Fisheries and Oceans Canada | Pêches et Océans Canada

Canadian Stock Assessment Secretariat
Research Document 99/153

Secrétariat canadien pour l'évaluation des stocks
Document de recherche 99/153

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A Review of the Biology and Fisheries of the Pink Scallop and Spiny Scallop

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ISSN 1480-4883
Ottawa, 1999

Canada

Abstract

A review of the biology of pink and spiny scallops is presented, based on scientific literature, previous surveys and technical reports. There are considerable differences in the growth characteristics, growth rates, maximum size and reproductive characteristics between the two species. Spiny scallops are faster growing and reach a larger maximum size than pink scallops. Spiny scallops also have a considerable higher reproductive effort in comparison to pink scallops. Spawning in each species occurs at different times.

A review of the scallop fisheries in British Columbia is presented. There has been a commercial fishery since 1982. There are two fisheries for pink and spiny scallops in British Columbia, a dive fishery and a small trawl fishery. The dive fishery has landed 85% of the total cumulative landings. There is presently unlimited entry in both fisheries. There is evidence of declining effort in the trawl fishery in recent years, with concurrent increasing effort in the dive fishery. There is also evidence of localized stock depletion in some areas, which has resulted in area closures.

Present management controls include a minimum size limit of 55 mm shell height for both species, numerous small closures in parks and study areas, and a maximum width of 2 m in the trawl. The two species are being managed as one species, one stock.

Information shortfalls are identified including: trawl effects on co-occurring species, habitat, or bycatch, or size selectivity; stock status and delineation; and basic biological parameters such as biomass, recruitment and mortality. The present management system is not sufficient for this fishery. The only monitoring systems in place are harvest logs and sales slips, with a calculation of catch per unit effort (CPUE). This is not adequate for stock assessment requirements in order to implement a risk averse management system. Recommendations for additional information requirements for stock assessments and management plans are given.

Résumé

Un examen de la biologie des pétoncles rose et épineux est présenté. Il a été préparé à partir de publications scientifiques, de relevés antérieurs et de rapports techniques. Les deux espèces diffèrent de façon appréciable en ce qui a trait aux caractéristiques de croissance, au taux de croissance, à la taille maximale et aux caractéristiques de la reproduction. Le pétoncle épineux croît plus rapidement et atteint une taille maximale plus importante que le pétoncle rose et présente un effort reproductif beaucoup plus élevé que le pétoncle rose. Ces deux espèces ne fraient pas au même moment.

Un examen de la pêche du pétoncle en Colombie-Britannique, où il existe une pêche commerciale depuis 1982, est présenté. La pêche des deux espèces se pratique de deux façons en Colombie-Britannique : une pêche par plongeurs et une petite pêche au chalut. Du total cumulatif des débarquements, 85 % provenait de la pêche par plongeurs. Actuellement, la participation à ces deux pêches n'est aucunement limitée. On a noté ces dernières années une diminution de l'effort de la pêche au chalut qui s'est accompagnée d'une augmentation de celui de la pêche par plongeurs. On note aussi un appauvrissement des stocks dans certaines zones, ce qui a entraîné la fermeture de la pêche dans ces zones.

Les mesures de gestion actuelles comprennent l'imposition d'une taille limite minimum de 55 mm pour la hauteur de la coquille, pour les deux espèces, de nombreuses petites fermetures dans des parcs et des zones d'étude et une largeur de chalut maximale de 2 m. Les deux espèces sont gérées comme si elles formaient un seul stock constitué d'une seule espèce.

Les carences d'information mentionnées ont trait à : les effets du chalut sur les autres espèces présentes, l'habitat, ou les prises accessoires, ou la sélectivité quant à la taille ; l'état du stock et ses limites géographiques ; et les paramètres biologiques généraux comme la biomasse, le recrutement et la mortalité. Le régime de gestion actuel s'avère insuffisant pour cette pêche. Les seuls systèmes de contrôle en place sont représentés par les registres des captures et les bordereaux de vente utilisés dans le cadre d'un calcul des prises par unité d'effort (PUE). Cela est insuffisant pour effectuer une évaluation du stock permettant de mettre en place un régime de gestion par minimisation des risques. Les recommandations formulées ont trait aux besoins d'information supplémentaire relativement à l'évaluation des stocks et aux plans de gestion.

