during an El Niño year. Analysis of 192 statolith pairs using the daily ageing criteria of Yang *et al*. (1980, 1986) and Jackson (1994) indicted linear type growth, with maturation in less than 200 days and life spans not exceeding 250 days. Similarly, Jackson (1994) demonstrated higher growth rates than previously reported, with maturation in less than 200 days and life spans not exceeding 300 days. Results of Butler's *et al*. (1999) assessments suggest growth rates of about 0.6 mm DML per day. Growth in length was best described with the linear equation: $DML = -14.7 + 0.627*Age$ (days), with no significant variation in growth rate between male, female, and indeterminate individuals.

In California, males and females have the same weight-length relationship until they reach a mantle length of approximately 120 mm[1] (Fields 1965). At larger sizes males weigh more than females of the same mantle length, and the difference becomes greater with increasing size. Adult males have a larger head as well as thicker, longer arms and tentacles than females (Fields

[1] Opal squid in B.C. mature at smaller sizes than those in California, so it is likely that sexual differentiation becomes apparent at smaller sizes.

1965). Males also attain greater mantle lengths than females. The average length and weight from the commercial catch at Monterey were 150 mm ML and 70 g for males and 140 mm ML and 50 g for females (Fields 1965). This pattern of growth and sexual dimorphism is typical of other cephalopods, where differences in size of males and females tends to become most dramatic only in mid to later life stages with the approach of sexual maturity. The post-hatching period of rapid (exponential) growth produces males and females of equal size. It is later that differential growth of the sexes is seen. The general pattern of rapid growth until sexual maturity, then spawning once and dying seems accurate for females, but less so for males, which tend to mature before contemporary females, yet continue to grow after maturation (Forsythe and Van Heukelem 1987). In *L. opalescens* fully mature reproductive organs constitute between 25 to 50% of the total body weight of the female (Fields 1965). In pre-spawning mature males the weight of the reproductive organs constitutes 10 to 12% of the total body weight of small males (80-110 mm ML) and between 4.5 and 7% of the body weight of larger 'average spawning size' (150 mm ML) males (Fields 1965; Hixon 1983). Presumably, males can continue to grow after reaching maturity since only a relatively small amount of energy need be diverted from somatic to reproductive growth (Forsythe and Van Heukelem 1987).

Maturity Stages

The maturation process in loliginind squids entails somatic preparation for the production of gonadal and supportive cells, build-up of accessory structures, and physiological and behavioral triggers to initiate reproduction (Lipinski and Underhill 1995). The process includes both continuous phases and "leaps". Understanding the maturation process is vital to understanding the life cycle of squid and revealing clues to population structure, dynamics and migrations. The maturation process has been investigated for various species of squid and *Loligo vulgaris reynaudii* (chokka squid) in particular. Lipinski and Underhill (1995) have explored the maturity process using various 'measures' (gonadosomatic indices, histological, morphological) and have suggested that the morphological scale of maturity with possible broad application is a better representation of the maturation process. Defined morphological categories can be directly linked to microscopic development and "leaps" on a microscopic level (ontogenetically new types of cells) can be linked to morphological changes on a macroscopic level (Sauer and Lipinski 1990).

Maturity stage assessments pertaining to *Loligo* in general, and *Loligo vulgaris reynaudii* in particular, are described in Lipinski (1979), Sauer and Lipinski (1990) and Lipinski and Underhill (1995). In defining maturity stages for California *L. opalescens* Jackson successfully utilized Lipinski and Underhill's (1995) work (G. Jackson, Univ. of Tasmania, pers. comm.). We adpated the same stage information to assess maturity of *L.opalescens* taken from British Columbia waters in 2001. Detailed results of assessments of B.C. opal squid samples taken in 2001 can be found in the British Columbia (*L. opalescens*) section.

Maturity stages were characterized as follows (Table 2):

Stage 1

It is difficult to distinguish between males and females when fresh without the aid of a microscope. The sexual organs are very small in proportion to mantle length and usually are translucent.

> Males – when preserved in alcohol or formalin the spermatophoric complex is clearly visible and testes are no longer translucent or semi-opaque.
>
> Females – in alcohol the nidamental glands are easily visible but less visible in material when preserved in formalin.

Stage 2

Morphological differentiation of the sexual organs is apparent at this stage. Gonads are larger and the accessory organs become fairly well differentiated.

> Males – separate parts of the spermatophoric complex are clearly visible and Needham's sac does not protrude. The vas deferens is inconspicuous, translucent or semi-translucent. The testis is also small and may be semi-translucent.
>
> Females – the nidamental glands do not obscure underlying viscera and may be semi-translucent, semi-opaque or white. Accessory nidamental glands should be visible, as well the oviducal gland is visible, and the ovary is semi-transparent, rather flat, and irregularly segmented though in defrosted material the ovary is seldom clear.

Stage 3

This stage is notable for the secondary differentiation of the reproductive system, mainly in the accessory sexual organs. The physiological maturation is almost complete, especially in males.

> Males – the spermatophoric complex is enlarged and opaque, and has a white band of tentative spermatophores visible inside. The vas deferens is whitish or white, clearly visible though not yet dorsal of the spermatophoric complex. The Needham's sac clearly protrudes, and none or only tentative spermatophores are present in the Needham's sac (very rarely in the penis). The testis is enlarged and opaque and usually no structure is visible.
>
> Females – the nidamental glands are enlarged and partially obscuring the underlying viscera. The accessory nidamental glands are partially covered by the nidamental glands and covered densely with red dots and/ or patches. There are no eggs in the oviduct and the ovary is still rather compact and semi-opaque, with clusters of oocytes (large), and single oocytes visible. There are no or only a few eggs inside the uniformly granular ovary in Stage 3 females.

Stage 4

At the end of this stage functional maturation is reached, with individuals morphologically and physiologically ready to spawn.

Males – the spermatophoric complex is large and opaque and spermatophores are visible inside. The vas deferens is white and clearly visible on the posterior as well as the anterior part of the dorsal side of the spermatophoric complex. The length of Needham's sac is greater than the spermatophoric complex. The testis is large and opaque, and the structure is clear on all surfaces. In stage 4 males, the lack of densely packed spermatophores in Needham's sac and general absence of spermatophores in the penis distinguish it from stage 5 males.

Females – the nidamental glands are large and cover large parts of the viscera, and their secretion begins late in this stage. The accessory nidamental glands are covered (sometimes almost entirely) by red patches. The oviducal gland is large and the midline on its ventral side is well defined. The ovary is also enlarged and extends forward, and the few mature oocytes tend to be placed proximally. Distinguishing stage 4 from stage 5 is somewhat subjective. Generally in stage 4 the oviducal meander is not packed with mature eggs, and the proximal part of the ovary has few mature oocytes. However, in smaller *Loligo* specimens such as those collected in British Columbia waters the oviducal meander can be difficult to detect.

Stage 5

Animals at this stage spawn actively and functional maturity is reached with an activated behavioral response. This period may be prolonged.

Males – this stage is similar to stage 4 except that well-formed, functional spermatophores are densely packed in Needham's sac and some can be found in the penis. The testis is still large and the mantle is not particularly thin and/or loose or flaccid.

Females – stage 5 differs from stage 4 in that the oviducal meander is now densely packed with mature eggs. Most of the proximal part of the ovary is packed with mature oocytes, whereas the distal portion is usually immature or mosaic. In general there are many mature oocytes in the ovary and the nidamental glands are still large. The mantle is also not particularly thin and/or loose or flaccid.

Stage 6

Squid at this stage are finished spawning and possibly near the end of their lives. However, spawning itself may last several days, weeks or months, making the duration of this stage highly variable and changes in the reproductive organs rather gradual.

Males – there are more functional intact spermatophores in the penis than in Needham's sac and those in Needham's sac may be disintegrating. The testis is small, but its structure is clearly visible. The mantle is usually very thin.

Females – the ovary can no longer be divided into proximal (with a larger number of mature oocytes) and distal portions (with a larger number of immature oocytes and a mosaic pattern). It is now relatively small, consisting of a mosaic with a prevalence of mature oocytes. The nidamental glands are small and the mantle may also be very thin.

Reproduction

Opal squid reproductive behaviour involves an elaborate courtship where the males pass sperm packets to the females, with the sperm often being stored until the eggs are mature. Males possess a hectocotylized left ventral arm, and females have a seminal receptacle (bursa copulatrix) below the mouth on the buccal membrane. Males initiate mate selection, and males ready to mate display a colour pattern in which the head and arms flush red and then dark maroon (Fields 1965; Hurley 1977). Males copulate with females by grasping them from below and inserting their right ventral arm into the female's mantle cavity. The right arm is withdrawn just before the hectocotylized left arm carrying spermatophores is inserted in its place. The spermatophores ejaculate and are anchored near the opening of the oviduct. Males will often remain in a copulatory embrace after withdrawing the hectocoylus, even while the female begins laying the first few egg capsules. The seminal receptacle of pre-spawning, sexually mature females usually contains sperm, indicating that *L. opalescens* also copulates in a head-to-head position in which the spermatophores are placed near the seminal receptacle (Hixon 1983). Multiple matings are typical and after separation both individuals will mate with other partners (Hixon 1983). Although the ratio of males to females is generally 1:1 for *Loligo* populations, in spawning aggregations there appears to be a skew toward slightly more males, which establishes a selection gradient of males competing for females (Hanlon 1998).

Spawning, like mating generally takes place at night, but it has been observed during the day (Fields 1965). Eggs pass from the oviduct and out through the funnel enveloped in the combined secretions of the oviducal and nidimental glands. The emerging egg capsule is enclosed within a cone-shaped space formed by the arms and tentacles. Fertilization takes place when sperm released either from spermatophores within the mantle cavity or from the seminal receptacle penetrate the gradually hardening sheath of the egg capsule and egg chorion. Egg laying behaviour often ensues after mating occurs, and can be elicited in the laboratory by introducing a real or artificial egg cluster (Hurley 1977). The egg cluster acts as a visual stimulus for the female to attach the newly laid egg capsule to the egg cluster (Hixon 1983).

Spawning squid generally migrate to sheltered bays and inlets, where they form large aggregations and lay eggs in large communal masses. For many loliginids spawning aggregations commonly comprise hundreds, thousands or even hundreds of thousands of squid (Hanlon 1998). However, as with *L. vulgaris reynaudii and L. pealei*, very small groups or individual pairs of *L. opalescens* may also lay eggs in isolation (Hanlon 1998). These mating-spawning aggregations are most frequent during winter in the southern part of the range and progressively later in the season northward. While spawning occurs throughout the year, in B.C., it generally occurs between December and September, with two major peaks in activity in March and July. There is a general pattern of winter spawning in Georgia and Queen Charlotte Straits and summer spawning near Victoria and on the west coast of Vancouver Island. In southern California, the main spawning peak occurs from December through February and in Monterey Bay from February through April. Peak spawning in Oregon is in spring and early summer and in the Straits of Juan de Fuca in mid- to late summer. Spawning activity peaks in Puget Sound from December through February and in southeastern Alaska from March through May (Bernard 1980; Street 1983; Jefferts 1983). As the spawning schedule is variable, peak activity may occur earlier or later than indicated (Maupin 1988).

Trophic Relations

Opal squid are carnivorous and feed primarily in the water column. Adults feed mostly on crustaceans, especially euphausiids, with copepods, mysids and cumaceans also comprising part of their diet. Molluscs, including cephalopods and gastropods, as well as fish are also fed upon (Roper *et al*. 1984; Karpov and Caillet 1978). Juveniles seem to feed more on calanoid copepods, cumaceans, decapod megalopae and larval fishes (Karpov and Caillet 1978; Hixon 1983). On the spawning grounds Karpov and Caillet (1978) found demersal feeding to be more important with benthic organisms such as megalops larvae, polychaetes, gastropods, and eggs being commonly consumed. *L. opalescens* are active and often voracious pelagic predators with significant metabolic demands, however consumption is reduced during spawning, especially in females. Karpov and Caillet (1978) estimated that the opal squid population consumes daily the equivalent of at least 14% of the total opal squid biomass.

Loligo opalescens is cannibalistic and cephalopod fragments occur most frequently in stomach samples taken from spawning grounds (Karpov and Caillet 1978). Fields (1965) observed that 75% of the diet consisted of other squid in spawning schools. However, in general the incidence of whole cephalopod remains in the stomach is low compared to other food types (Loukashkin 1977; Karpov and Cailliet 1978). Field study and the analysis of stomach contents also indicate that males tend to ingest cephalopod parts more frequently and to eat more megalops per meal than females (Karpov and Caillet 1978).

During feeding, an opal squid changes color and forms a cone with its arms to hide its tentacles. It then makes short darts at prey and captures it by shooting out tentacles. Prey is returned to the open arms and held and eaten, so the squid can capture additional prey with its tentacles while eating. The prey held in the sucker-bearing arms and tentacles is paralyzed with a neurotoxin. Large or shelled organisms are also broken apart with powerful beaks (Fields 1965; Wolotira *et* *al*. 1990). Generally opal squid feed between 20-50 m in the water column during the day, but may rise to the surface to feed at night when moonlight is bright or where lights are present (Wolotira *et al*. 1990).

As a forage species, opal squid are an important source of food for salmon, flatfishes, sharks and other finfishes, marine mammals and seabirds (Roper *et al.* 1984). They play a significant role as an intermediary in many food chains. Morejohn *et al*. (1978) looked at the extent of predation on opal squid in Monterey Bay. Observations from this study suggested *L. opalescens* ranked first in the diet of curlfin turbot, *Pleuronichthys decurrens*, and ranked second in the diet of four marine fish: lingcod, *Ophiodon elongatus*; speckled sanddab, *Citharichthys stigmaeus*; Pacific sanddab, *Citharichthys sordidus*; and coho salmon, *Oncorhynchus kisutch*. As well, Sandercock (1991) indicated that opal squid were a relatively minor component of coho salmon diets and Healey (1991) observed this species as a minor component of chinook salmon, *Oncorhynchus tschawytsha*, diets off San Francisco in the spring. While to some extent sockeye, *Oncorhynchus nerka*, pink, *O. gorbuscha*, and chum, *O. keta*, salmon also prey on squid (or squid larvae in the case of chum) during their oceanic phase (Burgner 1991; Heard 1991; Salo 1991), the species consumed are not likely to be opal squid. A summary of known opal squid predators that are found in B.C. waters is in Table 3.

Pearsall *et al*. (in prep.) examined the diet of fishes in Hecate Strait in northern B.C. Opal squid were found in the diets of nine of the 29 species examined: dogfish, *Squalus acanthias*; big skate, *Raja binoculata*; ratfish, *Hydrolagus colliei*; Pacific cod, *Gadus macrocephalus*; redbanded and yellowtail rockfish, *Sebastes babcocki* and *S. flavidus*; sablefish, *Anoplopoma fimbria*; petrale sole, *Eopsetta jordani*; and Pacific halibut, *Hippoglossus stenolepis*. Opal squid accounted for more than 1% of the stomach contents in only two species (redbanded rockfish and dogfish) and approximately 1% in big skate and Pacific cod.

Of the thirteen bird species examined by Morejohn *et al*. (1978), all consumed *L. opalescens,* and it ranked first in the diet of five birds: rhinoceros auklet, *Cerorhinca monocerata*; black-legged kittiwake, *Rissa tridactyla*; California gull, *Larus californicus*; sooty shearwater, *Puffinus griseus*; and short-tailed shearwater, *Puffinus tenuirostris* (Table 3). Opal squid were an important component of the diet of common murres, *Uria aalge*, in central California (Ainley *et al*. 1996). In B.C., opal squid were reported as prey of rhinoceros auklet; tufted puffin, *Fratercula cirrhata*; and northern fulmar, *Fulmarus glacialis* (Vermeer 1992).

Of the marine mammals in Monterey Bay, samples were collected from only 9 species and opal squid was found to rank first in the diet of the Alaskan fur seal, *Callorhinus ursinus*. Other species known to feed heavily on opal squid included the California sea lion *Zalophus californianus*; harbor porpoise, *Phocoena phocoena*; and Dall's porpoise, *Phocoena dalli* (Table 3)(Maupin 1988). Opal squid were one of the most important items in the diet of California sea lions in southern California (Lowry and Carretta 1999), and were utilized by Guadalupe fur seals in central and northern California (Hanni *et al*. 1997). Opal squid were also the most common item in the diet of harbour porpoise in Monterey Bay (Sekiguchi 1995).

Parasites and Disease

Dailey (1969) investigated parasites in opal squid used to feed experimental marine mammals at the Point Mugu Marine Bioscience Facility. In this survey he found that 20 of 26 commercially caught specimens sampled (76.9 %) were infected with two types of juvenile cestodes. All were larvae in the plerocercoid stage of development belonging to the orders Tetraphyllidea and Pseudophyllidea. The tetraphyllideans were identified as *Scolex pleuronectis bilocularis*. Those larval stages belonging to the order Pseudophyllidea were identifiable only to ordinal level. Two nematodes were also found in separate hosts. Sites of infection included the eye, stomach, caeca, body cavity and mesenteries (Dailey 1969). Fields (1965) observed that the parasites sometimes found in *L. opalescens* included solitary nematode worms and plerocercoid larvae of tetraphyllidean cestodes, which were found in the caecum and elsewhere. The cestode *Pelichnibothrium speciosum* has also been noted as a common parasite of *L. opalescens* (Hochberg 1983). McConnaughey (1959) reported the dicyemid *Dicyemennea nouveli* from *L. opalescens*, but Hochberg (1983, 1998) felt that the report was probably an error in host identification, as dicyemids characteristically infect benthic rather than pelagic cephalopods. Hochberg (1998) indicated that unidentified phyllobothrid and pseudophyllidean helminths and an unidentified philometroid nematode were also reported from *L. opalescens*.

The small polychaete worm *Capitella capitata ovincola* are known only from benthic egg masses of *Loligo opalescens* (Hochberg 1990). These worms live in compact clumps which penetrate the gelatinous matrix of the egg finger. They do not appear to harm eggs or embryos, but feed on the jelly in which the eggs are imbedded.

Population Structure and Dynamics

Estimates of the abundance of *L. opalescens* and the factors that influence population size and the large-scale patterns of this species are sparse. However, historical evidence as well as recent catch data suggests that the biomass of this species is large. Between 1991 and 2000, excluding 1992 and 1997, it was California's top commercial marine species by volume ranging between 37,000 to 118,000 t (82 to 260 million pounds) landed. While opal squid are known to migrate inshore to spawn, little is known about the geographic or depth distribution during non-reproductive seasons (Maupin 1988). Juveniles and immature squid are collected at times in otter and midwater trawls, purse seines and in the stomachs of predatory nekton (Fields 1965; Caillet *et al*. 1979). Fields (1965) theorized that young squid, upon hatching, swim toward light, thus reaching the surface where they become dispersed by currents. Few hatchlings have been found in surface, mid- or bottom water near the spawning grounds (McGowan 1954; Okutani and McGowan 1969). However, other work has shown that the largest number of hatchlings were collected by towing a small plankton net, mounted on a sled, over the bottom near a major spawning ground. This finding suggests that *L. opalescens* hatchlings may be quickly dispersed to deeper water offshore by bottom currents (Recksieck and Kashiwada 1979).

Catch statistics from the fishery at Monterey (which seems to be the best fishery for reflecting abundance) suggests that the population size fluctuates widely from year to year (Fields 1965).

Climatological changes seem to strongly influence squid catches (Dickerson and Leos 1992; Vojkovich 1998). For example, in the Monterey area, warmer than normal water temperatures appear to have a positive effect on catches 18 months later (McInnis and Broenkow 1978). However, El Niño events, which are associated with reduced upwelling and diminished primary productivity, seem to have the opposite effect. Declines in squid landings have traditionally corresponded with the onset of El Niño conditions in the California Current system. During 1973-74, 1983-84, 1992-93 and 1997-98 El Niño years reduced squid catches were reported.

Fields (1965) noted a disappearance of the larger-sized opal squid and a general reduction in the size of squid landed in the fishery at Monterey. The mean mantle length of spring and summer spawning males decreased from approximately 160 mm ML in 1948 to about 130 mm ML in 1952. Females declined from approximately 152 mm ML to below 140 mm ML in the same period. These small sizes predominated until 1962 when the mean size returned to those observed before 1948. Fields (1965) discounted overfishing as the cause of the size decline, but he noted that the reduction in squid size coincided with the virtual disappearance of the California sardine from central and northern California. He speculated that the smaller-sized opal squid may have resulted from either an undetected reduction in the population of a food resource common to the opal squid and sardine, or to the loss of the sardine itself as prey of the squid. Perhaps what Fields (1965) was observing was the influence of El Niño events, which for that time period coincidentally occurred during 1941-42, 1951-52, 1953-54, 1957-58 and then not again until 1965-66.

During El Niño the trade winds relax in the central and western Pacific leading to a depression of the thermocline in the eastern Pacific, and an elevation of the thermocline in the west. Subsequently there is a reduced efficiency of upwelling and the supply of cool nutrient rich water to the euphotic zone is suppressed. The result is a rise in sea surface temperature and a drastic decline in primary productivity in the eastern Pacific, the latter of which adversely affects higher trophic levels of the food chain, including opal squid (NOAA 2002).

Studies have shown that the diverse aspects of the life history of *L. opalescens* are influenced by the complex predator-prey relationships that exist in the food web of the California Current ecosystem. Predator-prey interactions were demonstrated in a study by Cailliet *et al*. (1979) showing how *L. opalescens* in Monterey Bay co-occurs with a small group of other nektonic organisms such as anchovy, juvenile rockfish and Pacific hake. It was concluded that the main organizing factor responsible for such recurrent pelagic assemblages could be a mutual dependence upon a common food source of euphausiids. Laboratory rearing studies also suggest that young opal squid may selectively prey upon larval anchovies and thereby have a tremendous effect upon the anchovy population (Hurley 1976; Hixon 1983).

Changes in predator-prey relationships would be expected to have consequences for *L. opalescens*. Fielder *et al*. (1986) observed that the El Niño event of 1982-1984 caused physical and biological changes in the northern anchovy (*Engraulis mordax*) habitat off southern California. Growth of juvenile and adult anchovy, which opal squid are known to co-occur with, slowed during El Niño, probably due to reduced availability of zooplankton prey. Spawning range expanded in 1983 due to shifts in sea surface temperature boundaries and early larval mortality was unusually high in the yolk-sac stage (Fielder *et al*. 1986). Similarly Butler *et al*. (1999) noted that during the 1997-98 El Niño event opal squid were elusive on traditional squid fishing grounds. During fishing efforts squid were not taken in trawl depths shallower than 95 m and although adults collected at depths of 95 m and below were mature, no egg cases were collected concurrently in the trawls. However, commercial trawlers reported significant volumes of squid eggs in nets deployed at depths of 720 m off Carmel, California. These eggs were incubated and positively identified as being opal squid (Jerry Spratt, CDFG, *pers. comm*., from Butler *et al*. 1999). While it appears opal squid were spawning in southern California, they were not at the normal depths of the traditional fishing grounds, probably due to warmer temperatures both at the surface and at depth (Butler *et al*. 1999). It appears that El Niño conditions may profoundly affect distribution, abundance, growth and perhaps even mortality of *L. opalescens*. It may be that squid are forced to search fringe habitats, utilizing valuable energetic resources. If other food is scarce, survival may depend on increased cannibalism, which would ultimately impact overall abundance.

Fields (1965) postulated that there were two populations of *L. opalescens* based upon his observations of two distinct seasonal spawning peaks at Monterey. Past attempts to distinguish separate stocks within the entire range of *L. opalescens* using morphological indices (Evans 1976; Kashiwada and Rieksiek 1978), beak measurements (Kashiwada *et al*. 1979) and various biochemical and electrophoretic procedures (Ally and Keck 1978; Christofferson *et al*. 1978) suggested that variation does occur. However, recent information suggested that gene flow prevents population differentiation, based on microsatellite allele frequency patterns (Reichow and Smith 2001). This sample included eleven samples, primarily from California, but also from Bamfield Inlet and Puget Sound.

Loliginid Squid Fisheries

Jig and net fisheries for loliginids are carried out in many areas of the world. Assessment and management frameworks for most of these fisheries are not well documented or not readily available in the literature. We have chosen several of the better documented fisheries to review: fisheries for opal squid off the west coast of North America; the fishery for chokka squid, *L. vulgaris renaudii*, off South Africa; fisheries in the northwestern Atlantic for veined squid, *L. forbesi*, and common squid, *L. vulgaris*; and the fishery for longfin squid, *L. pealei*, in the northwest Atlantic (see Table 4 for summary information).

California (L. opalescens)

Overview

The California fishery for *L. opalescens* was established over 130 years ago in Monterey Bay. It is one of California's oldest fisheries and was started by Chinese immigrants during the mid-1800s. Initially small skiffs with lit torches were used to attract squid to the surface, which were captured with hand-held brail nets. Later, two small skiffs would use a net to encircle another skiff that carried a lit torch to aggregate squid at the surface (California Department of Fish and

Game [CDFG] 2002b). Squid were subsequently dried for shipment to the Orient, though some was probably consumed locally and in nearby San Francisco (Scofield 1924; Vojkovich 1998).

Immigrant fishermen from Sicily introduced the lampara net[2] for catching squid around 1905. Chinese squid fishing was displaced by this more efficient fishing method, and by the 1920s canned and frozen products were being exported (Hardwick and Spratt 1979; Vojkovich 1998). Purse and drum seines were legalized in the late 1980s, and lampara nets became obsolete (CDFG 2002b). The establishment of the fishing ports of Monterey Bay and San Pedro were largely built by the efforts of these European immigrants (Leet *et al*. 1992; Vojkovich 1998). The fishery expanded to southern California after the 1950s, but remained relatively minor until the 1980s when worldwide demand for all squid species increased.