Table of Contents

List of Tables

List of Figures

1. Introduction

Thirteen species of scallops have been found in British Columbia waters (Bernard 1983) (Table 1). Four species were originally thought to be large enough and occur in sufficient abundance to generate interest in commercial fisheries: weathervane scallop, *Patinopecten caurinus*; rock scallop, *Crassadoma gigantea*; pink scallop, *Chlamys rubida*; and the spiny scallop, *Chlamys hastata* (Bourne 1987). However, since 1982, small commercial fisheries have been limited to pink and spiny scallops.

Anecdotal information from some commercial fishers suggests that over harvesting of pink and spiny scallops may be occurring in some areas. There are concerns that the present management system may not be appropriate. This paper was requested

- to provide a review of the known biology of pink and spiny scallops;
- to examine management regimes presently used in other jurisdictions for these and similar species;
- to review the British Columbia fishery for these species;
- and to consider management options to adopt, and identify stock assessment requirements for these management options.

Following a Fisheries and Oceans Canada (DFO) moratorium on new invertebrate fisheries in the Pacific Region in 1992, a seafood diversification board was formed with representatives from DFO and the British Columbia Ministry of Fisheries. The mandate of the board was to develop the Pacific Region Policy for New and Developing Fisheries. This policy describes a phased precautionary approach, to ensure an orderly development of a sustainable, viable fishery. This paper was requested to ensure the management of the pink and spiny scallop fishery is based on biologically sound principles, and follows a phased precautionary approach.

1.1 Plan for the Development of a Directed Fishery on Pink and Spiny Scallops

Within the Stock Assessment Division of DFO, a framework was developed for the provision of scientific advice for the management of new and developing invertebrate fisheries, including established fisheries whose expansion is limited due to a lack of information of the species distribution or abundance (Perry *et al.* 1998). This framework included three phases for the precautionary development of a fishery:

Phase 0: Collection of all available information on the target species, and from similar species elsewhere, to provide a baseline with which to advise on the alternative management options and to identify areas where information is lacking;
Phase 1: Involves surveys and experimental fishing where the objective is the collection of data required to fill in the information gaps identified in the first phase and to explore the fishery potential.

Phase 2: Fishing for Commerce. A fishery is developed at the commercial level, while stocks are monitored and management strategies are evaluated.

This paper presents the Phase 0 review of known and derived information on the pink and spiny scallops found in British Columbia. It includes a review of scallop distribution, life history and biology, population dynamics, abundance and a summary of scallop fisheries in B.C.

1.2 Biological Objectives

The biological objective for a fishery on pink and spiny scallops is to maintain a viable, healthy, and productive stock throughout their natural range in British Columbia. Rice *et al.* (1995) provided three basic biological objectives for the management of Pacific Region fish and invertebrate stocks. These provided the framework for the specific biological objectives for pink and spiny scallops:

1. Ensure the population and subpopulations of pink and spiny scallops along the B.C. coast do not become biologically threatened, as defined by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), throughout their ecological range.
2. Ensure sufficient production and survival of progeny, after accounting for all sources of mortality (including all fisheries and natural mortality), to ensure sustainable reproduction throughout its ecological range.
3. Ensure that a fishery for pink and spiny scallops does not violate the two previous objectives for other ecologically related species.

There is an underlying requirement to collect sufficient biological data, in order to determine a safe (in terms of risk averse) level of harvest. There is also a requirement to be able detect changes in stock dynamics (from any cause) in time to prevent long-term decline or collapse of the stock due to over-exploitation.

These two species are currently being passively managed as one species, one stock. This fishery has been prosecuted for the last 16 years, and yet there never has been a comprehensive assessment. There is a need to collect and analyze appropriate and sufficient biological information to ensure sustainability of the stocks with acceptable harvest practices and harvest levels. An understanding of the productivity characteristics of each species is required, and whether they are sufficiently unique as to require separate assessments and management measures. An understanding of stock distribution and delineation is required. There is anecdotal information on possible overfishing in some areas, yet it is not known whether there are unique populations, discrete stocks in each area, or a series of metapopulations distributed throughout the fishing areas.

2. Current Knowledge of *Chlamys rubida* and *C. hastata*

2.1 Biology and Life History

2.1.1 Background

The biology of scallops differs from most other bivalves due to some distinct anatomical features and behaviours. Scallops have unusually shaped gills and feeding behaviour in comparison to most other bivalves. Scallops also have eyes that are clearly visible around the margin of the shell. Some scallops also have the unique ability to propel themselves by rapidly clapping their valves and expelling water.

The focus of this discussion will be a review of various aspects of the biology of *Chlamys rubida* and *C. hastata*, where there is the available information. When specific information is not available for these two species, the biology of similar closely related species will be reviewed.

The pink scallop, *Chlamys rubida* (Hinds, 1845) and spiny scallop, *C. hastata* (Sowerby, 1843) are in the Subfamily Chlamydinae, Family Pectinidae, Superfamily Pectinacea, Suborder Pectinina, Order Ostreoida, Subclass Pteriomorphia, Class Bivalvia, Phylum Mollusca (Bernard 1983). These two species believed to have evolved in the *Chlamys* group and the *Chlamys islandica* complex. This complex of closely related species is characterized by a particular shell shape, called a chlamydoid form, where the height of the shell generally exceeds the length, and the anterior outer ligament is longer than the posterior outer ligament (Waller 1991).

C. rubida is also known as the smooth pink scallop, reddish scallop, and the swimming scallop (Harbo 1997). *C. rubida* was once considered to be a subspecies of *C. islandica*, as it is closest relatively to the Atlantic *C. islandica* of any other Pacific species (Waller 1991). A number of subspecies have been named for Asiatic populations. However they do not appear to have any morphological features that are outside the range of variation for eastern Pacific populations (Waller 1991).

C. hastata is also known as the pink scallop, Pacific pink scallop, and the swimming scallop (Harbo 1997). This species is the furthest removed from *C. islandica* than any other Pacific species (Waller 1991). There are number of subspecies named: *C. hastata hastata*, which ranges the furthest south; and *C. hastata hericia* and *C. hastata pugetensis*, which are the two more northerly subspecies (Waller 1991). For purposes of this paper, only the species *C. hastata* will be considered.

Grau (1959) gives a very detailed description of the shell of these two species, which is well beyond the comprehension and requirements of the average reader. Harbo (1997) gives a more succinct description of *C. rubida* as having a circular shell with prominent ridges. The front ears are about two times the length of the hind ears, and the byssal notch is almost triangular. The exterior of the upper (left) valve is pink to red-purple, white or yellow, and the lower (right) valve is paler. There are about 30 smooth prominent radial ribs (more than *C. hastata*), with small narrower ribs between them, and many fine scaly ribs. *C. hastata* are circular, with a broadly fluted or undulating margin. The byssal notch is deep and squarish (Harbo 1997).

There have been no detailed studies of natural populations of pink and spiny scallops along the West Coast.

2.1.2 Geographic Distribution

The pink scallop is found from 58 °N – 33 °N, Kodiak Island Alaska to San Diego California (Bernard 1983). It is not common south of Puget Sound, Washington (Harbo 1997). The spiny scallop is found from 60 °N – 33 °N, Gulf of Alaska to San Diego, California (Bernard 1983). Both species have a discontinuous distribution throughout their range along the coast, but can occur in small dense beds (Bourne 1991).

Since 1986, most of the commercial fishery has been in the Strait of Georgia in Pacific Fishery Management Areas 17,18,19 and 29.

2.1.3 Habitat, Ecological Relationships, and Co-occurring Species

Pink and spiny scallops are swimming scallops, unlike most other bivalves, are epibenthic. They typically lie with the right (more convex) valve on the bottom, and the left (top) valve is coloured to camouflage the shell against the bottom. The right valve is lightly coloured to be less visible against a watery background when the scallop is swimming and exposed to potential fish predators (Harbo 1997). Scallops have righting reflex, where if they are disturbed and turned over, they can right themselves by ejecting water downward with a powerful adduction (Brand 1991).

Pink scallops are found at depths ranging from 1 to 200m in water temperatures ranging from 1 °C to 17 °C (Bernard 1983). Pink scallops are usually found on softer substrates than spiny scallops (Bourne 1991). Ellis (1967) found only pink scallops in the characteristically soft sediments of Fulford Harbour. Grau (1959) reported pink scallops as usually found off rocky shores. Quayle (1963) found pink scallops throughout the West Coast on various substrates, predominantly in sandy substrates and mud, but also including gravel and rocky bottoms. The shells of pink and spiny scallops are usually encrusted in one of two species of symbiotic sponge, *Myxilla incrustans* and *Mycale adherens* (Harbo 1997). Barnacles, 25 to 30 mm in height, are also often attached (Grau 1959).