Fishing generally takes place at night, while during daylight spotter planes, satellite and sonar technology are employed in aiding fisherman in locating schools of squid (Lutz and Pendleton 2000). The squid's positive phototropic response enables fishers to use strong lights to attract spawning aggregations of squid to the surface at night, for capture by both seines and brails (Kato and Hardwick 1975; Vojkovich 1998). There are three classes of vessels participating in the fishery: roundhaul net boats (primarily purse seiners) that capture squid by encircling them with nets; light boats that attract and hold squid for net boats (usually for a portion of the catch, reported to be 20% of the landing value); and brail boats that attract squid and then capture them with dipnets or brails (CDFG 2001, 2002b)

While European seafood consumer markets generally prefer larger squid, the smaller opal squid fills the niche of a high quality and relatively low cost product (Lutz and Pendleton 2000). Initially, Chinese and Asian markets accounted for most opal squid exports, however these markets closed in 1933 (Leet *et al*. 1992). During the early 1990s China, after implementing economic and trade reforms, gradually developed a market for opal squid, propelling the California squid fishery into phenomenal growth.

In 1999 China accounted for 27.1% of total squid exports from California, second in exports, was Spain at 14.4% followed by Japan and the Philippines at around 9.5% each (CDFG 2000; Lutz and Pendleton 2000). Recent lower ex-vessel prices have been linked to the strength of the US currency, as well a 45% tariff exacted on US imports by China, which affected pricing (Anon. 2000). Regardless, opal squid has been one of California's most valuable fisheries since 1993 when it ranked 5th. It ranked 2nd in value for 1995 and 1996, and 1st in value (millions of dollars earned) during 1997, 1999 and 2000.

There is also a fishery for live squid for bait in recreational fisheries (CDFG 2002b). Squid are taken by bait haulers using seines, lampara nets or brails, and sold either from the catcher vessel at sea or from harbour-based bait dealerships. Many recreational vessels capture their own squid using lights and crowder nets or rod-and-reel. Bait fishery catches are not documented, but are believed to be minimal compared to commercial harvests. Preliminary data show a catch of 4.4 t

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[2] A lampara net is similar to a seine. The primary difference is that the net is set around a school of squid and the leadline closed by retreiving both ends simultaneously, rather than using a purse line.

(9,800 lb) for the 2001-2002 season, but data come from voluntary submissions only, and are only a minimum estimate of the catch for bait.

Effort

About 1977 there was a shift in fishing gear from brail vessels to seine vessels in southern California. Economics seem to be the main factor driving the change, as tuna and "wetfish" vessels[3] were looking to participate in more lucrative fisheries closer to home. Brail vessels had difficulty competing, as seiners could meet market demand more efficiently (Vojkovich 1998). At present opal squid are commercially landed by a fleet of purse seine vessels, 'California's purse seine fleet', which fishes spawning populations of squid in limited areas around Monterey and southern California. Brail vessels still land a small portion of the catch, as they can fish in areas closed to seine boats and can deliver smaller landings for a higher value (CDFG 2002b). Southern California's fishery focuses mainly on the Channel Islands, as well as Santa Catalina Island, with landings at Port Huenene, Oxnard, Ventura, and San Pedro.

The waters of southern California have seen a rapid squid fishery expansion since the early 1990s, due to increased market demand, fueled by the emergence of international markets (notably China), and a previously underutilized population of squid. The Monterey area does not appear to host as large or as exploitable a squid population as does southern California. In recent years, Monterey has had much smaller landings than either Southern California or North and Central California. Most squid landed in recent years are from Southern California (CDFG 1999; Vojkovich 1998; Lutz and Pendleton 2000).

During the 1970s and 1980s, an average of 85 vessels were active in the squid fishery, but by 1997 the number of vessels landing over 0.5 ton of squid had increased to nearly 135 (Vojkovich 1998). By mid-1998, 240 opal squid vessel permits and 41 light boat permits were issued for the 1998-1999 season. For the 1999-2000 season there was an estimated 218 opal squid vessel permits and 53 light boat permits issued (Lutz and Pendleton 2000). In 2000-2001, 195 vessel permits and 50 light boat permits were issued; the number of permits issued has declined since the 1997 moratorium (CDFG 2002b).

Despite the large number of permits issued, the majority of landings are reported from relatively few vessels; 75% of the reported catch was landed by 26, 37 and 24 vessels in the 1998-1999, 1999-2000 and 2000-2001 seasons, respectively (CDFG 2002b).

CDFG records indicate that the average purse seine vessel length is 19 m (62 ft) with an average hold capacity of 76 t (168,000 lb)(CDFG 2002b). At present, most of the fleet uses either purse seines (67%) or drum seines (27%), with few (6%) using lampara nets. The average seine is 381 m (1,250 ft) long and 48 m (156 ft) deep.

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[3] "Wetfish" vessels fish for a number of species other than opal squid, including jackmackerel (*Trachurus symmetricus*), Pacific mackerel (*Scomber japonicus*), Pacific sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*) and bonito (*Sarda chiliensis*)(Lutz and Pendleton 2000)

Landings

Landings of opal squid from California dominate the fisheries on the west coast of North America (Figure 6). From the mid-1910s to the early 1920s landings of opal squid were less than 700 metric tons. Landings increased gradually to an average of 6,200 metric tons by the late 1960s with notable fluctuations throughout (Leet *et al*. 1992). By the late 1980s landings were around 20,000 metric tons (Vojkovich 1998) and due to increased market demands by the early 1990s there was a dramatic increase.

Since 1987, landings have at times been more than four times the 1980s level, making it one of California's largest fisheries in both volume and market value (Table 5). However, the fishery is characterized by volatility where annual landings can decrease profoundly as a consequence of low squid availability, possibly linked to El Niño events. In 1996, California fishermen caught a then-record 80,000 metric tons of opal squid, with an estimated dockside, or ex-vessel value of $33.3 million. During the 1997-1998 El Niño, annual landings plummeted to less than 3,000 t in 1998, compared to over 70,000 t in 1997. No squid were landed in Monterey Bay in 1998. During this period revenues from both Pacific mackerel and Pacific sardine exceeded those of opal squid (CDFG 1999; NMFS 2002). Low landings were also reported in 1984 and 1992 (Table 5), years following El Niño events (Table 6). Opal squid landings and effort decrease in times when squid availability is low; effort and landings in years when squid are readily available are reflective of market conditions (CDFG 2002b).

California's squid fishery recovered in 1999 with approximately 99,943 t landed, worth an estimated $34,953,433 US (NMFS 2002). While the Monterey Bay fishery was slower to regain momentum the southern California fishery recovered rapidly. During the 2000-2001 season some squid fisherman reported that opal squid were so abundant they could land squid during daylight (Lutz and Pendleton 2000; CDFG 2000; NMFS 2002). Landings as reported by NMFS database for the year 2000 indicate opal squid reached 117,953 t worth an estimated $27 million US. In addition landings for the calendar year 2001 totaled 72,400 t with a monthly maximum of 14,365 t landed in November and a low of 1,784 t landed in June.

Management

Rapidly increasing catches and effort in the California fishery since 1994 have raised concerns regarding whether such growth could be sustainable (Vojkovich 1998). Prior to 1997, the fishery was open access and essentially unregulated with minor area closures in effect along Santa Catalina Island and a weekend closure in Monterey Bay[4]. There were no statewide restrictions on the opal squid fishery prior to 2000 (Lutz and Pendleton 2000). It was noted that "authorities lack many different levels of information including total harvest rate and the number of reproductive stocks; both of which are required for the effective management of this resource" (Pomeroy 1997). All that was needed to fish for opal squid was a California commercial fishing

[4] The regulation prohibited fishing for squid with seine nets between noon Friday and noon Sunday, and between noon and midnight any day Monday through Thursday.

licence and boat registration. As other commercial fisheries became more restricted and controlled, entry into the open and profitable squid fishery was seized by many seeking new opportunities, including an influx of vessels from other states (CDFG 2002b).

Significant measures were taken in the management of California opal squid with the passage of the Sher Bill (Senate Bill 364) in 1997. The bill established a three-year moratorium on new entrants to the fishery, effectively capping potential effort, and a $2,500 permit fee was implemented for all fishery participants for the commercial season beginning 1 April 1998[5]. Interim measures included in the Bill were a requirement for logbooks, extension of the weekend closure to southern California, and wattage limitation and shielding requirements for lights, the last intended to address concerns regarding effects of squid vessel lights on nesting birds in the Channel Islands)(CDFG 2002b). Permit fee revenues generated approximately $2 million US, which was used to fund a CDFG study of the fishery, establish a Squid Fishery Advisory Committee and a Squid Research Scientific Committee, and fund management, enforcement and related activities. The committees were asked to recommend interim management measures for the fishery, and a series of statewide public hearings were held on the matter (CDFG 1999). The bill also provided the California Fish and Game Commission with interim regulatory authority over the fishery for the period of the moratorium.

The Channel Island National Marine Sanctuary facilitated a panel discussion at the 1997 California Cooperative Oceanic Fisheries Investigations (CalCOFI) Conference and suggested a number of restrictions for consideration. These included: limited entry of new vessels; clearly defining and enforcing harvest parameters; a season that would depend on the number of boats permitted within the fishery and the estimated overall biomass of the resource; gear restrictions, including lead line composition and limitation in light emission; and time and area closures (NOAA 1997).

The Marine Life Management Act (MLMA), passed into law in 1998, transferred fishery management authority for squid (and other species) from the state legislature to the California Fish and Game Commission (CFGC), who were tasked with development of an overall implementation plan for the MLMA, development of management plans for California state fisheries and development of a plan for dealing with emerging fisheries (CDFG 2002b). Subsequent Senate Bills in 2000 and 2001 reduced the squid permit fee from $2,500 to $400 until April 2003, extended the sunset date of the 1997 legislation to January 2004, and required the CFGC adopt a squid management plan by 31 December 2002.

The squid fishery was included in the Coastal Pelagic Species Federal Management Program (CPS/FMP) as a monitored but not managed species. The CPS Management team, made up of state and federal managers and biologists, was directed by the National Marine Fisheries Service to produce estimates of Maximum Sustainable Yield (MSY) and allowable biological catch (ABC) for the opal squid fishery. However, the task was problematic considering the lack of biomass estimation techniques and biological data required for estimating MSY and ABC. One option considered was setting MSY in the range of landings of the 1995-96 and 1996-97 seasons

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[5] The official commercial fishing season runs from April 1 through to March 31 of the following year, correlating with harvest peaks from October to March (Vojkovich 1998, CDFG 2002b).

(82,000-113,000 t) with an ABC equal to the MSY or within this range (Lutz and Pendleton 2000).

The CFGC adopted interim measures in 2000, including continuation of weekend closures, logbook requirements for squid vessels and light boats and lighting limits and shielding requirements. In 2001, the CFGC established a coastwide harvest guideline of 113,379 t (125,000 short tons or 250,000,000 lb). This guideline was based on maximum annual production to date, and was designed to prevent volumetric growth of the fishery should market demand increase (CDFG 2002b). Several area closures and restrictions were implemented for southern California including commercial fishing being prohibited in three State Ecological Reserves within the Channel Islands National Marine Sanctuary and restrictions of commercial fishing on a number of Ecological Reserves throughout the state (Lutz and Pendleton 2000; CDFG 2000).

At present, fishers must hold a commercial opal squid vessel permit in order to land more than two short tons (1.8 t) of squid per day. As well, fishers must hold a commercial squid light boat owner's permit in order to attract squid by light to seine vessels. In order to renew a permit, an applicant must have been issued a permit in the immediately preceding year.

A proposed Market Squid Fishery Management Plan was released for public comment in May 2002 (CDFG 2002b). The plan proposed to continue some current management practices and presented several new options for deliberation and consultation. Options presented in this plan are listed in Table 7 and described in the following sections.

State-wide Seasonal Catch Limit

In data-limited fisheries, a catch limit (CL) can be developed by estimating average catch (C_{AVG}) for a time period over which there is no evidence (qualitative or quantitative) of declining abundance, and decreasing this by a factor dependent on an estimate of stock size. For example, if estimated stock size is above B_{MSY}, then CL=1.00*C_{AVG}; if it is below B_{MSY} but above MSST, then CL=0.67C_{AVG}; if it is below MSST (*i.e.*, overfished), then CL=0.33*C_{AVG}[6]. Where B_{MSY} cannot be estimated, "informed judgement" may be required to determine the TAC (CDFG 2002b).

The CFGC considered four options for establishing landing limits (CDFG 2002b). They chose to estimate average catch using the previous three years catches, excluding El Niño years, as this more accurately represents recent demand and fishing effort while still encompassing between three and six generations of squid. The options presented were:

1. Establish a seasonal catch limit of 83,138 short tons. This was based on the three-year average landings and the assumption that the stock is currently below B_{MSY} but above MSST.

[6] B_{MSY} is the long-term average biomass that would be achieved if the stock were fished at a constant mortality rate that would result in MSY; MSST is the Minimum Stock Size Threshold (1/2 B_{MSY}).

2. Establish a seasonal catch limit of 125,000 short tons. This was based on the three-year average landings and the assumption that the stock is above B_{MSY}. This is less precautionary the option 1.
3. Do not set a seasonal catch limit. This options reflects the advice of the Squid Fishery Advisory Committee, which oppose catch limits. A catch of 125,000 short tons was considered unlikely given the implementation of weekend closures.
4. Establish a catch limit based on environmental conditions. The Squid Research Scientific Committee recommended a seasonal harvest of 115,000 short tons in non-El Niño periods and a cap of 11,000 short tons during El Niño periods.

Daily Trip Limits for Seine and Brail Vessels

Daily trip limits were considered to prevent change in the size composition of the fleet once permits become transferable, and to spread effort throughout the season, rather than concentrating on peaks of spawning activity. This option would prevent increased landings (on a trip basis) should market-imposed limits be lifted or technological advances increase fishing efficiency.

Processors commonly limit landings to 30 short tons due to limitations in their processing and freezing capacity. Between January 1990 and November 1999, 95.6% of permitted vessels landed 60 short tons or less per trip and 99.7% landed 90 short tons or less per trip. Only 2.3% of all squid landings between 1981 and 2001 exceeded 60 short tons per trip. Brail vessels are considerably smaller, and rarely land more than 15 short tons per trip. A trip limit on brail vessels would prevent them from improving harvest efficiency by technological or other means. The two options presented were:

1. Establish a daily trip limit between 60-90 short tons for roundhaul vessels and 15 short tons for brail vessels.
2. Do not establish daily trip limits.

Weekend Closures

Interim regulations extend the weekend closure south of Point Conception, making it a coastwide closure. The closure is intended to ensure two successive nights of spawning each week in the absence of fishing pressure. Options are either to continue the closure or not continue the closure.

Research and Monitoring Options

The proposed research and monitoring program was divided into three main components: monitoring of the fishery using egg escapement methods, sampling and survey programs, and a logbook program.

Monitoring using egg escapement methods was developed jointly by the CDFG and NMFS, and was the preferred approach recommended by the Pacific Fisheries Management Council (PFMC)

Stock Assessment Review (STAR) Panel for Market Squid[7]. Reproductive escapement can be achieved through either allowing a certain quantity of spawning adults to escape harvest, or by allowing a certain number of eggs to be laid[8]. The model links histological work on the ovaries of harvested females to an eggs-per-recruit model, based on spawning stock biomass per recruit theory. Eggs remaining in captured females are compared to potential fecundity (maximum reproductive output) to estimate reproductive output, in terms of eggs laid, to a population of females. Estimated reproductive output of the harvested population is then compared to the estimated output of the population in the absence of fishing. The Coastal Pelagic Species Management Team of the PFMC recommended that an egg escapement threshold level of 0.30 (30%) be used initially, as a precautionary measure (a reproductive escapement threshold of 0.40 [40%] is used in the Falkland Islands fishery for *Loligo gahi*).

The egg escapement model requires that the fishery maintain its focus on spawning squid (capture of immature squid invalidates the assumptions of the model) and requires the CDFG to monitor the fishery at an appropriate level. The plan notes that the egg escapement model is a temporary proxy for MSY, until an acceptable biomass estimate can be developed, but notes that if no biomass estimate can be developed, the egg escapement model performance can be improved by increasing current biological sample sizes (CDFG 2002b).

The sampling and survey program, initiated in 1998, includes collection of fishery and biological information by port samplers; fishery-independent surveys to characterize spawning habitat, measure egg production and develop indices of relative abundance; collection of information on age and growth of squid; and collection of fishery information through a logbook program and analyses of satellite data to track pattern of effort in the fishery. After the STAR Panel review in 2001, CDFG began tracking seasonal variations in length, weight, sex, age and maturity, and to tabulate catch data on a daily basis. Given all of this, the CDFG acknowledges the inadequacy of current understanding of squid biology, distribution, population dynamics and stock structure in developing detailed stock assessments.

A logbook program was developed in 1999 and 2000 to collect better information on effort and effects of the fishery. Information collected includes set times, set locations, water temperature, net length, mesh size and the role light boats played in the fishing event. Light boats provide information on wattage, search time, searching equipment (*e.g.*, sonar) and estimates of the amount of squid attracted and captured.

Options presented for the research and monitoring program were:

1. Monitor the fishery using the egg escapement model while developing biomass estimation methods.

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[7] STAR Panel. 2001. Report of the Stock Assessment Review (STAR) Panel for Market Squid. Panel report from Stack Assessment Review (STAR) meeting, NOAA/NMFS/Southwest Fisheries Science Center, May 14-17, 2001, La Jolla, CA. 18 p.

[8] Maxwell, M.R. 2001. Reproductive (egg) escapement model and management recommendations for the market squid fishery. Summary paper from Stock Assessment Review (STAR) meeting, NOAA/NMFS/Southwest Fisheries Science Center, May 14-17, 2001, La Jolla, CA. 27 p.

2. Continue existing research and monitoring programs with an emphasis on development of management models.
3. Maintain the logbook program.

Harvest Replenishment Areas

Area closures were proposed that would protect portions of the squid stock from exploitation, and to serve as replenishment areas (*i.e.*, sources of recruitment) for squid. Several existing state ecological reserves are known squid spawning areas, and are protected from fishing using seine boats. Proposed Marine Protected Areas in the Channel Islands would also serve as squid refugia. Options presented were:

1. Do not set aside areas as harvest replenishment areas for squid.
2. Close areas where squid spawning occurs that are not regularly employed by squid fishermen, such as waters <100 m depth around San Nicholas Island.

Live Bait Fishery

Information on the capture of opal squid for live bait is very incomplete. No permits are required if catch is less than two short tons per day, nor are there reporting requirements. Options presented were:

1. Continue existing regulations that do not require a permit when fishing for live bait or when catches do not exceed two short tons per day. Modify current live bait logs to include opal squid.
2. Establish a permit for fishing opal squid for live bait.

Limited Entry Program

Limited entry was proposed as a means of balancing needs to provide a viable economic opportunity and to protect the resource. A number of capacity goals for seine vessels were identified using number of days with landings by current permit holders (highest annual average was 45 days in 1981-1982, maximum number of days by a single vessel was 130 in 1999-2000) and maximum theoretic daily catch. The number of light boats permitted should match the number of seine vessels, based on a long-term average of one light boat per seine vessel in fishing operations. A brail vessel capacity goal was determined using maximum catch level and average number of days to catch the largest brail catch on record. Potential capacity goals presented were:

1. Establish a capacity goal using maximum catch on each trip and maximum number of days fished (highly productive specialized fleet). This would result in 130 days fished per season, and set capacity at 10 seine vessels (and 10 light boats).
2. Establish a capacity goal using maximum catch on each trip and average number of days fished (moderately productive and specialized fleet). This would result in 45 days fished per season and set capacity at 52 seine vessels (and 52 light boats).

3. Establish a capacity goal using average catch per trip and average days fished (less productive and less specialized fleet). This would result in 45 days fished per season and a capacity of 104 seine vessels (and 104 light boats).
4. Establish a capacity goal for brail vessels at 18 vessels.
5. Do not establish limited entry.

A complicated series of options were presented for determining initial issuance criteria for seine vessels, light boats and brail vessels, all dependent on whether the permits were transferable or not. Other options were to allow permit purchase by any permit holder in the first year of the moratorium, continue the current moratorium program (number of vessels reduced through attrition), or not establish limited entry. Proposed transferability options included no transferability except under extenuating circumstances (*i.e.*, loss of vessel to fleet), full transferability, full transferability if the new vessel is of comparable (within 5%) capacity, transferability on a 2-for-1 basis if the new vessel exceeds the capacity of the vessel replaced by between 5-35% and a 3-for-1 basis if the new vessel exceed the capacity of the vessel replaced by more than 35%. One option proposed allowed light boat permit holders to "trade up" to a brail vessel permit on a 4-for-1 basis. Permit transfer fees, currently $250, could either remain the same or be increased to $1,000.

Gear Restrictions

Gear restrictions are related primarily to lights and shielding. Options presented were to maintain current 30,000 watt limitation and requirements for shielding of lights (*i.e.*, directing light downwards) or to remove the existing light regulations. Other potential gear restrictions address impacts of gear on egg cases, which can be reduced through modification of net structure or establishing a minimum depth that fishing may take place.

Time and Area Closures for Seabirds

Impacts of the fishery on seabird rookeries could be addressed using a number of time and area closures. Proposed closures involved combinations of islands used as seabird rookeries, and time closures of either February through October or March through August (height of breeding season). Options were either total closures to fishing or closure to fishing using lights. The final option was to maintain wattage and shielding requirements without closures.

Development of Advisory Committees

Options relating to advisory committee structure included having no advisory committee, continuing the current two-committee approach, or combining scientific, environmental and industry representatives into a single committee.

Permit Fees

Options for permit fees were to maintain the current $400 permit fee or return to the $2,500 permit fee for seine, light and brail vessels.

The draft management plan was released May 31, 2002, with a request that comments be returned by July 15, 2002[9].

Oregon (L. opalescens)

Overview

The opal squid fishery in Oregon is sporadic and effort is influenced by a number of external factors. The fishery is dependent on markets as much, or more than availability. When landings in the California squid fishery and the Oregon pink shrimp fishery are down, there is more interest in squid in Oregon (J. McCrae, Oregon Dept. Fish and Wildlife [ODFW], *pers. comm.*). Most of the harvest in Oregon has been with seine and lampara nets, with trawl gear coming in third. Seine and lampara gear have little problems with incidental catch. Trawl gear is less selective, but incidental catches can be small when fishing on known concentrations of squid (McCrae 1994). The main market for opal squid is as bait for crab, halibut and sablefish fisheries.

Effort

We could not obtain complete effort information, however, from 1984-1993 the average number of participating vessels was six, with a maximum of 17 vessels in 1992 and a minimum of one vessel in 1988 and 1991 (Table 8).

Landings

Since 1981, harvest of opal squid in Oregon has averaged 103.2 t, with a range of landings between 795 t in 1985 to no landings in 1990 (Table 8). Landings were very high in 1984 and 1985, then decreased until a period of relatively stable landings of approximately 100 t from 1994-1997. Landed value averaged $74,800 US from 1982-2000, and peaked in 1985 at $319,000 US.

Assessment

Abundance estimates for opal squid populations are not available. Estimates of individual spawning schools have been made through acoustic and video techniques. Acoustic surveys of one school off Oregon in 1985 estimated average densities of 0.8-19.2 squid/m^2 and a total

[9] In October 2002 the California Fish and Game Commission voted to approve the Channel Islands Marine Sancutary closures, encompassing approximately 132 square nautical miles. The closures remove from the fishery areas that accounted for approximately 10% of squid landings in the 2000/01 and 2001/02 seasons (CDFG 2002c). No other proposed actions had been taken taken at the time of report preparation.

biomass of 2,041-3,719 t (4.5-8.2 million lbs) of opal squid (Starr 1985; McCrae 1994). There is no active assessment of opal squid in Oregon, only monitoring of landings.

Management

In 1994 an experimental gear permit was needed to harvest opal squid using trawl gear with a mesh size less than three inches. Because of concerns of overfishing, a harvest review was also established: when 2,041 t (4.5 million lbs) coast wide or 1,361 t (3 million lbs) north or south of Heceta Head has been harvested, the Fish and Wildlife Commission will hold a public hearing to review the fishery (McCrae 1994). Currently, squid are managed in Oregon under the Developmental Fisheries Program. This limits the number of permits which can be issued. Presently, 30 permits for trawl gear and 30 for other gear (mainly seine gear) are available, although in recent years, few permits have been issued - a total of 7 in 2001 (J. McCrae, ODFW *pers. comm.*).

Washington (L. opalescens)

Overview

The opal squid fishery in Washington State is mainly for human consumption. There is a small targeted fishery, and minor amounts of squid are taken as bycatch in the trawl fishery for groundfish and discarded at sea. There is a popular sport fishery from docks in urban areas of South and Central Puget Sound, particularly in years of high squid abundance (G. Bargmann, D. Rothaus, Mel Stanley, Washington Department of Fish and Wildlife [WDFW], pers. comm.).

Effort

There was little information available regarding effort levels in the Washington opal squid fishery. Commercial effort has been nearly non-existent in recent years – only one permit was sold in 2001 (G. Bargman, WDFW, pers. comm.).

Landings

Landing receipts indicate only squid (all species), however it is thought the landings are almost exclusively opal squid (G. Bargmann, Mel Stanley, WDFW, pers. comm.). Landings of squid in Puget Sound averaged approximately 4.6 t from 1980-2001 (Table 9). Virtually all reported landings were from Puget Sound, with <1 t per year coming from the Pacific coast of Washington. Maximum reported landings in Puget Sound were in 1984, with higher than average landings in 1993, 1995 and 1996. No landings were reported from Puget Sound between 1998 and 2001 (Mel Stanley, WDFW, pers. comm.)(Table 9).

Assessment

The fishery in Washington State is not actively assessed, but landings are monitored.

Management

In Washington there are no special permits required. It is an open access fishery with its own license type and no limitations on the number of licenses issued. Fishers in Puget Sound are required to maintain a logbook. There are regulations which limit the size of net that can be used, and regulations to limit the impact of lights.

British Columbia (L. opalescens)

Overview

In B.C., opal squid are fished primarily with small-mesh seines (Adkins 1997, DFO 2001a, Rogers *et al*. 2002). Jigs (and automated jigging machinery), side-catcher, ring, frame, dip and lampara nets are permitted, but are not commonly used. Fishers go to areas known to support aggregations of squid, and sit with their lights on until a sufficient mass of squid are attracted. A high intensity attractor light is generally attached to or suspended from a stabilizer pole which is extended from the side of the vessel over the water. This attracts squid to one side of the vessel, where they are encircled with a seine. Generally, the fishing vessel is anchored, and the net set from a small seine skiff, then pursed and brailed from the main vessel. The squid are frozen in bags containing approximately 10 kg.

B.C. opal squid are used as bait, primarily in fisheries for crab, sablefish and halibut. Some participants in the commercial opal squid fishery also hold licences in hook-and-line fisheries, and they may retain opal squid for their own use in these fisheries. There has been interest in marketing B.C. opal squid as a food product, but B.C. fishers have been unable to compete with squid from the large fishery off California.

The primary management issues arising from the opal squid fishery have been under-reporting of catch, the unlimited number of licences available in the fishery and a lack of information regarding bycatch and habitat impacts (DFO 2001b, Rogers *et al*. 2002).

The daily sport catch limit for opal squid is five kg, with a possession limit of 10 kg, but opal squid are rarely targeted by recreational fishers and there is no information on sport catches. Cast nets and jigs are permitted gear types, and the fishery is open year-round. First Nations use of opal squid is not well documented (*i.e.*, there is no information). Opal squid are encountered in groundfish and shrimp trawl fisheries, although catch information that is reliably separated by species is not available.

Effort

Between 1992 and 2001, the maximum number of licences issued was 107 in 1996 and the minimum was 14 in 2001 (Table 10). Over the same period, an average of six vessels reported landings on logbooks and seven vessels reported landings on fish slips. Effort declined from relatively high levels in the mid-1980s through a period of low effort in the late 1980s and early 1990s to a peak in 1996, and then declined precipitously thereafter (Figure 7).

There have been eight active vessels over the last five years (1997-2001), none of which were active in all five years. Of these, three have submitted both logbooks and fish slips for all years fished, one has only fish slips but no logbooks, and three have only logbooks but no fish slips. One vessel submitted logbooks for three years, but fish slips for only one. Three additional vessels submitted nil reports.

In 2001, there were three active vessels in the fishery. All provided biological samples. One vessel reported landings on logbooks and fish slips, one vessel reported landings on logbooks but not fish slips and one vessels reported landings on fish slips but not logbooks.

As of November 1, 2002, ten vessels had purchased squid licences for 2002. One vessel reported landings, on both logbooks and fish slips, and submitted a biological sample. One other vessel submitted nil reports for April, May and June and indicated he would not be fishing squid until September at the earliest.

Landings

Between 1984 and 2001, 1,032 t of opal squid were reported on logbooks and 1,192 t were reported on fish slips (Table 11). Both data sources show strong declining trends in landings since the mid-1990s (Figure 8). However, the same problems with catch reporting noted in 2001 likely bring into question reported landings from previous years. As would be expected with decreased landings, landed value of the fishery declined precipitously after 1994, even though reported prices continued to increase (Figure 9).

Using logbook estimates where available and taking the fish slip data at face value, the reported catch for 2001 is approximately 32 t coastwide (although the validity of this estimate is questionable).

The fishery is prosecuted primarily in the spring and summer; 89.2% of total landings reported on logbooks between 1982 and 2001 occurred in April, May and June, and 82.0% in May and June (Table 12). The fishery traditionally operated primarily in or near Barkley Sound (Pacific Fisheries Management Area [PFMA] 23 and 123, Figure 10), with approximately 80% of all reported landings between 1982 and 2001 coming from the west coast of Vancouver Island, and nearly 70% from the Barkley Sound region (Table 13). South Coast areas produced the majority of landings until the mid-1990s, when Central and North Coast landings initially increased, then all areas decreased (Figure 11).

As would be expected given the problems associated with reported effort and landings in the fishery, catch-per-unit-effort (CPUE) analyses are not particularly informative. CPUE also only takes into account the number of days on which fishing occurred, not the time spent searching for and attracting squid, nor is it standardized by gear dimensions. Fisher experience, weather conditions and freezing capacity of the vessel will also influence CPUE.

CPUE based on logbook data show a general increase until 1991, followed by a general decrease to 1999 (Figure 12). CPUE increased sharply in 2000 and 2001. CPUE based on fish slip data also showed an increasing trend until 1991, followed by a decreasing trend through 2000 and a sharp increase in 2001 (Figure 12).

Landings and CPUE are currently limited by the freezing capacity of the vessels in the fishery. Other fisheries (*e.g.*, California) land fresh product to shore-based processing facilities, thus are limited only by hold capacity or limits imposed by the processors.

Bycatch in Trawl Fisheries

Landings and discards of squid in the B.C. groundfish trawl fishery are estimated from logbooks, at-sea observer coverage and dockside validation (K. Rutherford, Pacific Biological Station, pers. comm.). Species resolution is not ideal, and depends on what was recorded by fishers or observers at sea. It is likely that opal squid catches and discards are confounded in the generic squid data, and that reported opal squid landings and discards are incomplete.

Reported encounters (reported landings and reported discards) of opal squid in the groundfish trawl fishery in B.C. averaged 0.12 t between 1996 and 2001 (Table 14). More than half of the reported landings and discards came from the North Coast in 1998 and a significant portion came from the South Coast in 2000. No opal squid landings or discards were reported in 2001; it is likely that squid were not identified to species by fishers or observers in that year (*i.e.*, opal squid were only reported as "squid", likely along with other species).

Reported encounters of generic squid in the B.C. groundfish trawl fishery averaged 11.51 t annually between 1996 and 2001 (Table 15). Most of these landings came from the South Coast, although a significant proportion of the landings and discards could not be geo-referenced. There is no way of determining which species of squid are included in these statistics, or what proportion of the total might be opal squid.

Given the species identification problems associated with these data, comparisons of catches in the directed fishery with bycatch in trawl fisheries is pointless.

Assessment

Currently, there is no direct assessment of opal squid stocks in B.C. Logbook information is processed and retained at the Shellfish Data Unit in Nanaimo. Three biological samples were obtained in 2001 and processed at the Pacific Biological Station in Nanaimo. Two samples were collected from PFMA 123 and one from PFMA 2 in June. Samples were measured for dorsal mantle length (DML) and round weight; sex was determined by dissection, and the nidamental gland length was measured for all female squid. In addition, subsamples of 20-30 squid of each sex from each area sampled were intensively measured for morphometrics, and gonad and mantle weights were recorded. Maturity stages were assessed using information adapted from Lipinski (1979), Sauer and Lipinski (1990) and Lipinski and Underill (1995), described in Table 2.

A total of 968 opal squid was sampled from the 2001 fishery in British Columbia. These comprised three samples: one from the west coast of the Queen Charlotte Islands (PFMA 2) collected June 8; and two from Florencia Island (PFMA 123) collected June 1 and 2.

Males outnumbered females in all three samples, with sex ratios (M:F) ranging between 1.22:1 and 1.84:1, with an overall sex ratio of 1.36:1 in the combined samples (Table 16). B.C. samples had a higher male ratio than that reported for Monterey Bay (1.1:1) by Leos (1998).

Average DML for females was slightly higher than that of males in all three samples (Table 16), and length frequency distributions were all broadly unimodal (Figures 13-16). Average weights for each sex were roughly equal in each sample. Squid collected from the B.C. fishery in 2001 were smaller than those taken in Monterey Bay in the late 1980s and early 1990s (Leos 1998), and considerably smaller than squid caught in Monterey Bay historically (Fields 1965; Evans 1976)(Table 17).

All three samples taken in B.C. in 2001 were predominantly mature or spent individuals (maturity codes 5 and 6, respectively), regardless of sex (Table 18). No juvenile or immature squid (stages 1 and 2) were observed in the samples, and relatively few were in the preparatory or maturing stages (stages 3 and 4). This confirms that the fishery does target spawning aggregations (or at least did in 2001).

Small sample sizes make interpretation of trends in size at each maturity stage difficult (Table 19). However, when all samples are combined there appears to be a general trend of increase in size through maturity in both sexes (Figure 17). Both sexes increase in weight as they progress to maturity, and both lose weight after spawning (*i.e.*, between stages 5 and 6) (Figure 18). Male squid increased in weight until fully mature, then decreased in weight after spawning; female squid began to decrease in weight in between stages 4 and 5. Weight loss in both sexes between stages 5 and 6 is likely a combination of the weight lost as gametes and weight loss due to atrophy of other tissues to support gonad development. Some of the weight loss in stage 5 females could be due to partial spawning which resulted in some weight loss, but was insufficient to warrant classification as spent (stage 6).

Management

The directed fishery is managed under a 'ZE' licence, which allows harvest of opal squid only (DFO 2001a). Opal squid may be retained under "T" (groundfish trawl) or "S" (shrimp trawl) licences when fishing for other species and encounter opal squid inadvertently. Jigs, seines, frame nets and dipnets are permitted, and the maximum allowable length of seine net is 183 m (100 fms).

The fishery is closed year-round, except when opened by Variation Order (DFO 2001a). Fishers intending to fish opal squid must contact a Resource Management Coordinator to request an area be opened. Fishers are required to hail in fishing location and catch information weekly while fishing continues. There are also a number of permanent closures, either for navigational concerns, marine reserves, parks, concerns for interception of other species (*e.g.*, salmon or herring) or conservation (Table 20).

Landings and effort are reported two ways: through submission of logbooks and through submission of fish slips (DFO 2001a). Both are Conditions of Licence. Logbooks are to be completed by midnight of the day fished and submitted to the Shellfish Data Unit in Nanaimo no later than 28 days following the end of the month in which fishing occurred. Fish slips are required to be submitted to the Regional Data Center in Vancouver no later than seven days after landing the product.

In 2001, fishers were required by Condition of Licence to submit samples of their catch as biological samples. Three samples were submitted in 2001. Fishers were also requested to arrange for independent observers to record fishing information at least once annually. One observer trip was completed by DFO personnel in 2001. Observer coverage is extremely difficult to arrange due to the opportunistic nature of the fishery. Fishers often fish for squid when they are unable to conduct other fisheries due to weather. If they are going to be weathered in for more than one night, they will fish squid. These fishing events often occur in remote inlets, and the weather conditions which present the opportunity to fish also preclude the ability to obtain an observer.

Alaska (L. opalescens)

Overview

Alaska has no directed fishery for opal squid at his time. However, squid are a bycatch species, primarily in groundfish fisheries. Squid are not separated to species in the landings, so no estimate of catch of *L. opalescens* is available. Recent landings of generic squid were: 55.7 t (122,750.8 lbs) caught by 66 fishers in 2000 and 1,694 t (3,736,075 lbs) caught by 182 fishers in 2001. As there is no directed fishery, opal squid are not actively managed in Alaska (S. Amestoy, Alaska Department of Fish and Game [ADFG], pers. comm.).

South Africa (L. vulgaris reynaudii)

Overview

Chokka squid, *Loligo vulgaris reynaudii*, are distributed around a large part of the South African coastline, but are caught mainly off the southeast coast by means of handline jigging from small boats (Augustyn *et al*. 1993). In the early 1980s it was uncertain whether *L. vulgaris* occurring in European and West African waters was distinct from populations in South Africa. Subsequent investigation determined that South African squid were distinct and isolated and that the genetic differences were at a subspecific level. Hence, the European/West African subspecies was designated *Loligo vulgaris vulgaris* and the South African subspecies *Loligo vulgaris reynaudii* (Augustyn and Grant 1988; Augustyn and Roel 1998). *Loligo vulgaris reynaudii* is a fairly large species with a body length of up to 45 cm. The species is also relatively short lived, apparently not exceeding a life-span of 18 months. The population is usually made up of at least two, sometimes three, major cohorts (Augustyn and Roel 1998).

The inshore and offshore regions of the Eastern Cape are well documented as spawning grounds for chokka squid (Dorfler *et al*. 1999). Typically squid move inshore to spawn at the start of an upwelling event, when water temperatures are low and the water column is relatively clear. However, offshore areas or 'deep spawning' grounds (>70 m) are also utilized. Catch statistics for South African chokka squid show a high degree of variability on all time scales and a factor in this variability seems to be the usage of off shore areas for spawning when inshore conditions are unfavorable (Oosthuizen *et al*. 1996). For example, when temperatures are warm in coastal waters (>15ºC) chokka squid will spawn in adjacent deeper cooler water on the mid-shelf region, and therefore be unavailable to the jigs of the shallow water squid fishery (Roberts 1998). Laboratory trials have also shown that squid eggs have increased levels of abnormal development when exposed to water warmer than their optimal temperature range of 12-15ºC. Abnormal development increases considerably above 18ºC, with 50% of all eggs developing abnormalities at 21ºC. Similarly, squid eggs exposed to water temperatures below 12ºC show increased levels of abnormal development as well (Oosthuisen 1998; Roberts 1998).

In 1991 a permanent mooring station in St Francis Bay was installed to investigate environmental factors that influence the arrival of squid to the spawning grounds and survival of eggs and hatchlings. Measurements of current, temperature and turbidity were examined. Results of these investigations and others indicate good catches of squid correspond to low temperatures of coastal water while poor catches occur when bottom turbidity is high on the benthic spawning grounds. These results are corroborated by underwater video monitoring which also shows that spawning activity decreases with increases in water temperature. Chokka squid rely on visual communication for successful mating behaviour so water clarity is important, and in part explains why poor catches correspond to high turbidity (Marine and Coastal Management 2002).

Effort

The chokka squid is part of the South Africa's line fishing industry. The line fishery is split into three main sectors: squid-jigging, tuna fishing and general recreational and commercial fishing. The squid-jigging fishery targets chokka squid. Until the mid-1980s chokka squid was taken almost exclusively as a bycatch of the demersal trawl fishery. In 1985 a small-boat handline jigging fishery was established which grew explosively (Augustyn and Roel 1998). The jig-fishing fleet consists of about 300 mostly small to medium sized vessels, such as ski-boats and catamarans, as well as freezer vessels. Trawled squid now make a small contribution to the total catches of chokka squid, and have been declining consistently since 1979. Chokka squid is fished by means of jigging using handlines and brightly coloured hooked plastic and lead lures (jigs). Most fishing is carried out in shallow (10-60 m) inshore water along the southeast coast. Vessels use strong lights to attract squid at night (SACCSP 2002).

Landings

The fishery primarily targets spawning aggregations off the country's South Coast, and is characterized by sometimes erratic and highly variable catches. Similar to other squid fisheries, catch variability is strongly linked to environmental conditions and reflects of the sporadic nature of inshore migrations to spawning grounds. The squid fishery is based in the Eastern Cape and is of moderate size, compared with other major pelagic and demersal trawl fisheries. Average catch is approximately 6,000-7,000 t per annum (Table 21). Nevertheless, it is one of the most important South African fisheries for generating foreign revenue and supplying jobs. It generates approximately R340 million ZAR (South African Rand) which is almost $50 million CAD or $31 million US. In addition the chokka squid fishery supplies approximately 5,000 jobs to boat owners and fishermen. Within the impoverished Eastern Cape it is regarded as an important economic 'engine'. The main difficulties and threats to this fishery include: (1) highly variable catches, (2) variable global product prices, and (3) labour unrest and hardship. Government intervention in 1998 to make participation in the fishery more representative of the population by including previously disadvantaged groups has been a more recent destabilizing force (SACCSP 2002). Some discussions by those around the chokka squid fishery suggest that the government's attempt at transforming the industry has been slow and at times ineffectual. Efforts towards mitigating past inequalities accumulated during apartheid are not without challenges and difficulties (Eastern Cape Fishermen's Association 2002).

Chokka squid catches are strongly influenced by changes in environmental conditions; climatic phenomena such as El Niño can have a substantial impact. Market prices are determined by supply and demand, and inextricably linked to the performance of other squid fisheries around the world. Good catches in other squid fisheries cause a glut of product on global markets which in turn, diminishes the benefits to South Africa. During times of poor local catches or surplus global markets incomes of fishermen are reduced and jobs are lost. Given the highly erratic nature of squid catches, socio-economic hardship constantly underlies this fishery (SACCSP 2002). Virtually all South African squid is exported to markets in Europe (Italy and Spain) and the Far East (Japan) where it is sold fresh as calamari. Local demand is satisfied by imports (SACCSP 2002; Olyott 2002).

Recent trends in the fishery suggest relatively stable catches at 6,000-7,000 t per annum, however due to increasing levels of fishing effort, there has been a steady decline in catch-per-unit-effort (Roel *et al*. 2000).

Assessment

Because it is difficult or costly to obtain direct measures of stock abundance from research surveys, CPUE is generally used as an index of abundance (Roel and Payne 1998). As a prerequisite to resource assessment obtaining reliable estimates of CPUE from the commercial fishery is primary. However, in some cases CPUE does not provide reliable estimates of abundance. For example, in the jig fishery for chokka squid, where effort is concentrated on spawning aggregations, the usefulness of CPUE diminishes. As the stock is depleted, the number of aggregations decrease, while local abundance remains high and as a result CPUE is hyperstable until the final aggregations are fished out. However, unless a better estimate of resource abundance is available, CPUE can still be used provided the errors that may be introduced by hyperstable CPUE are taken into account in an appropriate manner (Gulland 1983; Roel and Payne 1998).

The South African chokka squid resource has four indices of abundance that may be used to assess its status. The time-series are jig CPUE, trawl CPUE and two research surveys, in spring and summer (Roel and Payne 1998). Jig CPUE is a large data set and can be related to spawner abundance, however effort is under-reported and no information on sounding or distance from the coast is available. Trawl CPUE is the longest time-series and obtained from fisheries targeting other species and therefore sampling should be more random in relation to sqiud distribution. But possible changes in fishing patterns and efficiency over time could be problematic. The autumn/spring surveys are random stratified and since 1986 the methodology used has been kept consistent. Of concern is the incomplete coverage of resource distribution and possible increase in efficiency over time as a result of 'learning from experience' (Roel and Payne 1998).

To determine sustainable levels all data sources were assessed in modelling exercises. It was subsequently found that the four series of data on which the squid resource status could be modelled showed different trends. The jig catch rates displayed a continuing decline and anecdotal evidence indicated possible creeping increases in effort, allied to a significant reduction in trawl catch rates (Roel and Payne 1998). Weighing the negative aspects of each of the time-series suggested the two fishery based series were likely most closely displaying the true trend in the resource. Therefore, the declining trend in resource status since the mid-1980s and the continuing decline shown by jig CPUE is a cause for concern. It appears that chokka fishery fully exploits the resource and requires a cautious management plan rather than further unchecked development (Roel and Payne 1998).

Management

The squid industry quickly became economically viable in the early 1980s. Squid were primarily caught by ski-boats operating from Jefferys Bay, St. Francis, Oyster Bay and Plettenberg Bay areas. As the economic value of the fishery increased, fishermen from as far north as Natal and as far west as St. Helena Bay came to the Eastern Cape to fish. Many non-fishermen were opportunistic and obtained commercial licenses (Eastern Cape Fishermen's Association 2002).

During the beginning of this fishery ski-boats of less than 8 meters and carrying a maximum of 9 crew were utilized, with only a few deck boats fishing for squid. The Department of Sea Fisheries soon introduced squid permits and some problems emerged, resulting in a 1988 moratorium on the issuing of squid permits. Nevertheless, larger companies with access to the markets in Europe captured the majority of permits (Eastern Cape Fishermen's Association, 2002).

During 1988 more freezer vessels appeared in the industry and demand for frozen-at-sea squid increased in overseas markets. As the transition was made to more expensive freezer vessels, several larger companies having the finances to invest in more costly freezer vessels became majority players in the fishery. Under the previous apartheid system squid permits were only issued to specific groups of non-blacks and in 1998 the first number of permits were issued to previously excluded applicants. During the 1999-2000 season approximately 63 new applicants received 533 squid permits. Most of these permits were rented to existing boat owners or large factories with only a few applicants receiving enough permits to operate freezer vessels (Eastern Cape Fishermen's Association 2002).

At present the South African chokka squid is protected by a closed season of 3-5 weeks when spawning is at its peak (usually November). Marine and Coastal Management conducts biomass surveys in autumn and spring each year to estimate the abundance of chokka squid on the continental shelf. The spring biomass, together with information about chokka squid catches for the first 7 months of each year, determines the length of the closed season in November-December, when squid spawning is at a peak (Marine and Coastal Management 2002).

The following decision rules are used:

Biomass/Catch	Closed Season
Biomass < 10,000 tons or Catch < 500 tons	5 weeks
Biomass 10,000 – 20,000 tons and Catch 500 – 5,000 tons	4 weeks
Biomass 10,000 – 20,000 tons and Catch > 5,000 tons	3 weeks
Biomass > 20,000 tons and Catch > 500 tons	3 weeks

All current chokka squid projects are aimed at providing management advice on sustainable levels of utilization of the resource (Marine and Coastal Management 2002). Interim management actions are undertaken to monitor the performance of the industry, to maintain effort at a level that does not foreclose on future options, and to enhance recruitment. Three different measures of abundance are used to determine the condition of the stock: demersal stratified random sampling surveys, bycatch-CPUE of demersal trawlers, and CPUE of commercial jigging operations. Some trends in the fishery are causing concern, particularly the steadily increasing effort, which is being limited through a permit system. In addition, a closed season and a closed area (the Tsitsikamma Coastal National Park, which straddles the main spawning grounds) are not only important in limiting effort, but also enhance the biological success of chokka by protecting spawners and egg beds during the peak spawning period in early summer.

Investigations of the length of spawning period and factors affecting the variability in fecundity are being conducted to assess the impact of spawning success on the size of the next generation. In addition, methods of visualizing, identifying and counting daily increments from the statoliths of large adult squids are providing a matrix of ages at lengths (or masses) in the population. Changes in this matrix with time may be used to estimate the relative size of the stock, and so enhance efforts to manage the resource properly (Marine and Coastal Management Research Highlights (5) 2002).

N.E. Atlantic (L. forbesi and L. vulgaris)

Overview

Loligo forbesi (veined squid) and *Loligo vulgaris* (common squid) occur along the northeastern Atlantic and Mediterranean coasts. *L. vulgaris* is less common in northern waters with a northern limit of the southern part of the North Sea. *L. vulgaris* is also the smaller of the two species with a maximum weight of 1.5 kg and a mantle length of <40 cm in females and <54 cm in males. It is most abundant in 20-250 m depths (Wilson 1999a). *L. forbesi* is larger, with maximum mantle lengths of 41 cm in females and 90 cm in males, and occurs in 10-500 m depths (Wilson 1999b). Both are annual species with a peak of seasonal maturity and breeding in winter (December – May), throughout the geographical range. Both *L. forbesi* and *L. vulgari*s mature between 11 and 14 months, however *L. forbesi* is thought to live 1-2 years, whereas *L. vulgaris* has a life span approximated between 2-5 years (Wilson 1999a,b). The population size structure of both species is complex and unstable, and as with other loliginids size and age are not consistently related making length based assessment methods generally not applicable.

The distribution and abundance of *L. forbesi* and *L. vulgaris* in the North Sea is variable from year to year. Squid were found to be particularly abundant in the northern North Sea (57ºN – 62ºN) and in the English Channel (between 48ºN and 51ºN) (Waluda and Pierce 1997). Distribution was also found to vary temporally and spatially, with seasonal trends reflecting migratory movements. Additionally, water temperatures appear to directly influence distribution and abundance through effects on growth and survival and indirectly through the passive movement of squid in the North Sea via the warmer waters of the North Atlantic Drift. According to Waluda and Pierce (1997), bottom temperature seems to be the factor most strongly associated with the spatial pattern of squid abundance in the North Sea. Landings of squid were generally highest during the autumn, September to December of a given year, corresponding with the recruitment of young squid to the fishery (Boyle and Pierce 1995), and lowest in the summer, May to August.

Effort

Loligo forbesi is the most common squid off the coast of Britain, and is the only cephalopod of significance to fisheries in this region. It is of some importance as bait for angling and long-lines and has been increasingly marketed for human consumption, however this species is caught primarily as a bycatch of the demersal trawl and seine net fisheries.

Landings

In 1980 neritic squid catches amounted to 5,000 t in the northeast Atlantic with mainly *L. vulgaris and L. forbesi* being landed (Worms 1983). In comparison Mediterranean catches reached 8,000 t of largely *L. vulgaris*. Recent reports of neritic or common squid (mainly *L. vulgaris and L. forbesi*) catches for the northeast Atlantic indicate landings of between 6,000 and 8,000 t since 1993-1998 (Table 22)(International Council for the Exploration of the Sea [ICES] 2000). In Scotland, yields of neritic squid amounted to 1,198 t with increases in catch coming from the northern North Sea. In Ireland catches are considerably smaller than in Scotland, however *L. forbesi* is a valuable seasonal bycatch of the otter trawler fleet and at times targeted in certain areas when abundant. In the English Channel and Celtic Sea an intense fishery takes place with common squid (*L. vulgaris* and *L. forbesi*) accounting for approximately 2,000 t each year (1993-1997), however in 1999 that figure dropped to 836 t (ICES 2000). Landings from coastal waters are consistently highest in October–December as the peak of the breeding season approaches and, in some years, there are also large amounts of squid caught in the Rockall area (Scotland) during June–August. Typically there is considerable inter-annual variation in landings (Pierce *et al*. 1994a,b). *L. forbesi* was also the most abundant species in catches in an assessment of the distribution and abundance of cephalopods using demersal trawl surveys west of Ireland and in the Celtic Sea (Lordan *et al*. 2001).