Spiny scallops are found at depths ranging from 2 to 150 m in water temperatures ranging from 0 °C to 23 °C (Bernard 1983). Spiny scallops are usually found on firm gravel or rock substrates (Bourne 1991) and rocky reefs (Harbo 1997) in areas of strong current (Bourne 1991). Current has been shown to be a stimulus to larval settlement (Cooke 1986). Grau (1959) usually found spiny scallops on sand or shale substrates and occasionally in mud. Ellis (1967) found spiny scallops at the centre of Satellite Channel in a relatively high current area and Boatswain Bank. Quayle (1963) found spiny scallops mostly in muddy substrates in Plumper Sound, in sandy substrates as well as gravel and rocks on Constance Banks, and on smooth rocky substrates in other areas.

A characteristic of post-settlement stages in most bivalves is the secretion of a byssus for attachment. Sessile forms retain the byssus attachment throughout their adult life. Some scallop species loose their byssus soon after metamorphosis, and others have a declining ability for byssus attachment with increasing age. Pink and spiny scallops, like many other *Chlamys* species, retain the ability to form a byssus throughout their life, retaining the ability to alternate between attached and detached phases, depending on the environmental conditions. This is characteristic of species with a small body size or species that inhabit relatively high current areas. (Brand 1991).

In addition to the righting response mentioned earlier in this section, many scallop species, including pink and spiny scallops have two very similar swimming responses. There is a jumping response, where water is ejected from the ventral mantle margin and the direction of travel is hinge forward. The shell adductions are low in frequency, and the scallop usually returns to the substrate after each adduction. In the swimming response, the scallop moves ventral edge forward propelled by water ejected dorsally on each side of the hinge, as a result of high frequency (2-5 /sec) adductions (Brand 1991). The swimming response in pink and spiny scallops was usually elicited by the close proximity of predators, such as the introduction of rock crabs and sea stars in display tanks (pers.obs.).

Predators on adult scallops include sea stars, crabs, gastropods and groundfish (Brand 1991). In the Atlantic, Elner and Jamieson (1979) found that smaller sea scallops were vulnerable to a wide range of predators and this vulnerability decreased considerably when the shell height reached 70 mm. This is close to the maximum shell size for pink and spiny scallops. Juvenile scallops and newly settled spat are very vulnerable to crab, sea stars, gastropods and groundfish, and in areas of high predator abundance, this may be a limiting factor in scallop distribution (Brand 1991).

2.1.4 Parasites and Disease

There is no specific information regarding parasites and disease of pink and spiny scallops in British Columbia waters. A review of diseases and parasites of scallops by Getchell (1991) shows a number of various scallop species affected by disease and parasites. Giant sea scallops (*Placopecten magellanicus*) along the Maine coast with abscessed adductor muscles appeared to be infected with Gram positive bacteria (Sherburne and Bean 1986 cited in Getchell 1991).

A mass mortality of sea scallops in Rhode Island was attributed to an infection of a thin-walled prokaryotic organism, measuring 1.9-2.9 µm x 0.5 µm (Gulka *et al* 1983 cited in Getchell 1991). There were myodegenerative changes in the adductor muscle and intracellular basophilic inclusion bodies in the epithelial cells of the gill, plicate membrane and other body surfaces. The normal structure of the gill was obliterated in areas of heavy infection. Follow-up experiments showed a heavy infection of gill tissue by a rickettsia-like organism within 20-25 days after inoculation with homogenates of infected gill tissue (Gulka and Chang 1984 cited in Getchell 1991). There was no evidence of myodegenerative change in infected sea scallops in either the laboratory or field challenges, indicating that the rickettsial agent has a low virulence and may only be a significant stressor in the sea scallop.

There is a wide range of parasites reported in many species of scallops reviewed by Getchell (1991) and only cases similar in circumstances expected in pink and spiny scallops will be summarized. Some *Chlamys* species have had trichodinids in their mantle cavity, and one species as a ectoparasite on the eye. Algal infections have been seen in the mantle, eyes and tentacles of sea scallops. A spinoid polychaete *Polydora* sp. has parasitized scallops by penetrating the shell. Mortalities due to infestations have been reported in the Gulf Islands region of British Columbia (Bourne *et al* 1989).

2.1.5 Food, Feeding Habits

Like other lamellibranchs, scallops are filter feeders with highly specialized gills that serve both as a feeding apparatus and a means of respiration. The gills are comprised of rows of filaments that arise from the mantle wall, which are arranged in sheets and are covered with fine beating cilia (Crawford 1992). However, unlike most other lamellibranchs, scallops are non-siphonate suspension feeders, where there is no fusion of the mantle edge. Water enters the mantle cavity along the ventral and anterior edge, and exits through the posterior exhalant opening. This is achieved by the preferential orientation directly into the current, with the exhalent opening facing away from the direction of the current (Hartnoll 1967 cited in Bricelj and Shumway 1991).