Assessment

Projects within the northeastern Atlantic looking at cephalopod species, including *L. vulgaris* and *L. forbesi*, have provided important information for the development of more accurate assessments of fished cephalopod stocks. Pierce *et al*. (1996) reviewed data collection used to support depletion models for cephalopod assessments. They indicated that data collected on a monthly basis did not provide enough resolution for satisfactory assessments. Better assessments could have been obtained by using data collected at shorter time intervals, such as weekly or bi-weekly, which would then provide more data points and a more accurate picture of the decline in CPUE. It was also desirable to investigate the use of other methods of assessment apart from the depletion model, as in some species and areas there was no clear decline in catches during the season.

Pierce *et al*. (1996) recommended extending the area surveyed to include other important fishery areas in the North Sea, continued data collection for those stocks for which depletion models are appropriate to determine stock trends and between year and area comparisons, collect data for the evaluation of alternative assessment methods including less data intensive methods, and improve monitoring and estimation of natural mortality by a systematic and extensive survey of fish diet for the occurrence of cephalopod prey.

The Stock Dynamics project described by Pierce *et al*. (1996) demonstrated that assessment of northeastern Atlantic squid stocks is feasible, even in the present bycatch fishery. However, an appropriate level of baseline biological information and access to good quality fishery statistical data is imperative.

Management

Loligo forbesi and *L. vulgaris* are currently not managed in northeastern Atlantic waters, and are outside the scope of the European Community's Common Fisheries Policy, however attempts to assess and model the population dynamics for future management purposes have been undertaken.

Boyle and Pierce (1995) summarized prospects for fishery management, suggesting a combination of forecasting from empirical models and survey data, and real-time or retrospective application of depletion models which would provide satisfactory assessments for squid in northeastern Atlantic waters. They also suggested that future research should be targeted at development of empirical models of spatial and temporal patterns of distribution, and improvement of estimates of natural mortality.

Although squid stock in European waters are not presently subject to quota management, the recent increase in commercial importance of cephalopods highlights the need for a viable method of assessment if cephalopods are to be included under the Common Fisheries Policy quota system (Pierce *et al*. 1996).

N.W. Atlantic (L. pealei)

Overview

The longfin squid, *L. pealei*, ranges from the Gulf of Venezuela to Newfoundland in the northwest Atlantic, and is primarily fished off the northwest Atlantic United States (Brodziak 1998; Cadrin and Hatfield 1999; Cadrin 2000). It is one of two squid species of commercial significance in the region, the other being the shortfin squid, *Illex illecebrosus*. Commercial fishing for *L. pealei* off the coast of New England occurs year-round and is now a fishery with domestic and foreign markets worth $25-30 million per year and landings averaging 16,000-20,000 t. Small-mesh otter trawls dominate the fishery, but substantial landings are also taken from pound nets and fish traps in spring and summer. Most landings are taken from Southern New England and Mid-Atlantic waters, with fishing patterns reflecting seasonal distribution.

Longfin squid concentrate in winter on the outer edge of the continental shelf from the southern edge of Georges Bank to Cape Hatteras. In the spring, they migrate inshore to spawn, and from May to November are distributed over most of the shelf (Rathjen 1983). Water temperatures influence movements; *L. pealei* will undertake seasonal migrations to avoid waters where bottom temperatures drop lower than 8°C (Lange and Sissenwine 1983). Thus, the autumn cooling of coastal waters precipitates offshore migrations early in the winter. Submarine canyons and areas along the edge of the continental shelf at depths of 100-250 m have warmer water temperatures during winter (9°-12°C) and provide habitat with suitable characteristics (Lange and Sissenwine 1983; Brodziak 1998). Diel migrations have also been noted; although adult *L. pealei* are primarily demersal, juveniles will migrate vertically upward in the water column at night to avoid predation or to acquire prey (Brodziak and Macy 1996). As a result of these movements, bottom trawl catches of juveniles and adults are generally larger during the daylight hours.

Similar to other *Loligo, L. pealei* were thought to live 14-22 months. However, new information from statolith analyses found that *L. pealei* grew rapidly and completed their entire life cycle in less than one year (Brodziak and Macy 1994, 1996). *L. pealei* spawn year-round and seasonal differences in growth were substantial between squid hatched during summer (June-October) and winter (November-May)(Brodziak and Macy 1996). Weight at age increased exponentially for both summer- and winter-hatched squid, but growth was slower, on average for winter-hatched squid, which experienced lower temperatures as juveniles. The slower growth of winter-hatched squid implied that the yield per recruit would differ for the winter fishery, which primarily captured summer-hatched squid, in comparison to the summer fishery, which primarily harvested winter-hatched squid (Brodziak 1998). As well, the species is sexually dimorphic with males generally growing faster and attaining larger sizes than females. Some males grow to more than

40 cm (16 in.) DML, although most squid harvested in the commercial fishery are smaller than 30 cm (12 in.) DML (Cadrin 2000).

Effort

Atlantic longfin squid are heavily fished in both offshore over-wintering sites along the edge of the continental shelf and in spawning aggregations in shallow inshore waters of New England and the northwest Atlantic. Landings fluctuate widely, as generations have minimal overlap and seasonal dynamics are sensitive to environmental factors (Cadrin 2000). Towed otter trawls intensively fish the spawning aggregations, and this species is currently characterized as fully exploited at a medium biomass level, with indications that it is in danger of being over-fished throughout the region (Glass *et al*. 1998). The fishery consists of distinct inshore and offshore components with inshore landings occurring primarily between April and September. Offshore landings are generally about three-fold greater and occur from October through March with pre-spawning adults and juveniles being targeted. Each cohort lives approximately one year and is fished as it matures; consequently, the potential for recruitment overfishing is substantial.

Landings

The peak of the foreign offshore fishery occurred during 1972-1976 when landings averaged roughly 32,000 t per year. In 1986 directed foreign fishing was curtailed (NFSC 1995). Since peak foreign landings in the mid-1970s the fishery has had both severe declines and moderate increases with landings ranging between 4,300 t (in 1992) and 19,400 t (in 1999) during the 1990s (NMFS 2002). In 1971 the fishery was worth approximately $50,000 and has steadily increased to a value of approximately $33 million in 1999 and $23 million in 2000 (NMFS 2002). The National Marine Fisheries Service commercial landings are described in Table 23, which reports the annual harvest of longfin squid for the northeast Atlantic (NMFS 2002).

Assessment

Assessments utilize a long time series of biomass and abundance estimates from swept-area bottom trawl surveys (Cadrin and Hatfield 1999). Use of different analytical approaches has led to widely varying estimates of stock size. In the 1970s and early 1980s assessments determined the stock was fluctuating around the long-term average, and catches were sustainable. The stock was underexploited and at high levels of abundance between 1989 and 1993. Since 1994 the stock has been characterized as at medium levels of abundance and fully exploited by the fishery.

Historical assessments used cohort analyses (based on length-frequency modes), dynamic pool models and stock-recruit relationships, but all of these were compromised by the assumption of a multiple year life history. Brodziak and Rosenberg (1993) developed an extended Leslie-DeLury depletion model to estimate abundance and exploitation rates of longfin squid in the inshore fishery. The model indicated high variability in availability of squid to the inshore fishery, the importance of immigration rates (total catch was not highly correlated with the initial biomass in the fishery zone), and the importance of recognizing two seasonal cohorts in the population. Immigration and emigration of squid from adjacent areas made interpretations difficult (Cadrin and Hatfield 1999).

The most recent assessment (Cadrin and Hatfield 1999) included data for landings, discards, commercial CPUE, and research surveys. Landings were compared to survey estimates to estimate relative exploitation rates. Although somewhat inconsistent over time, both fall and winter indices indicated that the exploitation rate was high in 1998, and recent indices of recruitment are below average.

Stock size and fishing mortality were estimated using length-based virtual population analyses. These analyses indicated that stock size fluctuated around a seasonal average of 7,700 mt but generally decreased since 1991 (four of the five most recent estimates were the lowest in the series), and that fully-recruited F in 1998 was greater than F_{MAX}. These analyses, combined with growth information (Brodziak and Macy 1996), indicated that longfin squid were fully recruited to the fishery at ages of 7.5 to 8 months and sizes of 19 to 24 cm DML.

Dynamic pool models were used to estimate biological reference points $F_{0.1}$, F_{MAX} and $F_{50\%}$ for summer- and winter-hatched cohorts. Production models were used to estimate MSY (4,900 t per quarter, total 19,600 t). These analyses indicated that the 1999 estimated biomass was approxiamtely 53% of B_{MSY} (very close to the biomass threshold of 50% B_{MSY}). These analyses also indicated a high probability that the 1998 F exceeded F_{MSY}. These models indicated that the stock has potential to quickly rebuild from low population levels. The overall recommendation was that F should be reduced to rebuild stock biomass to B_{MSY}.

Management

Since the late 1800s spawning aggregations have been fished in New England's inshore waters (Glass *et al*. 1998; Cadrin and Hatfield 1999). At this time the squid was used as a source of bait, and from 1928 to 1967 annual squid landings from Maine to North Carolina (including northern shortfin squid, *Illex illecebrosus* landings) ranged from 500 to 2,000 t (Cadrin 2000). However, during the late 1960s fleets from Japan, Spain, and the USSR began harvesting these squid in the offshore waters of New England and the Mid-Atlantic Bight (Lange and Sissenware 1983; Brodziak 1998). The catch was frozen at sea and then destined for either European or Asian markets (Rathjen 1983). Eventually this trawl fishery was managed on a total allowable catch basis under the auspices of the International Commission for the Northwest Atlantic Fisheries (ICNAF). A TAC for *L. pealei* was set at 44,000 metric tonnes in 1976-1977, however the United States withdrew from ICNAF after passage of the U.S. Fishery Conservation and Management Act (FCMA) of 1976. The FCMA established national responsibility for fishery resources within 200 miles of U.S. land boundaries. As a result, total landings of *L. pealei* by foreign nations were reduced through the late 1970s and early 1980s as domestic fishers supplanted foreign fishers. Foreign fishing for *L. pealei* ceased in 1987 (Brodziak 1998; Cadrin and Hatfield 1999).

The Mid-Atlantic Fishery Management Council currently manages *L. pealei* stocks under the Atlantic Mackerel, Squid, and Butterfish Fishery Management Plan. Management measures specified under Amendment 8 to the FMP include a moratorium on permits, seasonal quota specifications and gear restrictions (Cadrin 2000). In 1998, management targets for the longfin squid were re-specified. The target fishing mortality rate is 75% of F_{MSY}, and the minimum stock size threshold (40,000 t) is one-half of B_{MSY} (80,000 t).

Summary Status (*adapted from* Cadrin 2000)

Long-term potential catch (MSY)	19,600 metric tons
Biomass corresponding to MSY	B_{MSY} = 80,000 metric tons
Minimum biomass threshold	½ B_{MSY} = 40,000 metric tons
Stock biomass in 1998	42,000 metric tons (implies stock not overfished)
F_{MSY}	F_{MAX} (Proxy)
F_{TARGET}	75% F_{MSY}
Overfishing definition	$F_{THRESHOLD}$
F_{1998}	>F_{MSY} (implies overfishing occurred)
Age at 50% maturity	6 months
Size at 50% maturity	15 cm (5.9 in.) DML
Assessment level	Biomass dynamics model
Management	Atlantic Mackerel, Squid and Butterfish FMP

Notes: Estimated biomass is derived from autumn and spring swept-area trawl survey data; $F_{THRESHOLD}$ = F_{MSY} when biomass ≥ B_{MSY}, decreasing linearly to zero at ½ B_{MSY}.

Discussion

Opal Squid

Opal squid are a relatively small, annual squid species; in fact, they are smaller in B.C. than in California, the major center of abundance for the species. They have low fecundity relative to most finfish, less than 10,000 eggs per female (as compared to 30,000 per female in eulachon, *Thaleichthys pacificus* [Hay and Boutillier 1999]). As they are terminal spawners, this represents total lifetime fecundity. Any stock-recruit relationship that may exist has not been documented; population size fluctuates widely, presumably influenced by environmental variables. Distribution and movements throughout the life cycle are not well known; nor is there any information on stock structure in B.C., although Reichow and Smith (2001) indicated that gene flow effectively prevents development of genetically distinct populations south of British Columbia. Spawning peaks in different seasons in Georgia Strait and off the west coast of Vancouver Island may be influenced by environmental conditions in the two areas. We do not know if the inability of B.C. fishers to repeatedly locate spawning stocks large enough to fish is due to variation in abundance or to differences in spawning distribution between years. Without information on stock structure and movements, we cannot predict effects of localized overfishing.

Opal Squid Fisheries

The fishery for opal squid has always been focused on peak abundance in California. Although developmental fisheries have been pursued in Oregon and Washington, these have never produced consistent landings in the same order of magnitude as the California fishery. Opal squid are not available in sufficient abundance in Alaska to merit fisheries development.

In B.C., opal squid have historically supported small fisheries when markets existed for bait. The fishery has never seriously accessed a human food market. Many of the current participants in the fishery use the species to augment income (or defer bait costs) from other fisheries that are the primary focus of the vessel carrying the licence.

Ecosystem Considerations

Other than work done in Monterey Bay (Morejohn *et al*. 1978), the role of opal squid in marine trophic webs is not well understood. This paper outlines, in a qualitative sense, the known prey and predators of opal squid, but quantitative information is lacking. It is clear, however, that when abundant, opal squid could be important in transferring nutrients from primary and secondary consumers (zooplankton and small neretic fishes) to tertiary consumers (medium-sized pelagic and bottom fish) and apex predators (large fish, marine birds, pinnipeds and small toothed whales). Their trophic role in B.C. waters is not well known, nor is their importance as forage species realtive to Pacific herring, *Clupea harengus pallasi*, or Pacific sandlance, *Ammodytes hexapterus*, which are more abundant in B.C. than California.

Forage species are those that are below the top of a food chain, provide an important source of food to at least some predators, and suffer high predation mortality.[10] Forage species recruit to fisheries at ages that still experience high predation mortality, often undergo large fluctuations in abundance (in response to environmental factors), usually form dense schools for at least part of their annual cycle, are short-lived and have a coastal distribution for at least part of the year. Forage species support dependent predators, which derive a significant portion of their annual food ration from the forage species.

Fisheries on forage species require special consideration: management policies must not only ensure that recruitment fishing does not occur, but must also ensure that the food supply of dependent predators is not depleted, even on local scales. A DFO draft policy on fisheries on forage fishes is currently under development.[11] More information on the role of opal squid in B.C. ecosystems is required to determine if they meet the criteria of forage species.

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[10] Draft Policy on Fisheries on Forage Species, J. Rice, DFO National Headquarters, Ottawa, pers. comm.
[11] *op. cit.*

Assessment Considerations

Assessment and management techniques for annual squid species have been reviewed by many authors (*e.g.*, Okutani 1977; Caddy 1983; Voss 1983; Pauly 1985; Saville 1987; Rosenberg *et al*. 1990; Pierce and Guerra 1994). Information in this section is drawn from these sources, with other sources cited where applicable.

Pierce and Guerra (1994) listed critical parameters for assessment of squid resources. These included biomass, recruitment, growth rates, age, natural and fishing mortalities and fecundity. Also critical is to determine how these parameters interact with each other, and what effect environmental variation has on each parameter. Models developed for finfish are unsuited for use with cephalopods, due to biological differences between the two groups.

Determination of stock size has always been problematic in squid fisheries. Depending upon the species and area, annual biomass estimates have been developed using direct surveys, acoustic estimation, or post-season estimation using fishery-dependent data (depletion estimates). Direct survey methods are not always applicable to small, pelagic species like opal squid, which can either avoid trawls, or tend to escape through wing and body meshes, rendering data from synoptic trawl surveys less than ideal for developing indices of abundance. Acoustic estimation of squid on relatively small scales has been demonstrated (Vaughn and Recksiek 1978, 1979; Starr 1985, Jefferts *et al*. 1987; Starr and Thorne 1998; Goss *et al*. 2001). Cailliet and Vaughn (1983) proposed acoustic surveys with large midwater trawl sampling to assess abundance of adult squid away from the spawning grounds, and a combination of acoustic, video, biological sampling and egg case count data to estimate abundance of spawning schools. However, acoustic surveys would be costly to undertake on broad (B.C.-wide) scales. The B.C. opal squid fishery may be currently too small and spread over too great an area to effectively deplete the resource, and fishery-dependent data are too unreliable to seriously consider depletion models at this time.

Stock-recruit relationships and the factors that influence them are not well documented for opal squid. There is evidence that oceanographic conditions (particularly El Niño) can influence availability of opal squid to fisheries in California, but whether or not these conditions affect recruitment or distribution is not known. If opal squid live approximately one year in B.C., then the fishable biomass will consist of one cohort (with some overlap if spawning is protracted), linked to the previous year's biomass by a poorly understood stock-recruit relationship. Indications of stock size in any year will not be available until the fishery commences (or perhaps not until the fishery finishes) and assessments must start from scratch each year.

Use of length-based methods to determine age and growth of annual squids is difficult due to the presence of numerous "microcohorts" resulting from protracted spawning periods, often with multiple peaks in activity. Immigration of squid onto the spawning grounds and selectivity of sampling gear can introduce biases that must be considered when using these methods. Differential growth rates between microcohorts within a given year make assessment of recruitment and growth difficult. Recent work on age determination using statoliths has indicated that California opal squid grow much more rapidly and do not live as long as previously thought (Jackson 1998). Estimation of natural mortality rates cannot be undertaken without dependable age data. Age and growth of opal squid using statoliths in B.C. has not been explored.

Fecundity has been estimated for opal squid in California (Fields 1965), and they are assumed to be terminal spawners (Knipe and Beeman 1978). Research is required to determine if fecundity is size-related and whether opal squid in B.C., which mature at smaller sizes than those in California, are less fecund.

The fact that the California opal squid fishery, which is worth tens of millions of dollars annually, is not assessed or actively managed is a result of the cost and difficulty in acquiring stock assessment information. The CDFG spent millions of dollars over three years to develop recommendations for future research and assessment of the fishery. Funding of this sort is not available in B.C., and the current industry participants are not in a position to supply funding to support assessment and management of an opal squid fishery.

Proposed legislation in California referred to Essential Fishery Information (EFI) and program goals were to develop research to describe past and current monitoring, identify EFI and continue to monitor the fishery and obtain EFI. This is not a departure from proposed policy for New and Developing Fisheries in B.C. (Perry *et al*. 1999), it merely uses different terminology. The proposed California legislation identifies nine general EFI groups:

- age and growth characteristics;
- distribution of stocks;
- ecological interactions;
- abundance estimates;
- movement patterns;
- recruitment;
- reproductive characteristics;
- total mortality; and
- social and economic factors.

Several of these categories of information will be similar in B.C. to those characterized in California, and should be investigated in collaboration with American investigators. Age, growth, total mortality, reproductive characteristics and recruitment characteristics may differ considerably due to latitudinal and fishery effects. Information (either genetic or life history characteristics) from B.C. will be important in determining distribution of stocks (at the very least, as a conspecific outgroup for genetic comparisons). Ecological interactions will differ between California and B.C. because of faunal differences (*i.e.*, different species occupying niches that are similar between areas) and perhaps due to differences in relative abundance of forage species. The problem of developing abundance estimates is common to both areas; the difference is the amount of resources each government is willing or able to dedicate to the task (largely dependent on the income to constituents from the resource). Obviously, social and economic factors will be different in the two areas and their fisheries.

The distribution of opal squid throughout their life cycle in B.C. waters is not well documented. Bernard (1980) made generalizations about peaks in spawning in the Strait of Georgia and on the outer coast of Vancouver Island, but the data upon which he based these statements is no longer available. The current fishery concentrates on areas of known spawning concentrations. Information for pre-spawning populations may be gained from careful examination of bycatch data from other fisheries and increased awareness of opal squid in research or stock assessment endeavors for other species (bottom and midwater trawl surveys for groundfish or shrimp, acoustic and seine surveys for pelagics, notably herring). The distribution and timing of spawning in B.C. is not particularly well documented, and assistance from fishers and the general public is required to accumulate data.

Assessment requirements for the opal squid fishery will be dependent upon the management strategy for the fishery (see below). At a minimum, the development of assessment programs in other fisheries (particularly California) should continue to be monitored. Information could be gained through continued collection and processing of biological samples in years of different environmental conditions. The application of statolith ageing techniques could provide information on age and longevity of B.C. opal squid. Further genetic analyses would clarify stock distinctions within B.C. However, current funding levels and priorities do not provide support for these research initiatives.

Management Considerations

A summary of management strategies employed in the loliginid fisheries described above are in Table 24.

The short life span of opal squid requires that precautionary and risk-averse management measures control the fishery. Because opal squid are annual species, the buffer proffered by multiple age-class stocks in most finfish fisheries is not present. Failure of recruitment due to overfishing a given year's stock could be catastrophic. Management objectives should, at a minimum, ensure that sufficient spawners escape that the probability of good recruitment in the following season is not reduced (Beddington *et al*. 1990; Rosenberg *et al*. 1990; Pierce and Guerra 1994). Management measures will need to be more conservative in light of the poorly understood stock-recruit relationship, and more precautionary yet if opal squid are suspected to occupy a key forage species role in local foodwebs.

Managers should consider a number of economic factors when evaluating this fishery. First, the fishery is secondary to other licences carried by participants; no licenced opal squid fisher in the last five years depended upon opal squid solely for their income (*i.e.*, all have held licences in other fisheries). However, opal squid may have accounted for a significant portion of the income for some licence holders, depending upon restrictions imposed in other fisheries. The fishery is for bait, and the catch is "processed" at sea; thus there are no spin-off jobs in the processing sector, and no benefits to coastal communities. Costs of assessment and management (even though the fishery is at best monitored, not managed) greatly exceed economic returns of fishery.

California prices for food market range between $100-$500 US per short ton (2,000 lb) which equates to $0.11-$0.55 US per kg, considerably less than ~$2.00+ Cdn per kg reported on fish slips in 2000. One reason we cannot break into California's food market is that we cannot generate the volume of landings necessary to be profitable to individual fishers. The proposed daily vessel trip limit in California is 60 short tons (54.4 t), roughly equal to the average annual landings reported on logbooks for the entire B.C. fishery over the last 18 years. (55.8 t).

Primary management concerns should include quality of fishery-dependent data, particularly non- or under-reporting of catches. The degree to which this practice undermines fishery-dependent data is unknown, as there is little enforcement of licence conditions, no catch validation, and little incentive to report catches if they are not sold but bartered or kept for "personal use" as bait. If basic information such as what was caught where and when cannot be reliably collected from the fishery, then the fishery can hardly be said to be monitored, even in the loosest sense of the term.

Secondary management concerns should include bycatch of juvenile herring or salmon in small mesh seines, and the secondary effects of seining in shallow water (including destruction of squid spawn, other invertebrates and habitat impacts of contact of the seine with the bottom. Admittedly, these occurrences may be relatively rare when experienced fishers are involved, and certainly are rare given current levels of reported effort. Ideally, data related to these concerns would be gathered by at-sea observers on squid boats, however, the way in which the fishery is carried out in B.C. (*i.e.*, as an opportunistic secondary fishery to the one the vessel is primarily licenced for) effectively precludes reasonable observer coverage.

At current levels of effort and catch, these problems seem minor, however, all will become significant problems should a change in demand lead to increased effort.

The Organization for Economic Cooperation and Development (OECD) reviewed fisheries management strategies of its member nations (OECD 1997). Potential management strategies included an annual harvest limit or Total Allowable Catch (TAC); Individual Quotas (IQs); trip limits; effort limitations (limited entry, individual effort quotas); size and/or sex selectivity; time or area closures (either for reproductive escapement or other ecosystem concerns); and gear restrictions (to limit efficiency or prevent habitat and/or spawn destruction).

Total Allowable Catch

US fishery managers are directed to develop estimates of Maximum Sustainable Yield (MSY) from which an Optimum Yield (OY) can be estimated. In 2000, the PFMC Scientific and Statistical Committee noted the following impediments to setting MSY for the California opal squid fishery: fishery and biological data are not sufficient; landings may not be reflective of abundance because markets influence fishing effort; the MSY concept may not be practical for a short-lived species that is vulnerable to oceanographic variation (CDFG 2002b). The PFMC STAR Panel examined several different approaches to estimating MSY in 2001, and likewise questioned whether the MSY concept was appropriate for a species that is short-lived and experiences wide annual variation in abundance or availability, linked to habitat responses (El Niño episodes). The data demands of establishing a defensible estimate of MSY could not be met at that time, but the panel recommended that the MSY approach be re-visited when more substantial data (*e.g.*, logbook time series) became available[12].

Restrepo *et al*. (1998) suggested developing a proxy for MSY in data-limited fisheries by using recent average catch from a time period where no evidence (qualitative or quantitative) of declining abundance is detected. This option was rejected by the PFMC, however, because the method was not designed for short-lived species and because of a lack of quality effort data. This approach is not applicable for B.C. opal squid because we have no index of abundance to analyze for trends.

There is no possibility of developing a quantitative TAC based on MSY for the B.C. opal squid fishery at this time. Although we have roughly a twenty-year time series of logbook records, the quality and utility of these data is questionable. Discrepancies between logbook and fish slip databases are numerous and large (the 2001 data are the most obvious example). We suspect that mis-reporting, under-reporting and non-reporting of catches are common throughout the data series, although comparison of logbook and fish slip data, where both were available, indicate that the situation may be improving. Effort in the fishery and landings reported more likely reflect market demand than opal squid abundance.

Another method of determining TAC is through application of conservative harvest rates to estimates of total stock biomass. Reliable and affordable methods for estimating total biomass of opal squid are not currently available.

TACs benefit conservation as they do not allow commercial catch to expand beyond a maximum volume (CDFG 2002b). However, a constant TAC does not provide stock protection in years when abundance is low, and the limit is not reached. In it's most precautionary sense, a TAC does not allow further expansion of a fishery beyond a chosen level. However, given the high variability of stock size in annual squids, fixed quotas may be of limited utility. Difficulty in predicting recruitment might lead to setting TAC's that risk over-exploitation and recruitment overfishing, or conversely risk under-exploitation if the TAC is set deliberately low to allow for occurrence of years of low recruitment/abundance (Caddy 1983; Pierce and Guerra 1994).

A review of the use of TACs in a number of countries indicated that TAC management resuled in over-capacity, shortened fishing seasons, fluctuating landings, and increased costs of harvesting and processing (OECD 1997). The review also found that overexploitation was generally not prevented using TACs as a management strategy.

[12] STAR Panel. *op. cit.*

Individual Quotas

Individual quotas restrict the catch of individual vessels by dividing the TAC into shares (OECD 1997). Depending on which fishery is involved, potential benefits included elimination of the race to fish, improved safety at sea, bycatch reduction, reduced gear conflicts and gear loss, greater economic stability and improved condition of the landed product. Consideration of IQs for opal squid in B.C. are premature, until rational means of developing an overall TAC are developed.

Trip Limits

Trip limits are used to slow the rate of resource exploitation. These typically involve limits on the amount that can be landed in one trip, but can also include restrictions as to the number of trips that can be undertaken in a given time period. Trip limits can be effective in slowing or even capping total production if harvest vessels are totally committed to the fishery in question. Again, however, latent effort (expended on other fisheries) that could be focused on the fishery in question limits the effectiveness of trip limits. Because B.C. fishers are currently processing and freezing squid at sea, they are effectively limited by their freezing capacity. Trip limits might be effective if the B.C. fishery landed fresh product to shore-based processors (and thus were limited by wet hold capacity rather than freezing capacity).

Effort Limitations

The most direct means of limiting effort in a fishery is to limit the number of licences issued. Some authors have argued that establishing fixed effort measures allows catches to vary in proportion to stock size, thus reducing risk of recruitment overfishing (Rosenberg *et al*. 1990; Pierce and Guerra 1994).

Licence limitation has several pitfalls, however, particularly if other management strategies are not employed. The number of licences issued is usually a function of how much resource is to be harvested and fishing power of the harvest vessels (Rosenberg *et al*. 1990). If fishing power increases, either through gear improvement, increased harvester experience, increased processing and storage capacity or transfer of licences to larger, more efficient vessels, the resource can quickly be overharvested. Effective effort can also increase if licence holders devote more time to the resource in question, as opposed to expending effort on other resources under other licences. Limitation proposals in California include a requirement for multiple licence reitrement if an active licence is to be transferred to a larger or more efficient vessel. The requirement to trade two or three licences offsets the risk of increased fishing power undermining conservation objectives.

Individual effort quotas can limit the absolute amount of gear a fisher can use (*e.g.*, trap limits) or limit the amount of time a vessel can fish in a season (by limiting days at sea, days fished, or trips or having mandatory lay-over times between trips) (OECD 1997). Licence limitation is required for individual effort quotas to be effective. These limits tend to motivate fishers to increase their fishing power, and thus their CPUE and total catch, undermining conservation objectives.

Size or Sex Selectivity

Size or sex selectivity strategies can be used to protect juveniles (minimum size limit), mature fish (maximum size limit) or reproductively valuable segments of the population (female non-retention in crab fisheries, egg-bearing female release in lobster fisheries)(OECD 1997). As the opal squid fishery takes place on mature squid in the act of terminal spawning, size and sex selective management strategies are not workable.

Time or Area Closures

Closures can be used to protect portions of fished stocks either spatially or temporally. Opal squid fisheries are carried out almost exclusively on spawning stocks. California has implemented two-day-per-week (weekend) closures to allow temporal refuge to spawning opal squid, and has established or proposed several permanent area closures for environmental concerns or to serve as "squid harvest replenishment" areas.

The B.C. opal squid fishery has 32 permanent area closures: 19 for navigational concerns, 14 for marine reserves, seven for National or Provincial Parks; and two for conservation concerns (Table 20). Although some of these areas historically supported fisheries, and thus provide some protection for spawning stocks, we lack information on stock structure, movements and distribution of spawning squid to determine if these closures would provide sufficient protection under increased fishing pressure.

The fishery remains closed year-round unless opened on request by Variation Order. This provides motivation for fishers to hail their activities to managers, and provides managers with an opportunity to assess potential risks of opening the fishery. To date, however, the concerns have focused on potential bycatch problems and user conflicts, as there is no information that would allow assessment of potential impacts of a fishery on opal squid stocks.

Closures have been used in developing fisheries to restrict potential fishery impacts to a relatively small portion of the available stock (usually using some measure of habitat as a proxy), leaving most of the stock in reserve and concentrating the limited effort available into a smaller area to test potential responses to fishing (*e.g.*, sea cucumbers; Boutillier *et al*. 1998; Campagna and Hand 2002).

Gear Restrictions

Gear restrictions serve three purposes: to limit effectiveness (fishing power), to limit bycatch of incidentally caught species, and to limit environmental impacts of fishing gear. Restrictions can include which types of gear are allowed (*e.g.*, seines or brails allowed, but not trawls) or the dimensions of the gear (*e.g.*, length limit of 100 m for seines in B.C.).

The gear restrictions currently in place in B.C. limit the effectiveness of the harvesters by limiting the volume of water that can be fished. Length limits on seines also implicitly limit the depth of the net; if certain length-depth ratios are exceeded, the gear no longer purses effectively. They also limit capture of demersal species and destruction of squid egg masses by somewhat preventing contact of the gear with the substrate. California has also proposed a minimum depth restriction on squid fishing that would ensure that gear does not contact the bottom.

The issue of bycatch of other small pelagics (herring, sardine, sandlance or juvenile salmon) is not addressed by current gear restrictions. This occurs when significant numbers of small pelagic fishes are caught along with squid. B.C. squid fishers use a "best-practices" approach to the problem, and release the seine contents as soon as possible when other species are inadvertently captured.

Another interesting restriction enacted in the California fishery involves total wattage limits for lighting and requirements for shielding of lights. This is primarily to limit "light pollution" effects on foraging seabirds and their rookeries and coastal communities. B.C. fishers do not currently use as large an array of lights as California fishers do. Other options which might achieve the same objective are to institute closures in sensitive areas, much as is done with navigational closures in place in B.C., or to explore the use of underwater lighting to attract squid.

Management Strategies

At a basic level, there are four strategies open to fishery managers and senior management (in ascending order of precaution):

A. **Status quo (allow fishery to continue with inadequate monitoring or management to address potential expansion).** This option entails relatively high risk due to poor quality of data used to monitor the fishery and potential for uncontrolled expansion should market conditions change.
B. **Active development and promotion of an opal squid fishery.** This would require: development of food market potential[13], development of assessment and management frameworks, and requirements for fiscal support of assessment and management from a fishery association.
C. **Adoption of additional control or protective measures in the fishery.** One possible option is licence limitation, which could limit potential effort to levels that minimize risk of overharvest. Conditions of licence could be introduced (or made more enforceable) that would improve fishery-dependent data to monitor the fishery. Licence limitation also

[13] Although the FAO places a lower priority on fisheries that are not for human consumption, DFO policy direction on the issue is unclear.

opens debate on a number of issues surrounding licence transferability ranging from attritional closure of the fishery, through measures to limit increases in fishing power of existing licences, to potential to let new licences if demand increases and sufficient assessment and management frameworks are developed. Other options include limits on catch or effort, time or area closures, or gear restrictions.

D. **Close the fishery.** Managers may decide that costs of developing assessment and management frameworks exceed current and/or future economic returns of the fishery. This is a bait fishery, not a fishery for human food, and FAO guidelines rank bait fisheries lower than human food fisheries in importance or desirability. In times of fiscal limitation, senior management may decide that finite assessment and management resources may be better directed at higher priority invertebrate fisheries.

Conclusions and Recommendations

The B.C. opal squid fishery is currently in an undeveloped state, with fewer than 15 licences issued in each of the last three years, and fewer than five vessels reporting activity in any of those years. Biological information and stock assessment methods are extremely limited. While there are some precautionary management measures currently in place (gear restrictions and permanent area closures), neither of these can address possible overfishing if effort in the fishery increases. We therefore recommend:

1. **Managers should not allow effort or landings from B.C. opal squid fisheries to increase until stock assessment and management frameworks are developed.** Allowing fishery development in the absence of these frameworks is neither precautionary nor risk-averse.
2. **Managers should consider any development of B.C. opal squid fisheries within the context of Policy for New and Developing Fisheries.** The costs and benefits of opal squid fishery development should be weighed relative to other data-limited fisheries, particularly in times of limited resources to assess and manage new fisheries. Any expansion should be through phased development of the fishery dependent on development of essential fisheries information and assessment and management frameworks.
3. **Managers should consider the ecosystem impacts of development of B.C. opal squid fisheries.** Opal squid are integral part of food webs in California, but their role in B.C. is not well known. In the absence of information on the role of opal squid in B.C. trophic webs, a precautionary approach would consider opal squid as forage species.
4. **Stock Assessment and Fish Management staff should continue to monitor program development in loliginid squid fisheries elsewhere in the world, particularly the California fishery.** The current low priority of the opal squid fishery has prevented efforts to develop an assessment framework. Considerable effort is being expended in other jurisdictions to develop assessment techniques and evaluate management strategies. These efforts will provide an information base from which to develop assessment and management frameworks for the B.C. opal squid fishery.

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Table 1. The squids of British Columbia (Nesis 1982; Austin 1985).

Common Name	Scientific Name	Family
Opal squid	*Loligo opalescens* Berry, 1911	Loliginidae
Flowervase jewel squid	*Histioteuthis hoylei* (Goodrich, 1896)	Histioteuthidae
-	*Cranchia scabra* Leach, 1817	Cranchiidae
-	*Galiteuthis phyllura* Berry, 1911	Cranchiidae
-	*Leachia pacifica* (Issel, 1908)	Cranchiidae
-	*Taonius pavo* (Lesueur, 1821)	Cranchiidae
-	*Abraliopsis felis* McGowan and Okutani, 1968	Enoploteuthidae
-	*Chiroteuthis calyx* Young, 1972	Chiroteuthidae
-	*Octopoteuthis deletron* Young, 1972	Octopoteuthidae
Neon flying squid	*Ommastrephes bartrami* (Lesueur, 1821)	Ommastrephidae
Minimal armhook squid	*Berryteuthis anonychus* (Pearcy and Voss, 1968)	Gonatidae
Magister armhook squid	*Berryteuthis magister* (Berry, 1913)	Gonatidae
Boreopacific armhook squid	*Gonatopsis borealis* Saski, 1923	Gonatidae
Berry armhook squid	*Gonatus berryi* Naef, 1923	Gonatidae
California armhook squid	*Gonatus californiensis* Young, 1972	Gonatidae
Madokai armhook squid	*Gonatus madokai* Kubodera and Okutani, 1977	Gonatidae
Clawed armhook squid	*Gonatus onyx* Young, 1972	Gonatidae
Fiery armhook squid	*Gonatus pyros* Young, 1972	Gonatidae
Hookless armhook squid	*Gonatus tinro* Nesis, 1972	Gonatidae
Brown bear armhook squid	*Gonatus ursabrunae* Jefferts, 1985	Gonatidae
Boreal clubhook squid	*Onychoteuthis borealijaponica* Okada, 1927	Onychoteuthidae
Robust clubhook squid	*Moroteuthis robusta* (Verrill, 1876)	Onychoteuthidae

Table 2. Definition of opal squid maturity stages (Lipinski 1979, Sauer and Lipinski 1990, Lipinski and Underhill 1995).

Stage	Male	Female
(1) juvenile	Spermataphoric complex as a whole unit, “spot”. The rest invisible.	Nidamental glands as transparent strips. The rest invisible.
(2) immature	Parts of the spermatophoric complex visible.	Oviducal meander visible. Ovary still isomorphic (homogenous).
(3) preparatory	White streak on vas deferens (might be quite inconspicuous.	Oviducal meander extended. Immature oocytes visible.
(4) maturing	Vas deferens extended. White particles in the Needham’s sac. Testis structure (fine grooves and ridges on surface) present.	Nidamental glands large. Some mature (yellow) oocytes in the ovary. No mature oocytes in oviduct.
(5) mature	Spermatophores in the Needham’s sac. Testis structure present. Some spermatophores can be found in penis.	Proximal part of ovary packed with mature oocytes – distal portion usually immature or mosaic. Oviducal meander densely packed with mature eggs. Secretion of nidamental glands.
(6) spent	Degenerating spermatophores and spermatophoric complex. Testis small.	Ovary now small consisting of a mosaic of only mature oocytes. Nidamental glands are also small.

Table 3. Reported predators of opal squid that are found in British Columbia (CDFG 2002b)

Common Name	Scientific Name	Common Name	Scientific Name
		Finfish	
Common thresher shark	*Alopias vulpinus*	Lingcod	*Ophiodon elongatus*
Sablefish	*Anoplopoma fimbria*	Curlfin sole	*Pleuronichthys decurrens*
Pacific sanddab	*Citharichthys sordidus*	Plainfin midshipman	*Porichthys notatus*
Speckled sanddab	*Citharichthys stigmaeus*	Blue shark	*Prionace galuca*
Surfperches	Embiotocidae	Big skate	*Raja binoculata*
Northern anchovy	*Engraulis mordax*	Pacific sardine	*Sardinops sagax*
Petrale sole	*Eopsetta jordani*	Rockfishes	*Sebastes* spp.
Pacific cod	*Gadus macrocephalus*	Redbanded rockfish	*Sebastes babcocki*
Soupfin shark	*Galeorhinus zyopterus*	Yellowtail rockfish	*Sebastes flavidus*
Pacific halibut	*Hippoglossus stenolepis*	Pacific mackerel	*Scomber japonicus*
Ratfish	*Hydrolagus colliei*	Spiny dogfish	*Squalus acanthias*
Pacific hake	*Merluccius productus*	Albacore	*Thuunus alalunga*
Coho salmon	*Oncorhynchus kisutch*	Pacific electric ray	*Torpedo californica*
Steelhead trout	*Oncorhynchus mykiss*	Jack mackerel	*Trachurus symmetricus*
Chinook salmon	*Oncorhynchus tshawytscha*		
		Birds	
Rhinoceros auklet	*Cerorhinca monocerata*	Leach's storm-petrel	*Oceanodroma leucorhoa*
Black-footed albatross	*Diomedia nigripes*	Fork-tailed Storm-petrel	Oceanodroma furcata
Tufted puffin	*Fratercula cirrhata*	Brandt's cormorant	*Phalacrocorax penicillatus*
Northern fulmar	*Fulmarus glacialis*	Cassin's auklet	*Ptychoramphus aleuticus*
Pacific loon	*Gavia pacifica*	Sooty shearwater	*Puffinus griseus*
Western gull	*Larus occidentalis*	Pink-footed shearwater	*Puffinus creatopus*
California gull	*Larus californicus*	Buller's shearwater	*Puffinus bulleri*
Mew gull	*Larus canus*	Short-tailed shearwater	*Puffinus tenuirostris*
Glaucous-winged gull	*Larus glaucescens*	Black-legged kittiwake	*Rissa tridactyla*
Heerman's gull	*Larus heermanni*	Common murre	*Uria aalge*
		Marine Mammals	
Northern fur seal	*Callorhinus ursus*	Northern elephant seal	*Mirounga angustirostris*
Sea otter	*Enhydra lutris*	Harbour seal	*Phoca vitulina*
Steller's sea lion	*Eumetopias jubatus*	Dall's porpoise	*Phocoenoides dalli*
Pygmy sperm whale	*Kogia breviceps*	Harbour porpoise	*Phocoena phocoena*
Pacific white-sided dolphin	*Lagenorhynchus obliquidens*	California sea lion	*Zalophus californianus*

Table 4. Summary of life history and fishery characteristics of the species of *Loligo* reviewed in this report.

Species	Common Name	Geographic Distribution	Habitat	Maximum Size	Life Span	Annual Landings (t)	Comments
Loligo opalescens	opal squid	Eastern Pacific	Continental shelf, common in 10-16°C, spawns at 20-55 m	Females 17 cm DML, 90 g; males 19 cm DML, 130 g	~1 year	~ 80,000 t; much lower during El Niño	Primarily California purse seine fishery
Loligo vulgaris reynaudii	Chokka squid	South Africa	Continental shelf, common in 12-15°C, spawns in 20-50 m, will spawn at greater depth if temperature too high	40 cm, 1 kg	~1.5 years	6,000-7,000 t	Jig fishery
Loligo forbesi	Veined squid	*Northeastern and Eastern Atlantic	>8.5°C, occurs over the shelf in temperate region (10-500 m)	Females 41 cm DML, males 90 cm DML	~1.5 years	1983: total squids of 6,000-8,000 t (*L. forbesi* and *L. vulgaris*)	Bycatch in demersal trawl fishery
Loligo vulgaris	common squid European squid	*Northeastern and Eastern Atlantic	most abundant at 20-250 m	Females 32 cm DML, males 42 cm DML; 1.5 kg	Females ~2 years, males ~3 years		
Loligo pealei	longfin squid	*Northwestern and Western Atlantic	optimum at 10-14°C, occurs over the continental shelf at 0-400 m depth	Females 40 cm DML, males 50 cm DML	~1 year	16,000-20,000 t	Otter trawl fishery

(* looking at Northeastern and Northwestern Atlantic populations only)

Table 5. Annual landings and value from the fishery for opal squid, *Loligo opalescens*, in California, 1960-2000.

Year	Landings (t)	Landings (lbs)	Value ($US)
1960	1,161.9	2,561,500	72,014
1961	4,665.7	10,285,900	231,229
1962	4,249.3	9,368,100	167,629
1963	5,244.0	11,560,900	240,366
1964	7,454.2	16,433,600	332,520
1965	8,445.9	18,619,900	307,684
1966	8,630.1	19,025,900	450,607
1967	8,891.4	19,601,900	437,766
1968	11,309.4	24,932,700	553,281
1969	9,425.5	20,779,400	555,426
1970	11,154.4	24,590,900	666,692
1971	14,296.1	31,517,100	760,573
1972	9,144.2	20,159,300	533,810
1973	5,501.0	12,127,600	451,070
1974	13,111.1	28,904,700	1,437,187
1975	10,733.0	23,661,900	854,362
1976	9,225.2	20,337,800	751,233
1977	12,811.3	28,243,900	1,480,647
1978	17,159.3	37,829,400	2,892,718
1979	19,981.5	44,051,139	4,160,672
1980	15,383.1	33,913,482	3,007,142
1981	23,509.8	51,829,718	5,079,669
1982	16,308.3	35,953,360	3,572,358
1983	1,823.6	4,020,353	758,032
1984	564.0	1,243,458	299,302
1985	10,276.2	22,654,927	3,745,999
1986	21,277.6	46,908,622	4,524,293
1987	19,984.1	44,056,904	3,959,428
1988	37,232.3	82,082,352	7,867,575
1989	40,893.0	90,152,660	6,954,482
1990	28,447.1	62,714,437	4,748,188
1991	37,388.6	82,426,950	6,086,561
1992	13,110.2	28,902,800	2,494,694
1993	42,829.8	94,422,595	10,162,182
1994	55,383.4	122,098,327	17,607,466
1995	70,251.5	154,876,514	22,570,968
1996	80,561.3	177,605,533	26,876,174
1997	70,328.6	155,046,468	21,881,819
1998	2,894.5	6,381,235	1,623,738
1999	91,518.7	201,762,173	33,276,814
2000	117,953.1	260,039,295	27,071,076

Table 6. Years experiencing significant El Niño events in the North Pacific.

1902-03	1905-06	1911-12	1914-15
1918-19	1923-24	1925-26	1930-31
1932-33	1939-40	1941-42	1951-52
1953-54	1957-58	1965-66	1969-70
1972-73	1976-77	1982-83	1986-87
1991-92	1994-95	1997-98	

Table 7. Management options presented in the Draft Management Plan for opal squid in California (CDFG 2002b).

Issue	Options
Catch limits	1. Establish a seasonal catch limit of 83,138 short tons. This was based on three-year average landings and the assumption that the stock is currently below B_{MSY} but above MSST.
	2. Establish a seasonal catch limit of 125,000 short tons, based on three-year average catch and the assumption that the stock is currently above B_{MSY}.
	3. Do not establish a seasonal catch limit. Reflects advice from the Squid Fishery Advisory Committee, which opposes catch limits. A catch of 125,000 short tons was considered unlikely given weekend closures.
	4. Establish catch limits based on environmental conditions. The Squid Research Scientific Committee recommended a seasonal harvest of 115,000 short tons in non- El Niño periods and a cap of 11,000 short tons during El Niño periods.
Daily trip limits	1. Establish a limit between 60-90 short tons for roundhaul vessels and 15 short tons for brail vessels.
	2. Do not establish daily trip limits.
Weekend closures	1. Continue existing weekend closures.
	2. Do not continue weekend closures.
Research and monitoring	1. Monitor the fishery using the egg escapement model while developing biomass estimation methods.
	2. Continue existing research and monitoring programs with an emphasis on development of management models.
	3. Maintin the logbook program
Area closures	1. Do not set aside areas as harvest replensihment areas for opal squid.
	2. Close areas where squid spawning occurs that are not regularly exploited by fishermen, such as waters <100 m depth around San Nicholas Island.
Live bait fishery	1. Continue existing regulations that do not require a permit when fishing for live bait or when catches do not exceed two short tons per day. Modify current live bait logs to include opal squid.
	2. Establish a permit for fishing opal squid for live bait.
Limited entry program	1. Establish a capacity goal using maximum catch on each trip and maximum number of days fished (highly productive specialized fleet). This would result in 130 days fished per season, and set capacity at 10 roundhaul vessels (and 10 light boats).
	2. Establish a capacity goal using maximum catch on each trip and average number of days fished (moderately productive and specialized fleet). This would result in 45 days fished per season and set capacity at 52 roundhaul vessels (and 52 light boats).
	3. Establish a capacity goal using average catch per trip and average days fished (less productive and less specialized fleet). This would result in 45 days fished per season and a capacity of 104 roundhaul vessels (and 104 light boats).
	4. Establish a capacity goal for brail vessels at 18 vessels.
	5. Do not establish limited entry.
Gear restrictions	1. Maintain current 30,000 watt limitation and requirements for shielding of lights.
	2. Remove existing light regulations.
Seabird closures	1. Establish seabird areas and times where fishing for opal squid is not permitted.
	2. Establish seabird areas or times where fishing for opal squid using lights is not permitted.
	3. Do not establish closures, but maintain current lighting restrictions.
Advisory committees	1. Do not have an advisory committee.
	2. Maintain the current two-committee structure.
	3. Combine scientific, environmental and industry representatives into a single advisory committee.
Permit fees	1. Maintain the current $400 permit fee for seine, light and brail vessels.
	2. Return to the $2,500 permit fee for seine, light and brail vessels.

Table 8. Annual landings, effort and value of the fishery for opal squid, *Loligo opalescens*, in Oregon, 1982-2000.

Year	Landings (t)	Landings (lbs)	Effort (#vessels)	Value ($US)
1982	51.3	113,138	n/a	9,125
1983	134.9	297,410	n/a	79,908
1984	429.4	946,725	13	199,972
1985	794.6	1,751,773	16	318,706
1986	12.0	26,371	6	2,683
1987	0.0	29	2	-
1988	0.0	5	1	-
1989	43.6	96,025	3	7,685
1990	0.0	0	0	0
1991	0.0	95	1	-
1992	6.1	13,344	17	1,607
1993	59.3	130,646	2	31,241
1994	105.7	233,003	n/a	35,672
1995	111.8	246,406	n/a	41,480
1996	104.0	229,323	n/a	36,897
1997	123.0	271,246	n/a	49,456
1998	8.8	19,431	n/a	3,629
1999	1.1	2,471	n/a	1
2000	5.7	12,504	n/a	3,103

Table 9. Annual landings of the fishery for squid in Washington, 1980-2001.