In their review of the functional anatomy of scallops, Beninger and Le Pennec (1991) show that scallops have particularly shaped gills, called an euleutherorhabdic plicate gill, comprising of W-shaped left and right gills, each consisting of an inner and outer demibranch. Spiny scallops have extremely large gills relative to their body size. Meyhöfer (1985), in his comparison of pumping rates of four marine bivalves, showed that spiny scallops had an intermediate pumping rate per unit gill area, but they processed the largest absolute volumes. While scallops are commonly called filter feeders, there is evidence of a non-filter-feeding mechanism of particle capture, due to the shape of the relaxed gill. Water currents are mainly directed towards the gutters of the principal filaments and dorsally, and subsidiary currents pass through the interfilamentar spaces of the ordinary filaments. The cilia and mucous of the fused dorsal infrabranchial surface trap most of the food particles, and as the currents rise dorsally, more water is forced out the interfilamentar spaces. A ventral mucous string is formed along the ciliated tract of the ventral bend, and enters the buccal region. A more accurate term of suspensivores has been suggested for scallops rather than filter feeders. Scallops appear to have a lower retention efficiency of smaller size fraction particles and retain larger size particles in comparison to other bivalves (Beninger and Le Pennec 1991).

In addition to the labial palps found in all bivalves, scallops have a complex ramified pair of lips covering the mouth. The labial palps consist of right and left pairs of tissue flaps and the ends of the gills. The labial palps are considered to be sorting structures in other bivalves.

However, in scallops, there is contrary evidence, as the particles are either heavily embedded in mucous or form part of a mucous string, making any sorting very difficult. Also, the wide range of the size spectrum of food particles found in the stomach shows there is not likely a very rigorous size selection process. It is not really known where the pseudofaeces are formed, at the gill surface or at the labial palps, and under what conditions. The are a number of suggestions as how these lips function in feeding but the role of the lips has not been confirmed (Beninger and Le Pennec 1991).

The digestive system of scallops, consisting of the mouth, oesophagus, stomach, crystalline style, digestive gland, intestines rectum and anus is similar in anatomy and function to other bivalves (Beninger and Le Pennec 1991), and will not be reviewed in this discussion.

Scallops rely on suspended detrital matter and phytoplankton for food. Adult scallops appear to have the unique ability to resuspend surficial sediments with "shell clapping" (Bricelj and Shumway 1991). This behaviour may be especially significant in deep water scallops in habitats well below the photic zone. Phytoplankton settling during the spring and fall blooms is one of the main inputs of particulate organic matter from the pelagic to the benthic communities. The downward mixing of phytoplankton during certain times of the year is an important food source for deep water scallops (Shumway et al 1987).

There is very little information available on the specific food items utilized by scallop species in their natural habitat. Shumway et al (1987) compared two populations of *Placopecten magellanicus*, from a shallow water habitat, and from a deep water habitat. Over 27 species of algae were identified, ranging in size from 10-350 µm, as well as pollen grains, ciliates, zooplankton, detrital material and bacteria. The shallow water population had an equal mix of pelagic and benthic species, but the deep water population the benthic species outnumbered the pelagic species. A seasonal variation in food items was seen, coinciding with blooms of individual algal species. The gut contents generally reflected the availability of food organisms in the immediate vicinity. It was concluded that *Placopecten magellanicus* is an opportunistic feeder, using both pelagic and benthic organisms as food. This is likely the case for all scallop species with wide depth ranges.

At the Pacific Biological Station, cultured spiny scallop larvae have been fed unicellular phytoplankton species *Nannochloris atomus, Pavlova lutheri, Isochrysis galbana, Thalassiosira weisflogii* and *Dunaliella tertiolecta* in concentrations ranging from 10 to 40 x 10^4 in larval development and growth experiments (Cooke 1986). Adult scallops in culture are fed the diatoms *Chaetoceras simplex, C. gracilis, Thalassiosira pseudonana, Skeletonema costatum,* and the flagellates *Isochrysis* and *Rhodomonas lens* (Bourne *et al* 1989).