Year	Coastal Landings		Puget Sound Landings		Total	
	(t)	(lb)	(t)	(lb)	(t)	(lb)
1980	0.00	0	1.63	3,592	1.63	3,592
1981	0.04	86	5.23	11,533	5.27	11,619
1982	0.00	0	1.95	4,291	1.95	4,291
1983	0.03	61	40.33	88,918	40.35	88,979
1984	0.00	0	12.96	28,569	12.96	28,569
1985	0.02	43	1.24	2,733	1.26	2,776
1986	0.23	500	4.68	10,328	4.91	10,828
1987	0.76	1,669	3.20	7,051	3.95	8,720
1988	0.24	519	1.25	2,761	1.49	3,280
1989	0.01	33	0.52	1,153	0.54	1,186
1990	0.04	82	0.11	235	0.14	317
1991	0.08	176	0.11	247	0.19	423
1992	0.22	490	0.54	1,188	0.76	1,678
1993	0.00	0	5.14	11,327	5.14	11,327
1994	0.26	573	3.53	7,777	3.79	8,350
1995	0.30	656	11.45	25,239	11.74	25,895
1996	0.19	409	4.77	10,507	4.95	10,916
1997	0.07	156	0.00	0	0.07	156
1998	0.06	129	0.02	46	0.08	175
1999	0.07	150	0.00	0	0.07	150
2000	0.00	1	0.00	0	0.00	1
2001	0.05	120	0.00	0	0.05	120

Table 10. Number of licences issued, number of licences that submitted fish slips and logbooks and effort reported from fish slips and logbooks in the British Columbia opal squid fishery, 1984-2001.

	No. Licences			Days Fished	
Year	Issued	Fish slips	Logbooks	Fish slips	Logbooks
1984		26	14	n/a	177
1985		24	12	274	89
1986		18	10	288	118
1987		8	7	123	80
1988		8	8	98	80
1989		7	5	56	53
1990		9	8	115	64
1991		9	9	65	72
1992	47	5	5	77	60
1993	47	7	6	32	54
1994	46	7	7	155	96
1995	81	9	9	274	109
1996	107	17	17	377	176
1997	55	2	7	9	46
1998	86	4	7	44	71
1999	37	2	4	42	32
2000	15	1	2	5	11
2001	14	2	2	14	26

Table 11. Landings (t) reported on logbooks and fish slips, total landed value ($Cdn) and average price ($Cdn/kg) of opal squid in British Columbia, 1984-2001. Landings from logbooks in 2000-2001 and landings and landed value from fish slips in 1997 and 1999-2001 cannot be disclosed under provisions of the Privacy Act.

Year	Landings (t)		Landed Value ($Cdn•$10^3$)	Average Price ($Cdn/kg)
	Fish slips	Logbooks		
1984	69	75	25	0.36
1985	111	86	184	1.66
1986	89	87	127	1.43
1987	86	85	132	1.53
1988	88	88	113	1.28
1989	70	43	94	1.34
1990	72	49	81	1.13
1991	116	107	148	1.28
1992	93	72	135	1.46
1993	13	16	17	1.30
1994	175	116	199	1.14
1995	76	65	95	1.25
1996	78	70	97	1.25
1997	[redacted]	6	9	1.43
1998	22	23	44	2.05
1999	[redacted]	9	17	2.08
2000	[redacted]	[redacted]	[redacted]	2.76
2001	[redacted]	[redacted]	[redacted]	1.96

Table 12. Total landings (t) of opal squid by month in British Columbia as reported on logbooks, 1982-2001.

Month	Total Landings (t)	Percentage of Total
1	3.22	0.28%
2	4.37	0.37%
3	18.52	1.59%
4	83.46	7.15%
5	692.31	59.27%
6	265.92	22.77%
7	21.36	1.83%
8	21.40	1.83%
9	41.80	3.58%
10	4.70	0.40%
11	3.81	0.33%
12	7.21	0.62%
Totals	1,168.07	100.00%

Table 13. Total landings (t) of opal squid by area or region of British Columbia as reported on logbooks, 1982-2001.

Area	PFMA	Landings (t)	Percentage of Total
North Coast (old)	1-10, 130, 142	164.1	14.05%
South Coast (old)	11-29	1004.2	85.95%
North Coast (new)	1-6	41.1	3.52%
Central Coast (new)	7-13	167.3	14.32%
South Coast (new)	14-29	959.8	82.16%
East Coast Vancouver Island	11-19, 28, 29	66.6	5.70%
Georgia Strait	14-19, 28, 29	22.3	1.91%
West Coast Vancouver Island	20-27	937.6	80.25%
Southwest Coast Vancouver Island	23 and 24	919.3	78.69%
Barkley Sound	23	809.7	69.30%

Table 14. Total encounters (landings + reported discards in t) of opal squid in the B.C. groundfish trawl fishery by Area, 1996-2001.

Year	North Coast (PFMA 1-6, 142)	Central Coast (PFMA 7-13, 132)	South Coast (PFMA 14-29)	Total
1996	0.00	0.00	0.00	0.01
1997	0.00	0.00	0.00	0.01
1998	0.39	0.02	0.00	0.41
1999	0.01	0.00	0.02	0.03
2000	0.01	0.01	0.25	0.27
2001	n/r	n/r	n/r	n/r
Total	0.41	0.04	0.28	0.72

Source: PacHarv database, Groundfish Data Unit, Pacific Biological Station.
N.B. – n/r = no records, 0.00 = reported landings and discards less than 10 kg.

Table 15. Total encounters (landings + reported discards in t) of "squid" in the B.C. groundfish trawl fishery by Area, 1996-2001.

Year	North Coast (PFMA 1-6, 142)	Central Coast (PFMA 7-13, 132)	South Coast (PFMA 14-29)	Unknown	Total
1996	2.46	1.19	5.99	1.45	11.10
1997	1.37	0.49	5.52	0.62	8.00
1998	1.35	0.30	5.38	0.99	8.02
1999	0.35	0.06	12.08	3.31	15.81
2000	2.96	1.24	6.54	1.85	12.60
2001	2.30	2.93	5.55	2.75	13.54
Total	10.78	6.22	41.06	10.98	69.05

Source: PacHarv database, Groundfish Data Unit, Pacific Biological Station.
N.B. – Unknown Area catch was reported landings or discards that could not be geo-referenced.

Table 16. Average length and weight by sex and sex ratio of opal squid sampled from the 2001 fishery in British Columbia.

	PFMA 2 June 8, 2001		PFMA 123 June 1, 2001		PFMA 123 June 2, 2001		Total	
	M	F	M	F	M	F	M	F
No. sampled	217	118	237	195	116	85	570	398
Average Weight (g)	21.6	21.9	25.6	24.8	24.1	22.5	23.8	23.5
Range	11.9-34.1	11.9-33.1	10.9-43.2	13.4-35.8	12.2-37.6	15-33.7	10.9-43.2	11.9-35.8
S.D.	4.8	4.3	6.2	4.5	6.1	3.5	5.9	4.4
Average DML (mm)	102.1	103.2	108.5	110.0	107.0	110.2	105.8	108.1
Range	78-121	79-121	85-131	90-127	83-124	92-122	78-131	79-127
S.D.	7.9	6.5	8.1	5.9	8.4	5.2	8.6	6.7
% of Sample	64.8%	35.2%	54.9%	45.1%	57.7%	42.3%	58.9%	41.1%
Sex Ratio (M : F)	1.84 : 1		1.22 : 1		1.36 : 1		1.36 : 1	

Table 17. Comparison of weight and length data from the 2001 British Columbia fishery and historic estimates from Monterey Bay.

	Monterey Bay			British Columbia
	Fields (1965)	Evans (1976)	Leos (1998)	
Males				
Average Weight (g)	70	70.1	44.4	23.8
S.D.	n/a	22.4	17.0	5.9
Average DML (mm)	150	146.3	129	105.8
S.D.	n/a	13.9	16.9	8.6
Females				
Average Weight (g)	50	49.3	35.6	23.5
S.D.	n/a	13.4	9.9	4.4
Average DML (mm)	140	133.9	125	108.1
S.D.	n/a	10.1	10.7	6.7

Table 18. Maturity frequencies of opal squid sampled from the 2001 fishery in British Columbia.

	PFMA 2 June 8, 2001		PFMA 123 June 1, 2001		PFMA 123 June 2, 2001		Total	
Stage	M	F	M	F	M	F	M	F
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	1	1	0	2	0	3	1
4	9	15	25	0	14	16	48	31
5	97	56	11	1	47	35	155	92
6	111	46	79	84	68	39	258	169
Total	217	118	116	85	131	90	464	293

Table 19. Mean weight and length by sex and maturity stage of opal squid from the 2001 British Columbia fishery.

	Maturity Stage							
	3		4		5		6	
Sample	M	F	M	F	M	F	M	F
Area 2, June 8								
No. sampled	0	1	9	15	97	56	111	46
Average Weight (g)		19.0	18.9	23.9	22.3	23.8	21.2	19.0
Range			14.4-23.8	17.8-30.6	11.9-34.1	16.2-33.1	12.5-32.6	11.9-27.1
S.D.			3.6	3.5	5.1	3.7	4.5	3.8
Average DML (mm)		100.0	99.8	103.3	102.0	104.2	102.4	102.1
Range			89-110	93-110	78-119	91-121	86-121	79-119
S.D.			7.9	5.0	8.0	5.5	7.9	7.9
Area 123, June 1								
No. sampled	2	0	14	16	47	35	68	39
Average Weight (g)	13.8		21.8	28.4	27.3	24.9	23.9	21.9
Range	13.2-14.3		10.9-31.2	21.6-34.7	16.1-36.3	19.1-30.8	14.1-39.1	13.4-31.6
S.D.	0.8		6.2	4.0	6.2	3.0	5.8	3.5
Average DML (mm)	101.5		103.0	109.9	108.0	108.6	108.7	108.9
Range	97-106		85-119	100-119	89-124	90-120	93-131	98-121
S.D.	6.4		10.2	5.0	9.0	6.3	8.1	5.8
Area 123, June 2								
No. sampled	1	0	25	0	11	1	79	84
Average Weight (g)	16.8		20.0		26.2	33.7	25.2	22.4
Range			12.2-33.0		16.2-36.3		12.6-37.6	15.0-31.0
S.D.			5.5		5.9		5.7	3.3
Average DML (mm)	85.0		103.5		105.9	113.0	108.6	110.2
Range			89-115		91-120		83-124	92-122
S.D.			7.8		7.9		8.1	5.3
Samples Combined								
No. sampled	3	1	48	31	155	92	258	169
Average Weight (g)	14.8	19.0	20.4	26.2	24.1	24.3	23.1	21.4
Range	13.2-16.8		10.9-33.0	17.8-34.7	11.9-36.3	16.2-33.7	12.5-39.1	11.9-31.6
S.D.	1.8		5.4	4.3	6.0	3.5	5.5	3.7
Average DML (mm)	96.0	100.0	102.6	106.7	104.1	106.0	105.96	107.7
Range	85-106		85-119	93-119	78-124	90-121	83-131	79-122
S.D.	10.5		8.5	5.9	8.7	6.2	8.5	7.1

Table 20. Permanent closures (with Pacific Fishery Management Subareas) in the British Columbia opal squid fishery (DFO 2001a).

Navigational Closures	
Kelsey Bay (13-34)	Fulford Harbour (18-10)
Upper Baynes Sound (14-11)	Victoria Harbour (19-1)
Comox Harbour (14-14)	Esquimalt Harbour (19-2)
Bargain Bay (16-13)	Port San Juan (20-2)
Pender Harbour (16-14)	Sooke Harbour and Basin (20-6 and –7)
Head of Sechelt Inlet (16-15)	Bamfield Inlet (portion of 23-7)
Ladysmith Harbour (17-7)	Horseshoe Bay (portion of 28-2)
Nanaimo Harbour (17-14)	False Creek (28-8)
Sansum Narrows, Burgoyne and Maple Bays (18-7)	Burrard Inlet (28-10)
Cowichan Bay (18-8)	
Marine Reserves	
Discovery Passage (13-3, -4, -5, and portion of –6)	Mittlenatch Isl. (portions of 13-1, 13-3, 14-13, 15-2)
Lambert Channel (portion of 14-7)	Ogden Point (portion of 19-3)
Vivian Island (portion of 15-2)	Ten Mile Point (portions of 19-4 and 19-5)
Rebecca Rock (portion of 15-2)	Race Rocks (portions of 19-3 and 20-5)
Dinner Rock (portion of 15-2)	Botanical Beach (portion of 20-3)
Emmonds Beach (portion of 15-2)	Porteau Cove (portion of 28-4)
Beach Gardens (portion of 15-2)	Whytecliff Park (portion of 28-2
Parks	
Skookumchuck Narrows Provincial Park (portion of 16-9)	
Sidney Spit Marine Park (19-6)	
Pacific Rim National Park (PRNP), Juan de Fuca (portion of 20-1)	
PRNP, Broken Group (portions of 23-7 and –8)	
PRNP, Pachena Bay (portion of 123-1)	
PRNP, Long Beach (portions of 123-5 and 124-1)	
PRNP, Grice Bay and McBey Islets (portions of 24-9 and-11)	
Other Closures	
Deep Water Bay (portion of 13-7; salmon holding area)	
Saanich Inlet (19-7 to 19-12; conservation closure)	

Table 21. Annual landings (t) of chokka squid, *Loligo vulgaris renaudii*, in South Africa.

Year	Landings (t)
1985	2,626.1
1986	3,489.1
1987	2,796.4
1988	4,869.6
1989	9,775.1
1990	3,288.4
1991	6,693.7
1992	2,593.6
1993	6,387.4
1994	6,596.1
1995	6,869.8
1996	7,233.9
1997	3,916.1
1998	6,485.3
1999	6,942.7
2000	6,324.6

Source: M. Roberts, South African Climate Change and Squid Program, pers. comm.

Table 22. Annual landings (t) of common squid (includes *Loligo forbesi*, *L. vulgaris*, *Alloteuthis subulata* and *A. media*) in the Northeast Atlantic (ICES 2000).

Year	Landings (t)
1993	7,837
1994	6,381
1995	7,554
1996	6,966
1997	7,073
1998	6,467

Note: landings predominantly *L. forbesi and L. vulgaris* (ICES 2000).

Table 23. Annual landings (t) of longfin squid, *Loligo pealei*, from the Northwest Atlantic (Cape Hatteras to Gulf of Maine), 1963-1998 (Cadrin and Hatfield 1999).

Year	US	Foreign	Total
1963	1,294	0	1,294
1964	576	2	578
1965	709	99	808
1966	772	226	998
1967	547	1,130	1,677
1968	1,084	2,327	3,411
1969	899	8,643	9,542
1970	653	16,732	17,385
1971	727	17,442	18,169
1972	725	29,009	29,734
1973	1,105	36,508	37,613
1974	2,274	32,576	34,850
1975	1,621	32,180	33,801
1976	3,602	21,682	25,284
1977	1,088	15,586	16,674
1978	1,291	9,355	10,646
1979	4,252	13,068	17,320
1980	3,996	19,750	23,746
1981	2,316	20,212	22,528
1982	2,848	15,805	18,653
1983	10,867	11,720	22,587
1984	7,689	11,031	18,720
1985	6,899	6,549	13,448
1986	11,525	4,598	16,123
1987	10,367	2	10,369
1988	18,593	3	18,596
1989	23,733	5	23,738
1990	15,399	0	15,399
1991	20,299	0	20,299
1992	19,018	0	19,018
1993	23,020	0	23,020
1994	23,480	0	23,480
1995	18,880	0	18,880
1996	12,026	0	12,026
1997	16,308	0	16,308
1998	18,385	0	18,385

Table 24. Summary of management strategies for loliginid squid fisheries.

Jurisdiction	Species	Management Strategy	Comments
California (pre-1998)	*Loligo opalescens*	open access, unregulated, small area closures	significant increases in participation and landings
California (1998-present)	*L. opalescens*	proposed new measures include limited entry, logbooks, coastwide TAC, increased area closures, trip limits, gear restrictions, advisory committees, permit fees	cannot evaluate, changes too recent
Oregon	*L. opalescens*	Developmental Fisheries Program. limited entry	minor fishery, effort too limited to test management strategy or pose conservation risk
Washington	*L. opalescens*	unlimited entry, logbook required (Puget Sound only), gear and light restrictions	minor fishery, effort too limited to test management strategy or pose conservation risk
British Columbia	*L. opalescens*	unlimited entry, logbooks and fish slips required, gear restrictions, closed areas	minor fishery, not a conservation risk at present, but current management insufficient if effort increases
Alaska	*L. opalescens*	no directed fishery, bycatch in trawl fisheries	no management strategy
South Africa	*L. vulgaris reynaudii*	limited entry, short closure for spawning, closed areas, biomass surveys	concern over increasing effort
N.E. Atlantic	*L. vulgaris* *L. forbesi*	no limits noted	no management strategy
N.W. Atlantic	*L. pealei*	limited entry, seasonal TAC, gear restrictions, estimates of biomass and fishing mortality	stock not in overfished condition, however, indications of overfishing in some years

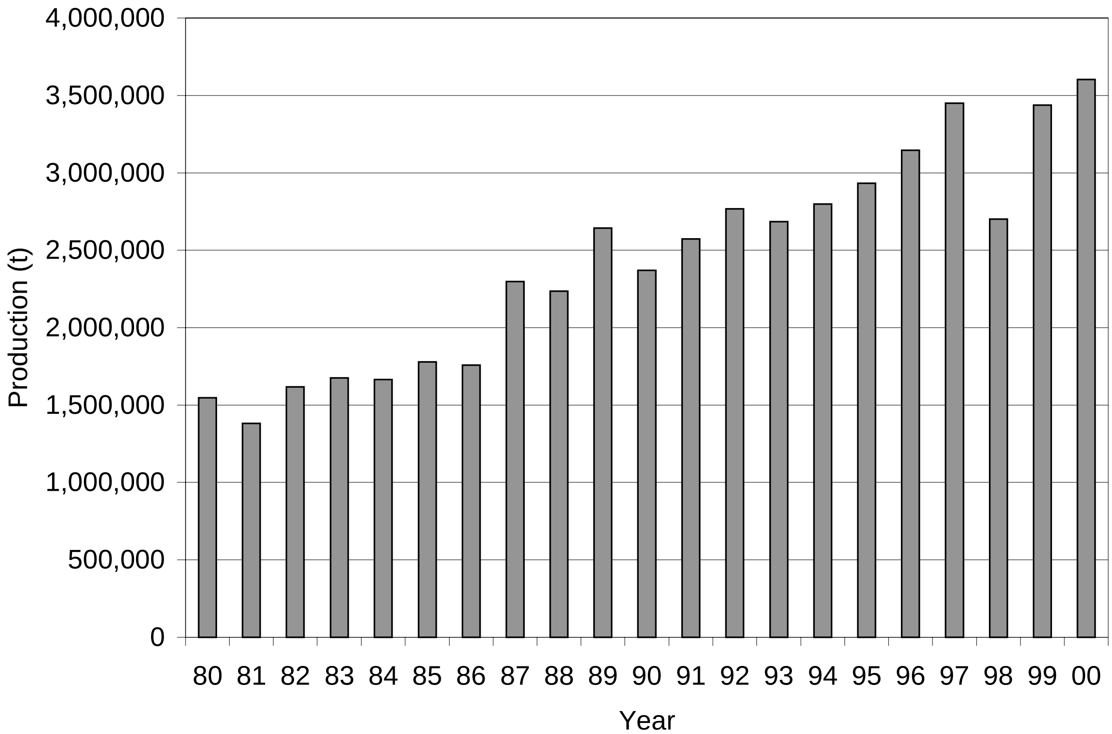


Figure 1. World fisheries production of cephalopods (t), 1980-2000 (FAOSTAT database).

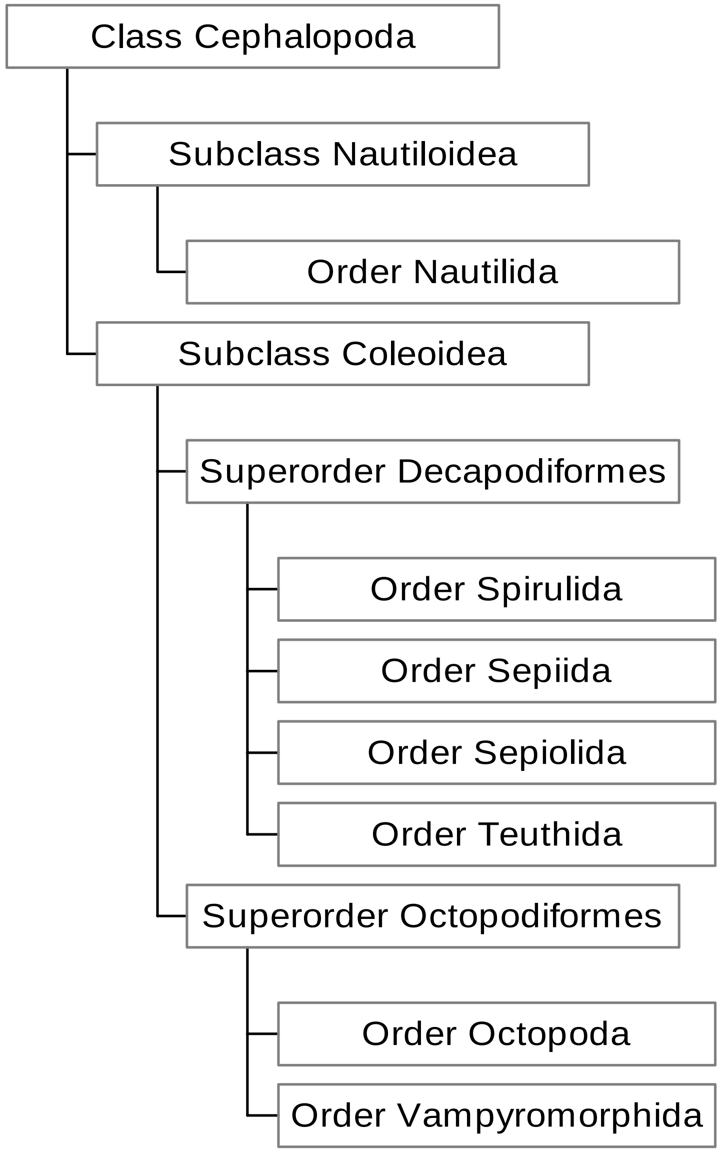


Figure 2. Higher classification of cephalopods.

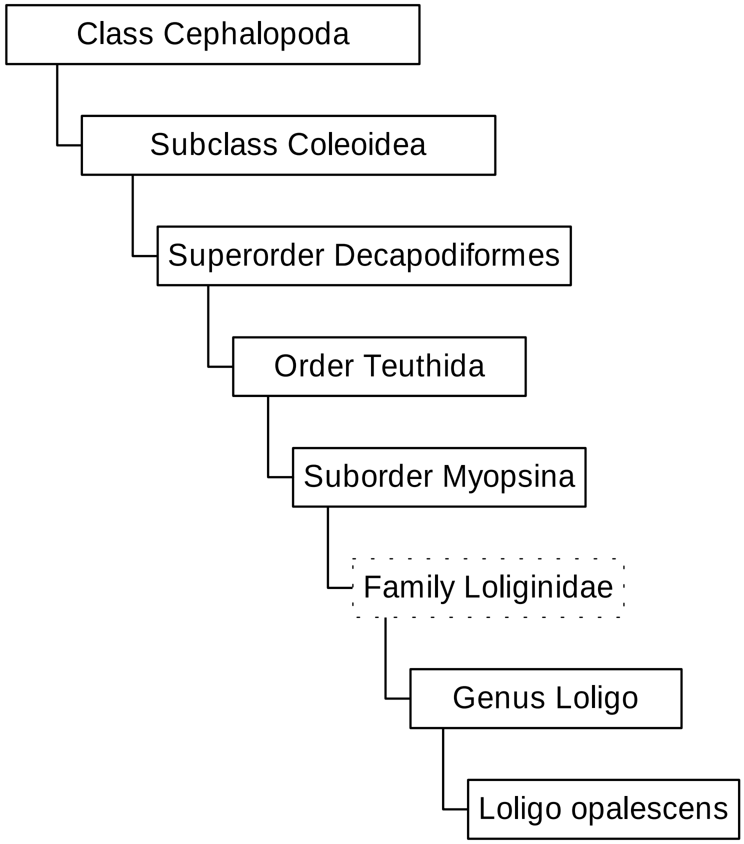


Figure 3. Hierarchical classification of opal squid.

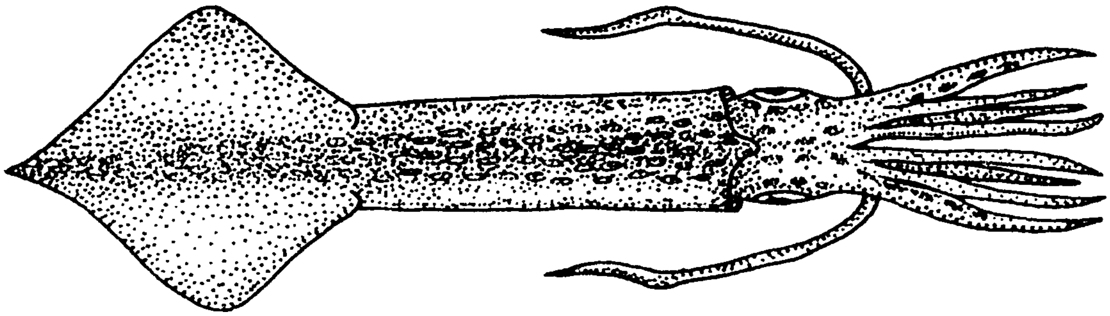


Figure 4. The opal squid, *Loligo opalescens*. Figure from Bernard (1980).

Figure 5. Opal squid, *Loligo opalescens*, from British Columbia. Male above, female below.

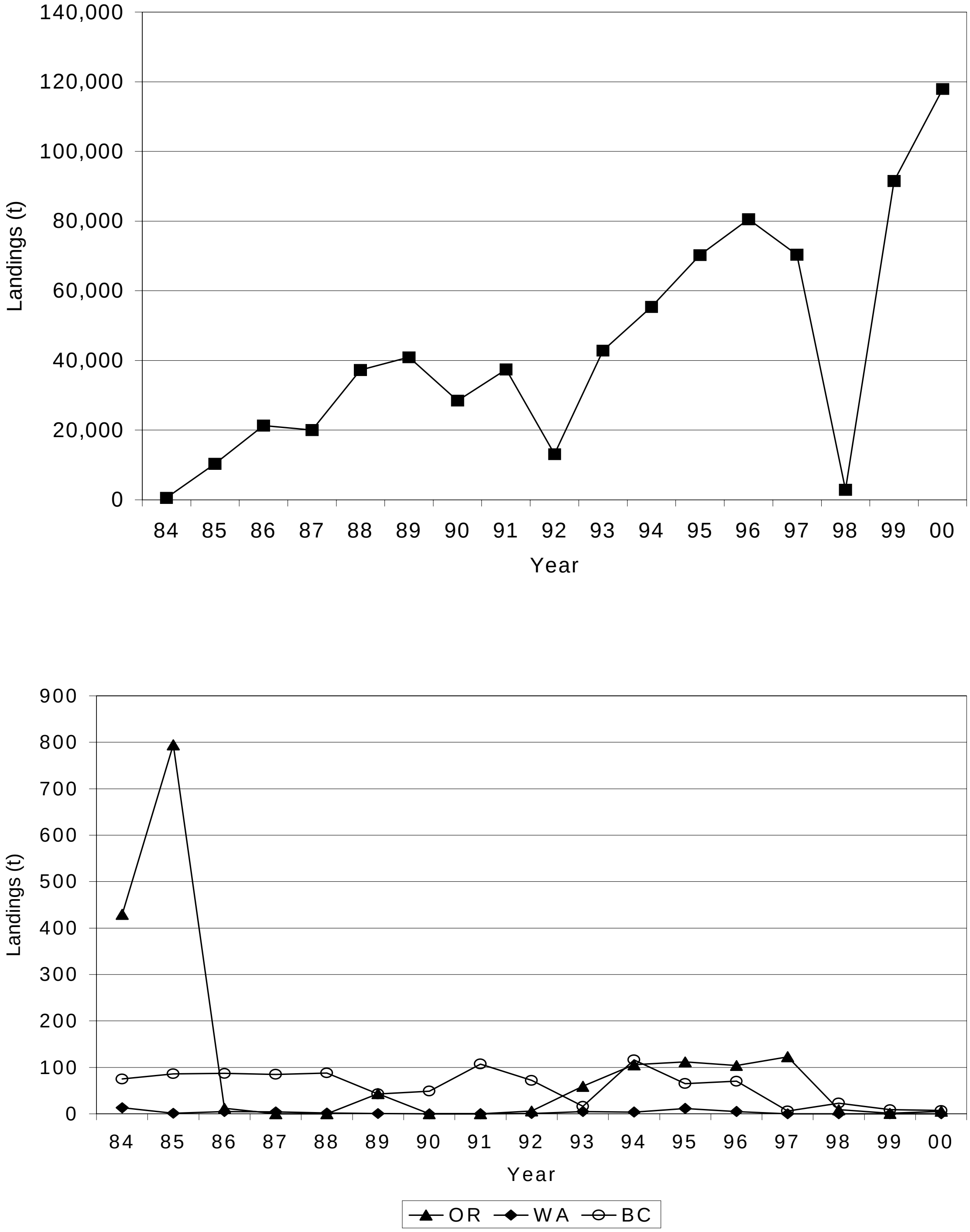


Figure 6. Annual landings (t) of opal squid in California (top) and the rest of western North America (bottom) 1984-2000. Note different scales on the y axes.

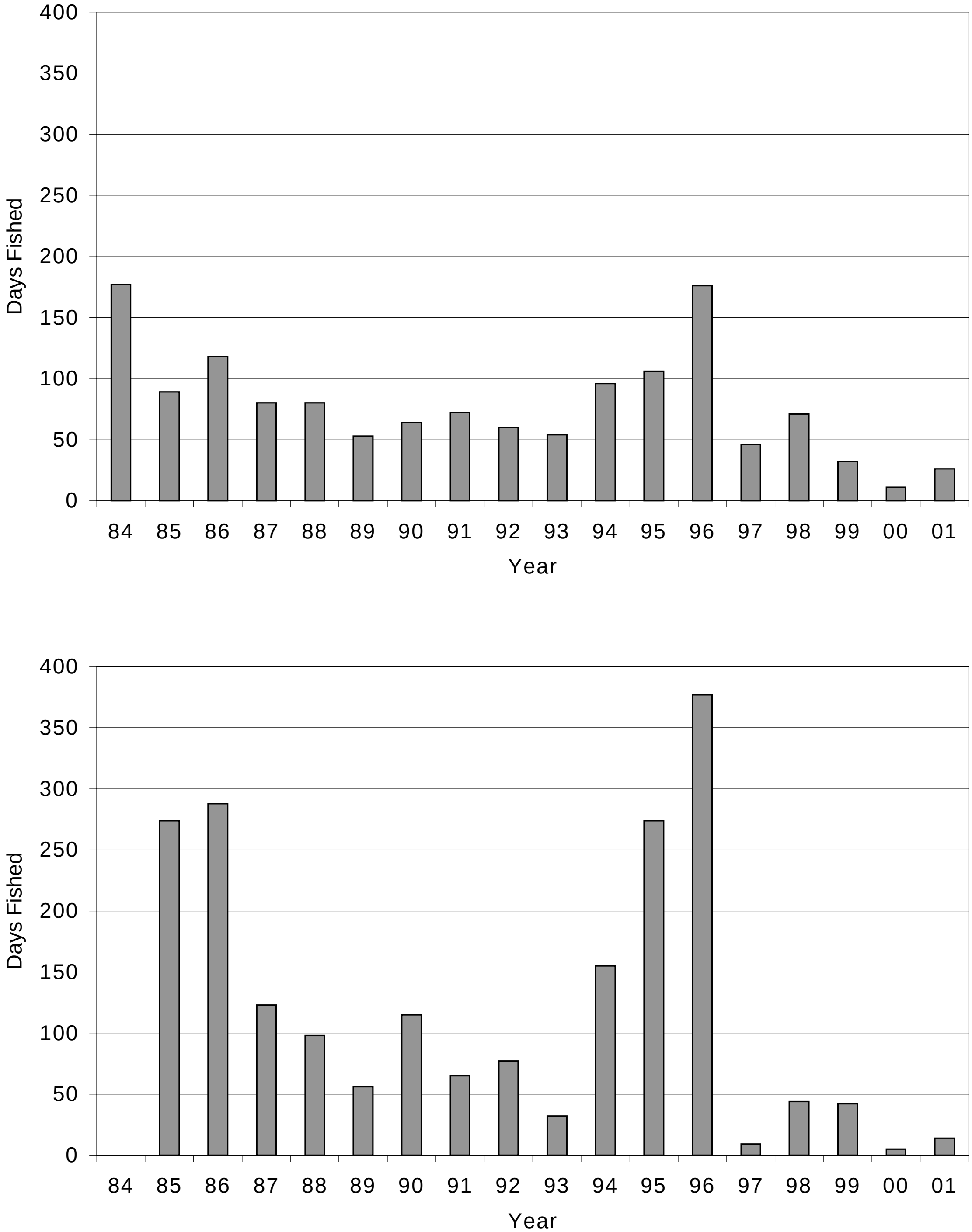


Figure 7. Effort (days fished) from the opal squid fishery in British Columbia, as reported on logbooks (top) and fish slips (bottom), 1984-2001.

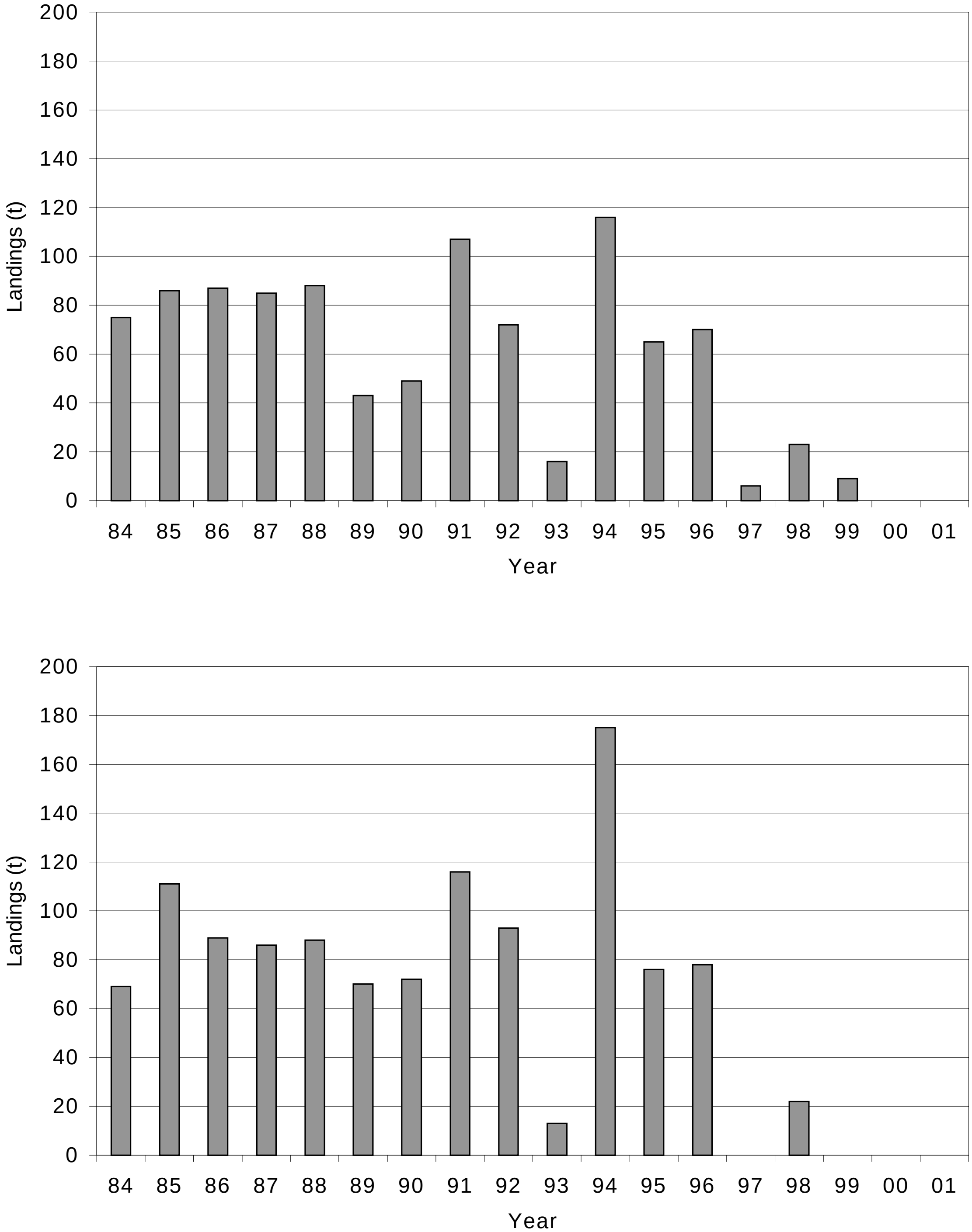


Figure 8. Annual landings (t) of opal squid in British Columbia as reported on logbooks (top) and fish slips (bottom), 1984-2001. Landings for 1997 and 1999-2001 from slips and 2000-2001 from logbooks cannot be disclosed under provisions of the Privacy Act.

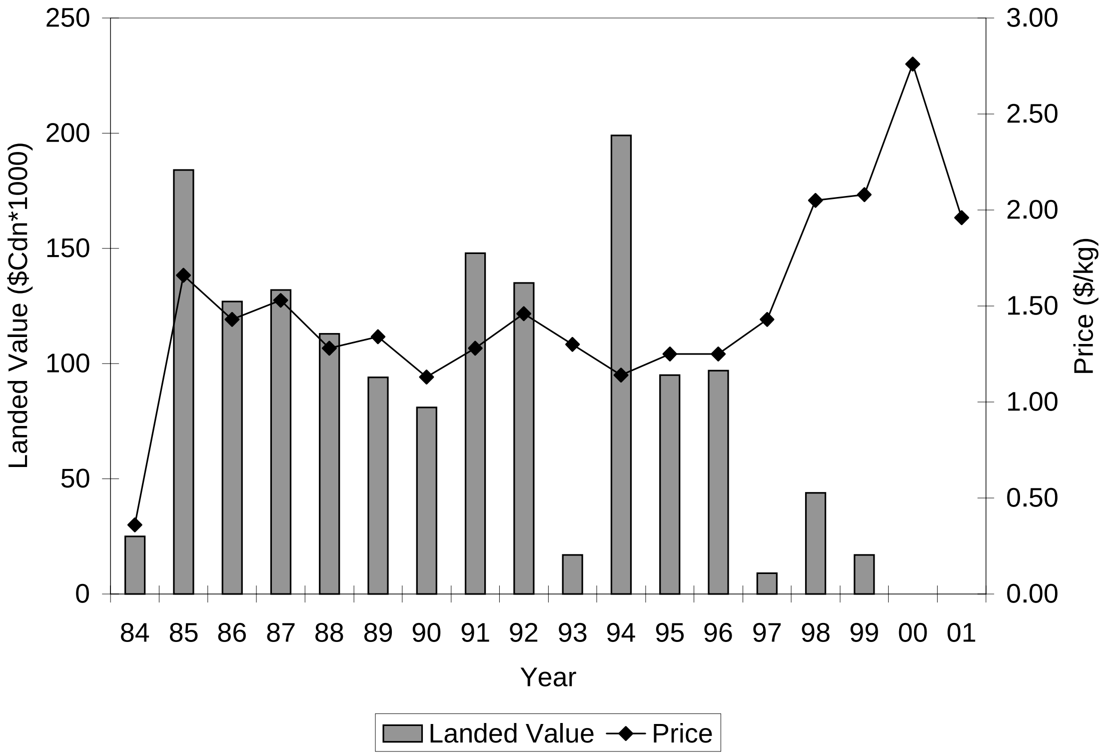


Figure 9. Landed value ($Cdn) and price ($Cdn/kg) of opal squid in British Columbia from fish slips, 1984-2001. Landed values from 2000-2001 cannot be disclosed under provisions of the Privacy Act.

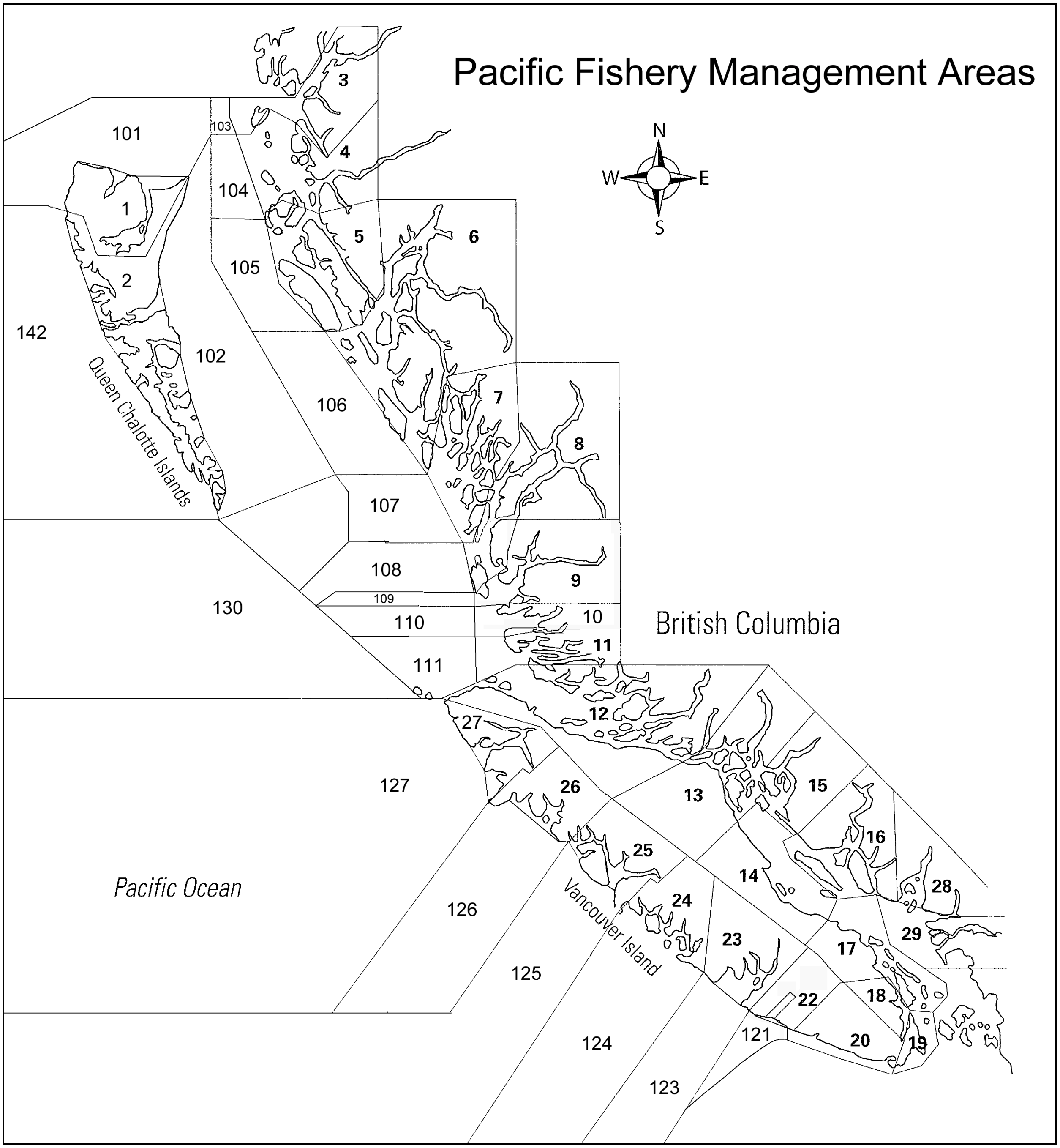


Figure 10. Pacific Fishery Management Areas (PFMAs) off the coast of British Columbia.

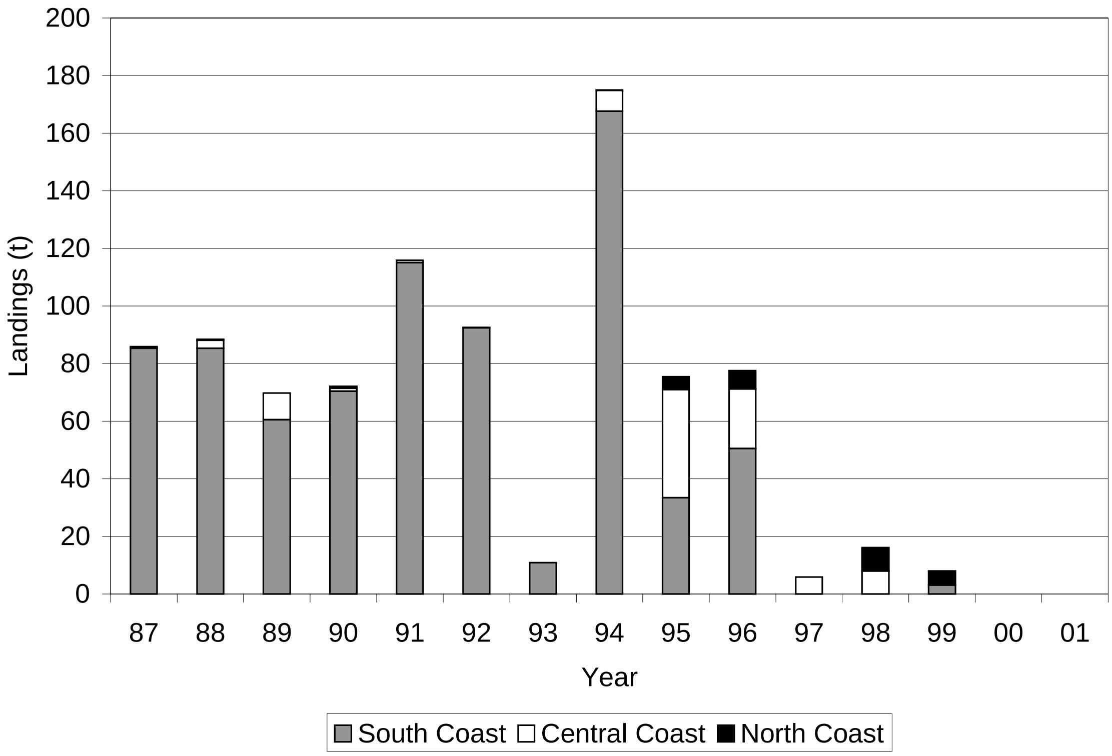


Figure 11. Landings (t) of opal squid in British Columbia by Management Area, as reported on logbooks, 1987-2001. Landings for 2000 and 2001 cannot be disclosed under provisions of the Privacy Act.

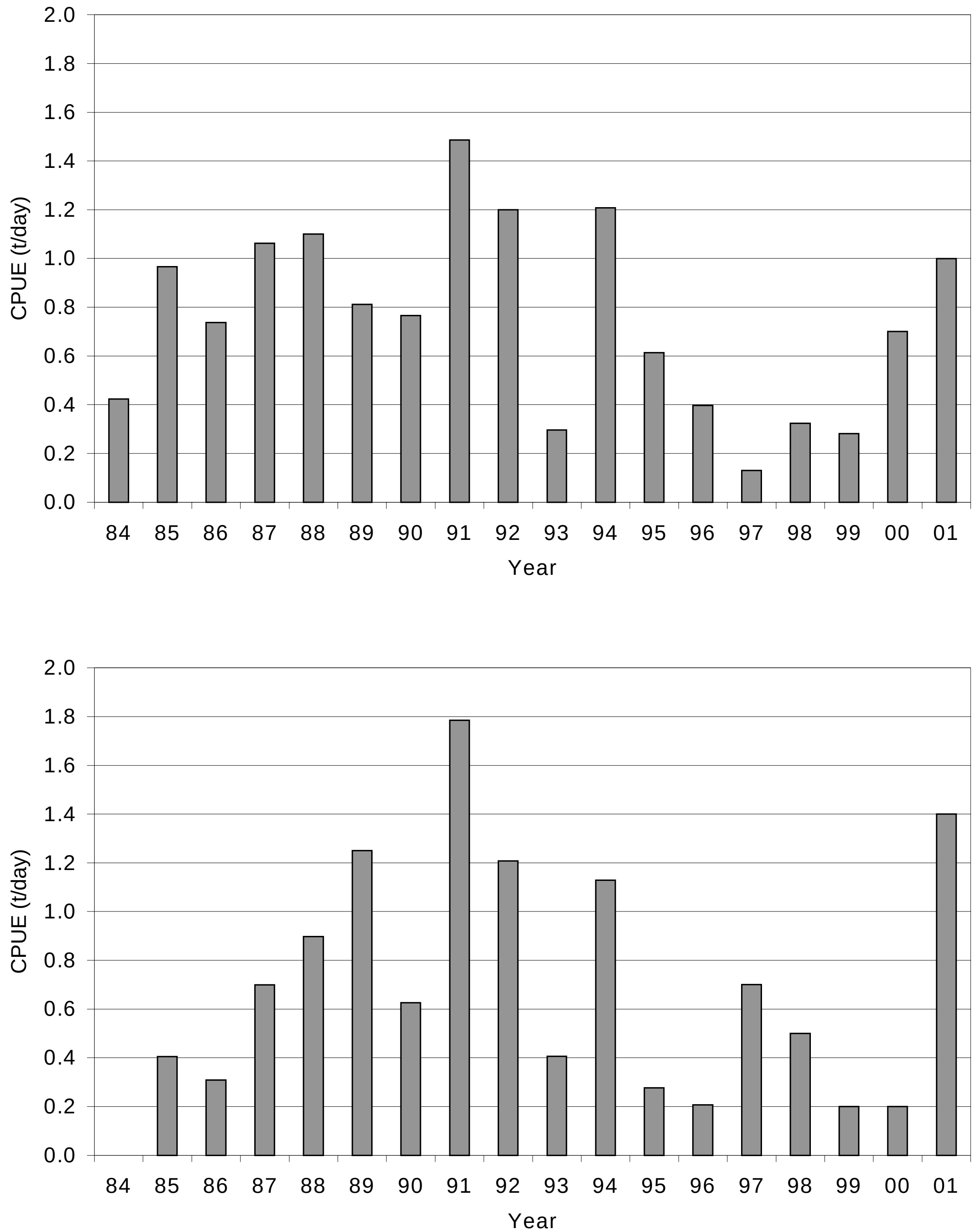
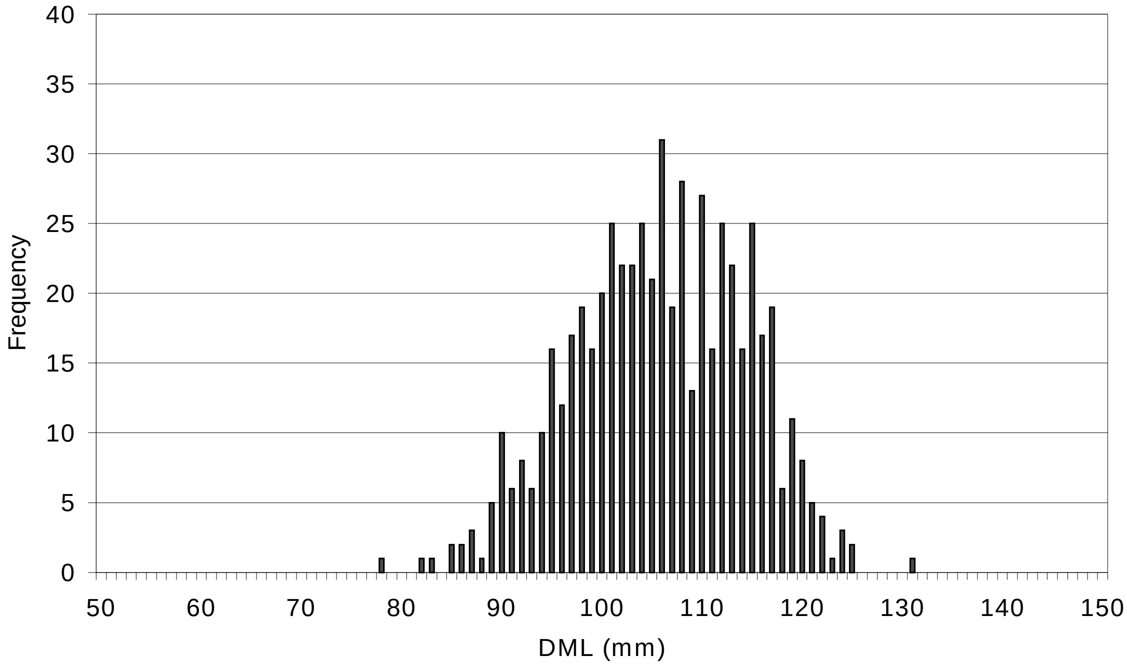


Figure 12. Catch-per-unit-effort (CPUE, t/day) of opal squid in British Columbia, as reported on logbooks (top) and fish slips (bottom), 1984-2001.