2.1.6 Phycotoxins in Scallops

Because phytoplankton is such an important food item for scallops, they are particularly susceptible to blooms of toxic algae. The algal species and their associated toxins (phycotoxins) are concentrated in the digestive gland, resulting in a number of various seafood poisoning illnesses, such as paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP), and amnesic shellfish poisoning (ASP), in human consumers. *Alexandrium tamarense* (= *Protogonyaulax catenella/ tamarensis*) appears to be one of the most common and widespread algal species affecting scallops (Shumway and Cembella 1993). The distribution of toxins in scallop tissues typically results in the highest toxicity in the digestive gland and the lowest in the adductor muscle. Pink and spiny scallops appear to concentrate the PSP toxin in their gonads and viscera (K. Schallie, pers. comm.). Conflicting results from a number of studies make it impossible to reliably estimate the PSP toxicity of scallop adductor muscles based on the extrapolation from the toxicity of surrounding waters (Shumway and Cembella 1993). No assumptions regarding the toxicity of individual scallop tissues should be made based on any such correlations. Scallops typically have a much longer retention time of phycotoxins in comparison to other bivalves (K. Schallie, pers. comm.; Shumway and Cembella 1993). Domoic acid has been retained by the digestive gland of sea scallops after 4 months of maintenance in a flow-through seawater system (Gigan *et al* 1990 cited in Shumway and Cembella 1993). Shumway and Cembella (1993) list a number of hypotheses to explain the chronically high PSP toxin levels and long retention time in scallops. These include: (1) low basal metabolic rates and reduced filtering activity in winter, resulting in lower rates of elimination; (2) toxin conversion to more toxic derivatives; (3) cryptic subsurface blooms of toxic vegetative cells, causing recontamination; (4) ingestion of faecal pellets during the senescent phase of toxic blooms; and (5) ingestion of toxic benthic resting cysts accumulating and overwintering in the sediments. Bourne (1965) rejected the hypothesis of low metabolic activity and suggested that feeding on benthic cysts that were considerably more toxic than the vegetative cells. More recent evidence shows benthic cysts may not be as toxic as originally reported (Shumway and Cembella 1993). There is a distinctive biphasic PSP detoxification phenomenon seen in a number of scallop species (Bourne 1965; Shumway and Cembella 1993), but the mechanism is not known.

Data collected by the Canadian Food Inspection Agency (formerly DFO Inspection Branch) on contaminated pink and spiny scallops is shown in Table 2. One area in particular, Valdes Island shows a very broad range in toxin concentration (170-930 µg/100 g) in a two day sampling period. There are a number of incidents of illness resulting from consumption of PSP contaminated pink and spiny scallops. On Thanksgiving Day, 1987, there was an illegal harvest of pink and spiny scallops by recreational divers near Pender Island. A few of these divers became very seriously ill and had to be evacuated by air to a major hospital. In 1994, a number of illnesses were reported in the United States resulting from consuming pink and spiny scallops harvested in the Gulf Islands and the Victoria area (K. Schallie, pers.comm.)

2.1.7 Reproduction

Knowledge of reproductive processes and cycles is critical in understanding the life history of any species, and it is important to the management of any commercial fishery or aquaculture operation. Successful recruitment may depend on the timing and method of fishing operations around spawning, dispersal and settlement periods. There is also the also the consideration of seasonal gametogenic cycle and the influence on potential meat yield. This is particularly important in scallops, as there is a seasonal variation in adductor muscle weight related to reproductive state (Barber and Blake 1991).

The gametogenic cycle in scallops consists of the following stages: vegetative state; differentiation; cytoplasmic growth; vitellogenesis; spawning; and resorption. There are a number of means of assessing gamete development, but the most common method with scallops is gross visual observation (Barber and Blake 1991), as the gonad is largely separated from the visceral mass (Beninger and Le Pennec 1991). When the gonad matures, it increases in weight and size, and with sexual differentiation, the male gonads become cream-coloured, and the female gonads become reddish (Barber and Blake 1991). Other methods included for assessing gametogenesis in scallops include: gonadal weights and indexes; histological techniques (oöcyte diameter and stereology); and larval and spat abundance.

Some scallop species such as the sea scallop (*Pecten maximus*), calico scallop (*Argopecten gibbus*), and bay scallop (*A. irradians*) are hermaphroditic, and simultaneous hermaphroditsm is the most common form (Cooke 1986). Other scallop species are dioecious, such as the pink scallop (*C. rubida*) spiny scallop (*C. hastata*), rock scallop (*Crassadoma gigantea*) (MacDonald *et al* 1991), weathervane scallop (*Patinopecten caurinus*), and Japanese weathervane scallop (*Mizuhopecten yessoensis*) (Cooke 1986). Fertilization is external in the Pectinidae and oocytes are usually 60-80 µm in diameter (Cragg and Crisp 1991).