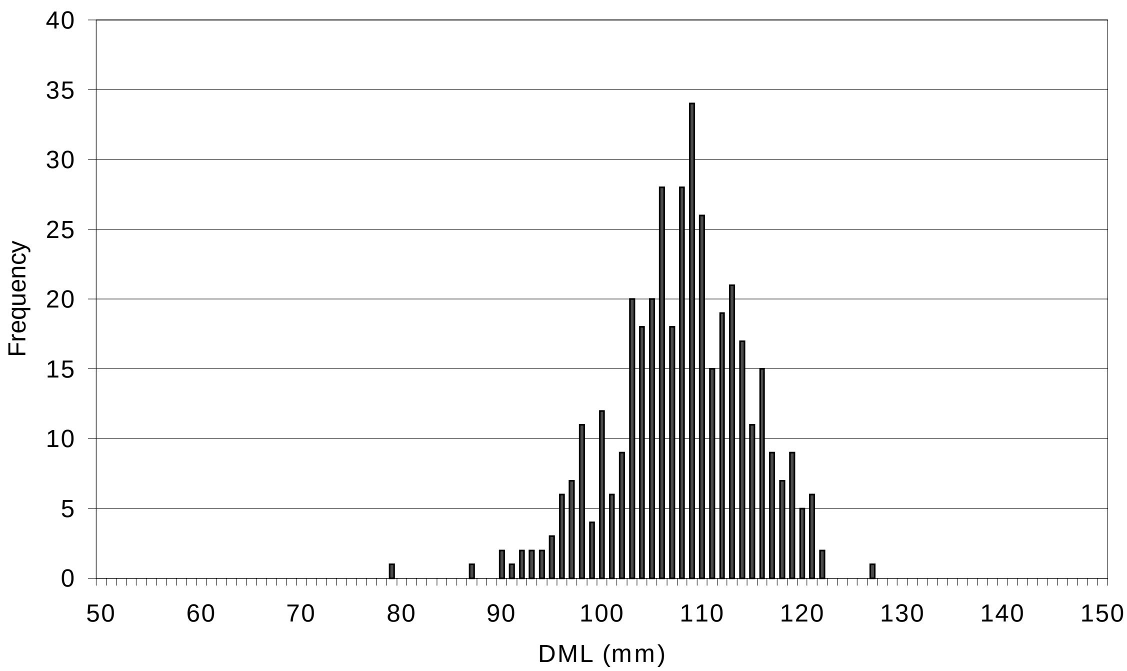


Figure 13. Dorsal mantle length (DML, mm) of male (top) and female (bottom) opal squid from the 2001 British Columbia fishery.

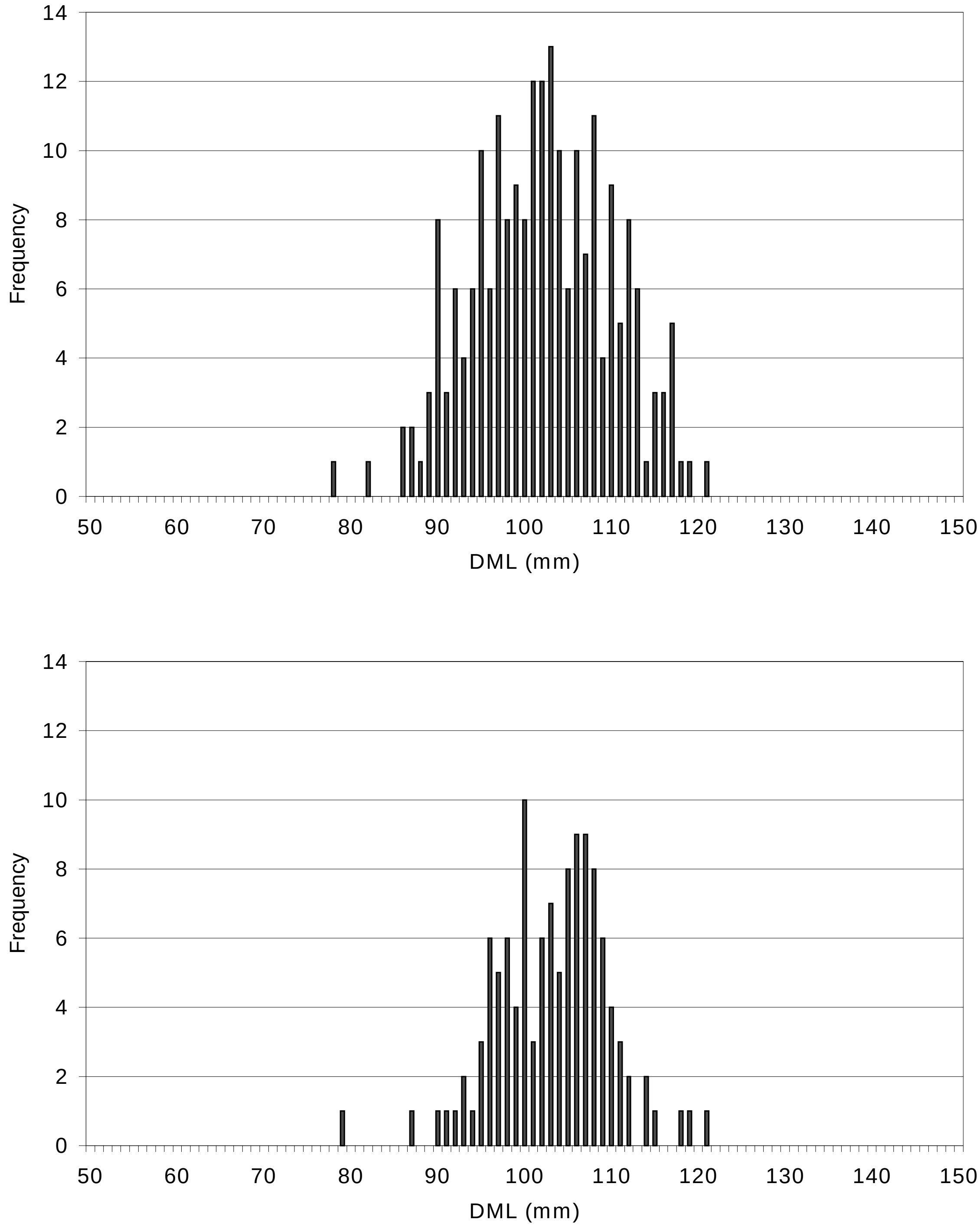
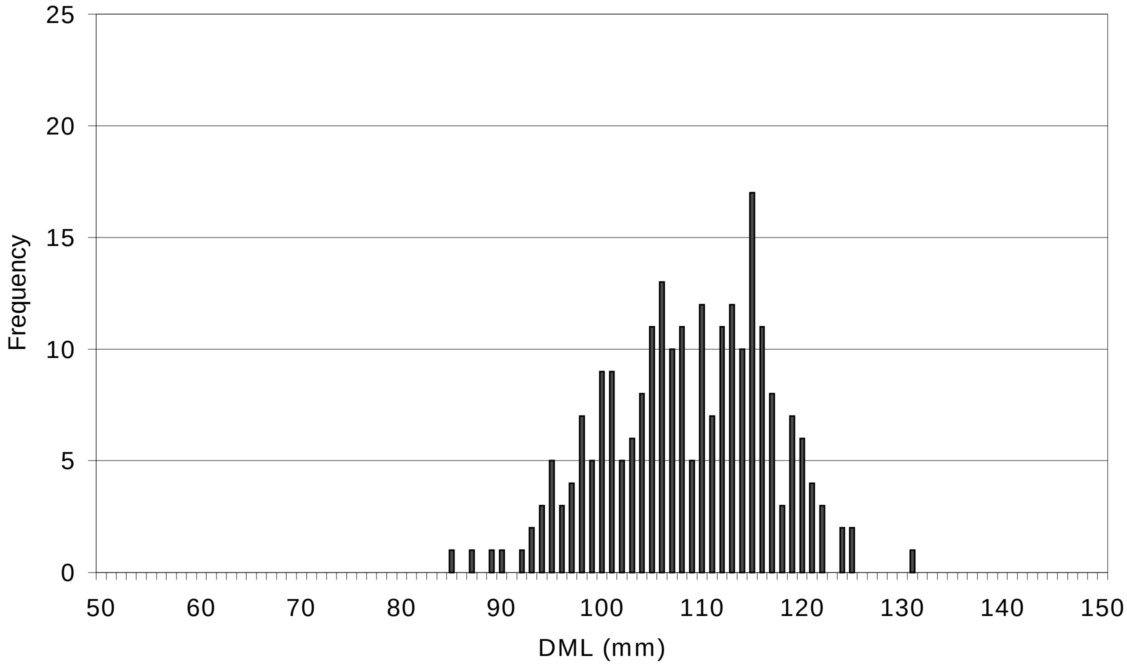


Figure 14. Dorsal mantle length (DML, mm) of male (top) and female (bottom) opal squid from Area 2, June 8, 2001.



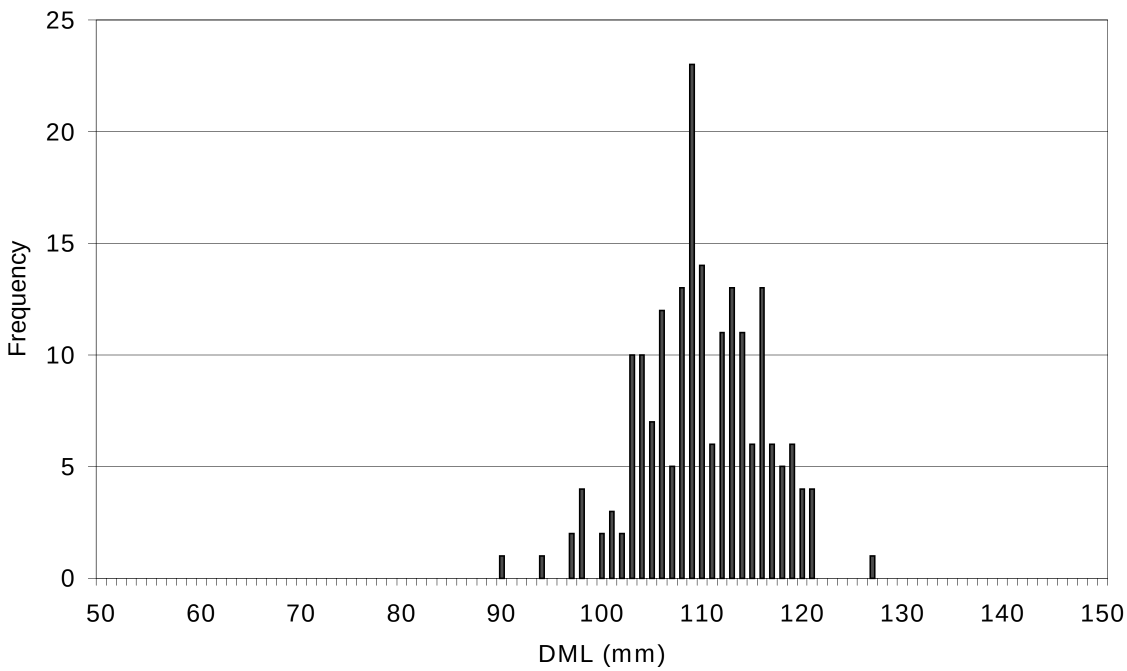
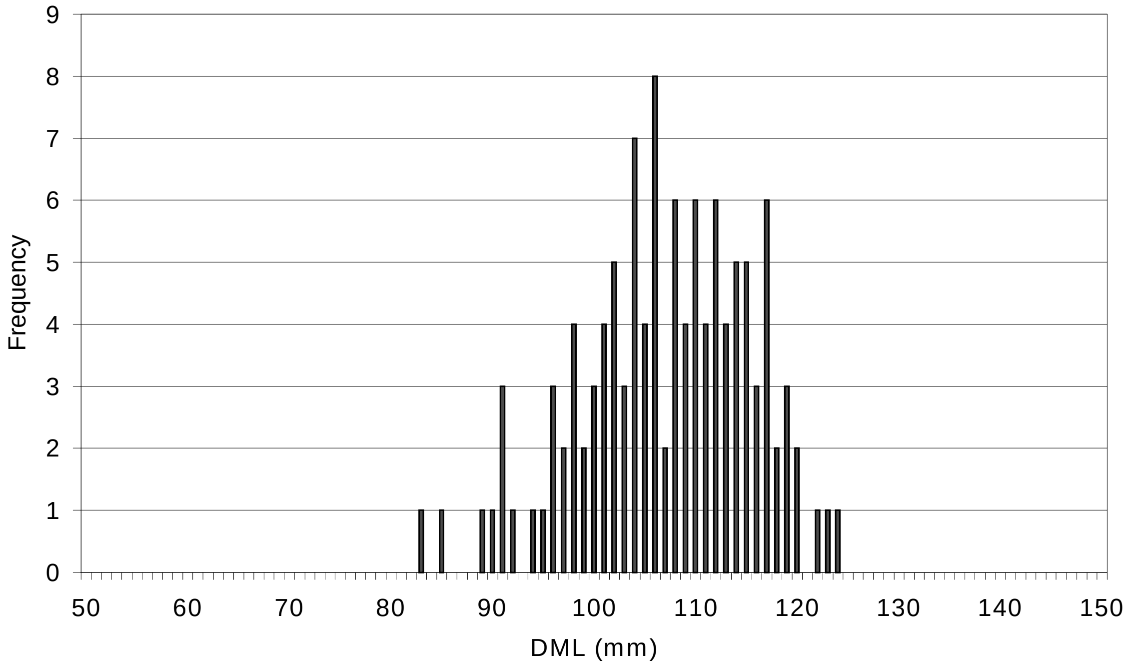


Figure 15. Dorsal mantle length (DML, mm) of male (top) and female (bottom) opal squid from Area 123, June 1, 2001.



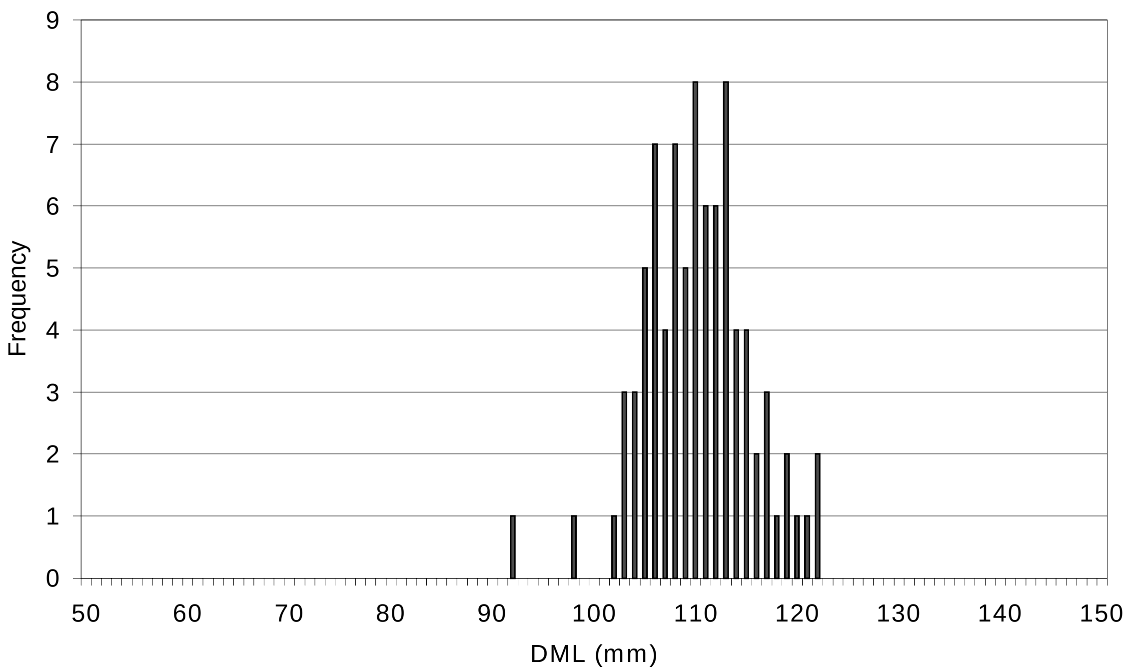


Figure 16. Dorsal mantle length (DML, mm) of male (top) and female (bottom) opal squid from Area 123, June 2, 2001.

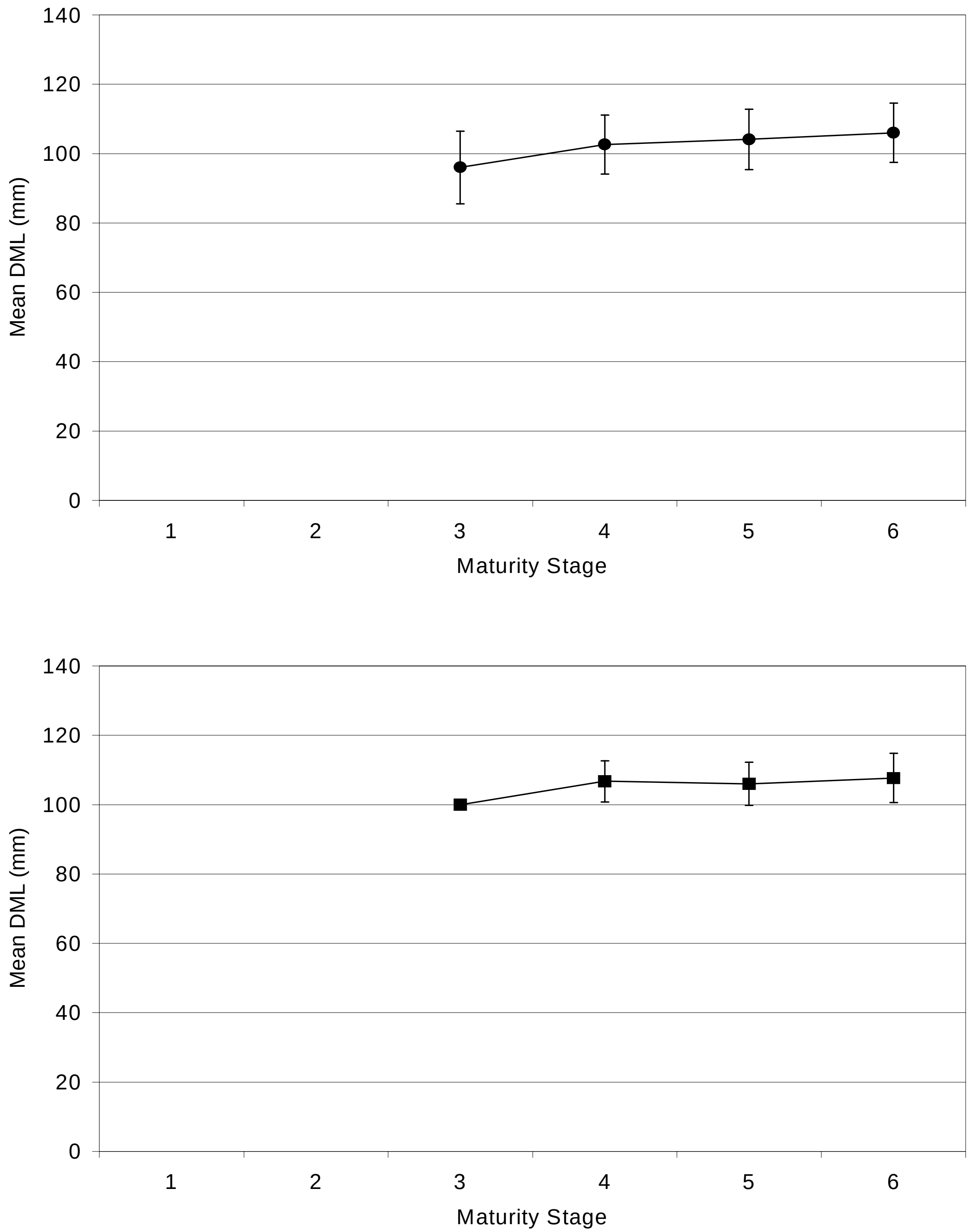


Figure 17. Mean length (DML, mm) by maturity stage for male (top) and female (bottom) opal squid from the 2001 British Columbia fishery. Error bars are ±1 SD.

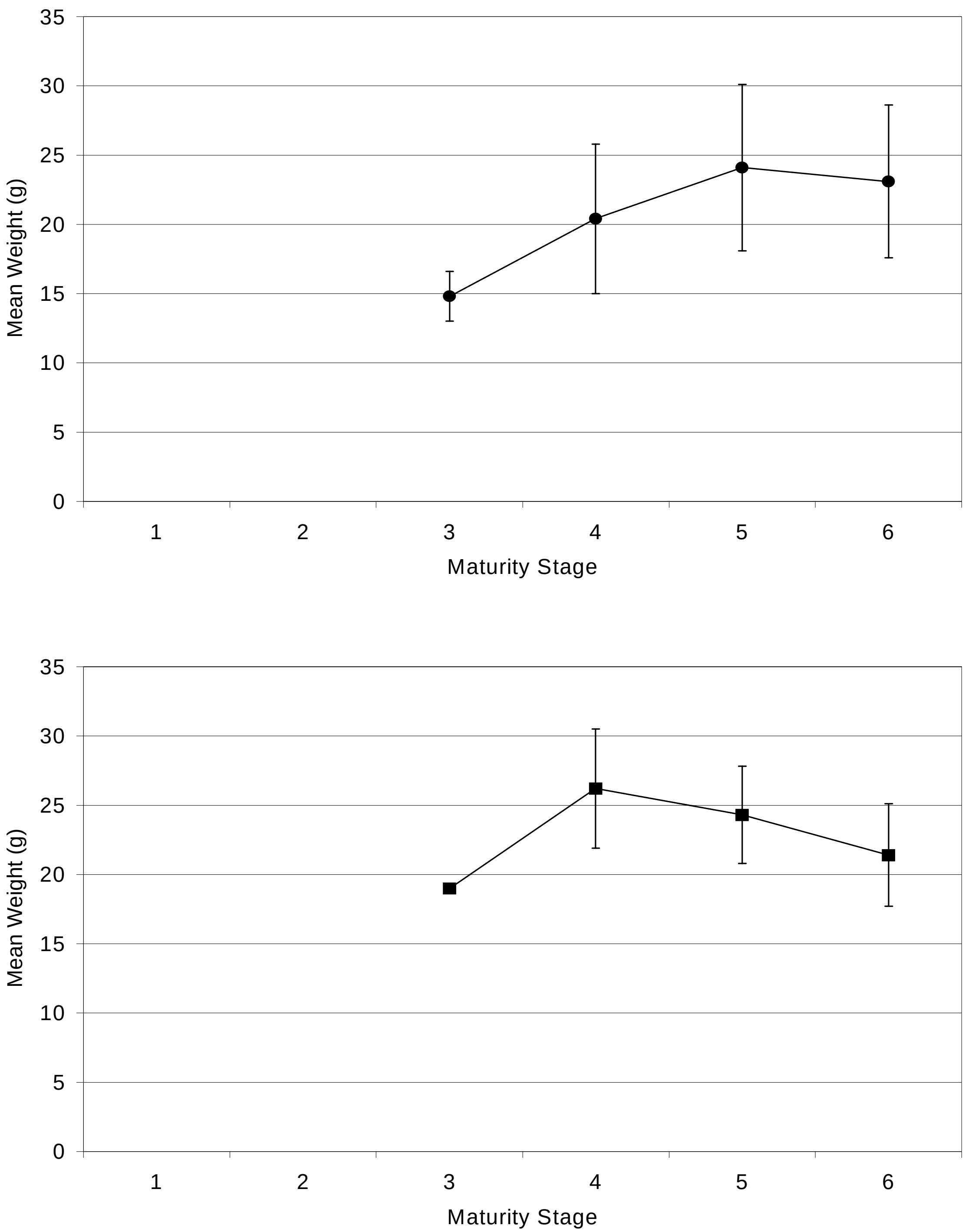


Figure 18. Mean weight (g) by maturity stage for male (top) and female (bottom) opal squid from the 2001 British Columbia fishery. Error bars are ±1 SD.