Spiny scallops from Barkley Sound were found to be sexually mature at 25-30 mm shell height, and all spiny scallops over 35 mm shell height had mature gonads. Pink scallops mature at a similar size. Both species are 2 years of age at maturity (Bourne and Harbo 1987). Pink scallops first spawn from March to April and again from September to early October (MacDonald *et al* 1991) in southern British Columbia. Spiny scallops spawn from July to August in southern British Columbia (MacDonald *et al* 1991). The gonads of pink and spiny scallops do not appear to completely empty when spawning, therefore these species can be sexed throughout the year by the characteristic male and female colours of the gonads (Bourne and Harbo 1987).

A very detailed study on the embryogeneis of spiny scallops (Cooke 1986; Hodgson and Burke 1988) showed development to the gastrula stage 18 hours after fertilization, trochophore 30 hours after fertilization and veliger larva 50 hours after fertilization. Settlement occurred at 34 days in 16 °C water, and 42 days in 12 °C water. Settlement and metamorphosis was only seen on fouled surfaces. In addition, a flow of water enhanced settlement and metamorphosis. Larvae settled preferentially along edges and corners, rather than on planar surfaces. A combination of fouled surface and water flow was most effective at inducing larva to settle and metamorphose. At metamorphosis, spiny scallops change from a swimming pediveliger larva to a crawling post-larva within 24-48 hours. Following complete metamorphosis, the left valve is first visible in 2 days, and the right valve is visible in 3-4 days.

2.1.8 Growth and Age

The most common assessment of growth and age in bivalves is the measurement of shell size and counting annual growth rings on the exterior of the shell in order to construct a growth curve for the population. In scallops, the shell height, the maximum distance between the hinge (dorsal) edge and the ventral margin, has been substituted for shell length (Thompson and MacDonald 1991). However, this is just one parameter in assessing the net growth of animal. Net growth can only occur if the absorbed energy intake exceeds the total metabolic losses including respiration and excretion. In bivalves, the total net growth, or production, is defined as the sum of energy released as gametes, energy incorporated in somatic tissue growth and energy incorporated into the organic matrix of the shell (MacDonald *et al* 1991).

The turnover ratio, defined as the ratio of production to biomass (P/B), has been widely used to estimate the production of natural populations from biomass estimates when mortality, growth or age composition are not available (Banse and Mosher 1980). Turnover ratios are also used to compare energy flow through different populations in relation to the standing stock (Thompson and MacDonald 1991).

There are a number of published works on age and growth in a number of commercially exploited scallop species, but only two age and growth studies were found on pink and spiny scallops. Bourne and Harbo (1987) examined growth of pink and spiny scallops from a sample randomly collected from the commercial catch. The growth curve fitted by eye is shown in Fig.1.

MacDonald *et al* (1991) assessed how energy was partitioned in spiny scallops near Bamfield B.C. and pink scallops near Denman Island, B.C. from water depths ranging 5-25 m. The relationship of shell height with age for the 2 species is shown in Fig 2, with their respective fitted von Bertalanffy equations. The von Bertalanffy growth model is described as:

$$H_t = H_\infty\left[1 - e^{-k(t-t_0)}\right]$$

where H_t is the shell height at time t,
H_∞ is the mean asymptotic shell height
k is the Brody growth coefficient
t_0 is the time when shell height is 0

The calculated parameters and 95% confidence limits from the MacDonald *et al* (1991) study are shown in Table 3. The somatic tissue weight in spiny scallops was considerably higher than in pink scallops (Fig 3). The annual production of somatic tissue (P_g), shell (P_s), and gametes (P_r) was calculated for each age class in both species. A comparison of energy partitioning allocated to growth and production shows some remarkable differences between the two species. Maximum annual production of somatic tissue occurred at 3 years in pink scallops, but there was considerably higher somatic tissue production in spiny scallops, with maximum annual production occurring at 4-5 years (Fig 4). Annual gamete production continued to steadily increase in spiny scallops throughout their reproductive life, and exceeded annual somatic tissue production after 5 years. In pink scallops, annual gamete production reached an asymptotic maximum at 4 years, and never exceeded annual somatic tissue production.

MacDonald *et al* (1991) show the reproductive effort (RE), calculated as RE= P_r x 100/ P_t where P_t is the total production (P_g+ P_s+ P_r), was an increasing function of age for both species (Fig 5a). There was a shift from growth of somatic tissue and shell in earlier years to production of gametes in later years (Fig. 4.) In spiny scallops, reproductive effort approached 70% in the final year, when gamete production exceeded somatic production. In pink scallops, maximum reproductive effort was 37% (Fig 5a). Turnover ratios declined in the two species with age (Fig. 6b). This study (MacDonald *et al* 1991) confirmed that short lived iteroparous species, such as pink and spiny scallops, continue to grow actively throughout their life-span, whereas in long lived iteroparous species, such as rock scallops, growth ceases in older senescent individuals and body tissue may be used to support gamete production.

2.1.9 Recruitment and Mortality

Connell (1985) defines settlement as the point when an individual first takes up permanent residence on the substratum and recruitment as the measure of survival of individuals for a period of time after settlement. Recruitment combines settlement with early mortality. Recruitment in broadcast spawning bivalves is typically erratic and unpredictable. The dispersion of gametes, vulnerability of gametes and planktonic larvae to predation, particular requirements of settling veliger larvae, and the high mortality usually endured by newly settled juveniles are all factors in the recruitment process. There is no specific information on recruitment of pink and spiny scallops.

There is no age frequency distribution data for pink and spiny scallops, and therefore catch curves are not available for estimating mortality. However, natural mortality estimates can be made using Hoenig's (1983) generalized model using the predictive equation:

$$\ln(z)=a+b\ \ln(t_{max}) \quad \text{where for molluscs: } a=1.23;\ b=-0.832$$

At maximum age of 6, the estimated instantaneous natural mortality is 0.77.

2.1.10 Density and Biomass

There is little known about the species distribution or population structure of pink and spiny scallops. There is also very little known about the distribution and size of the beds for either species. During observations of a pink and spiny scallop fishery off Victoria in 1982, diver estimates of scallop density varied from 20-30/m^2 on an almost level mud and gravel bottom at 26 m., to 10-20/m^2 on undulating rocky reefs at 27 m. (Harbo, unpubl.rep.)

3. Fisheries

3.1 Review of Scallop Fisheries in British Columbia

Pink and spiny scallops have been commercially harvested in British Columbia since 1982. The fishery is limited to inshore waters using divers and small trawls. Harvesters require a "Z-I" licence for the dive fishery and a "Z-R" for the trawl fishery. There are seasonal and area closures. Pink and spiny scallops are marketed whole, in the shell, fresh or frozen. Most other scallop species are considerably larger, and only the adductor muscle or the adductor muscle and gonad is marketed from these species (Bourne and Harbo 1987).

Total scallop landings from both the dive fishery and the trawl fishery from 1982 to 1998 are shown in Fig.7. The landings for 1998 are only preliminary. The dive fishery has landed 84.6% of the total cumulative commercial scallop fishery to date. A summary of the annual landings (tonnes) for the dive and trawl fishery is shown in Table 4. There are a number of unresolved inconsistencies between the data in Table 4, which was obtained from the 1997 Fishery Update, and the data depicted in Fig. 7, which was obtained from a very recently updated harvest log database. However, there is evidence of declining effort in terms of number of vessels with landings as well as vessel days with the trawl fishery in recent years, and a concurrent increasing effort in the dive fishery (Table 4).

Table 5 shows where each respective fishery has concentrated. In the dive fishery, 35.8% of the total landings were from Pacific Fishery Management Area (PFMA) 18, followed by 33.9% from PFMA 29, and 26.0% from PFMA 17. In the trawl fishery, 45.7% of the total landings were from PFMA 14, followed by 33.5% from PFMA 20, and 10.1% from PFMA 18.

The annual landings from the three highest reporting Pacific Fishery Management Areas in the dive fishery and trawl fishery were plotted to assess the source of the rise and fall of landings seen in Fig 7. In the dive fishery (Fig. 8), annual landings in PFMA 29 increased substantially from 18,160 Kgs. in 1992 to approximately 41,000 Kgs. in 1993 and 1994, and 53,000 Kgs. in 1995, and subsequently declined to 24,500 Kgs. in 1996. As landings from PFMA 29 declined, landings from PFMA 17 increased from 11,000 Kgs. to 27,250 Kgs., and in PFMA 18 increased from 10,000 Kgs. to 41,000 Kgs. In the trawl fishery (Fig.8), landings peaked in PFMA 20 at 27,250 lbs. in 1989, and declined to only sporadic fishing in this area due to continuing PSP problems. In PFMA 14, landings peaked at 20,500 Kgs. in 1991 and 1992, and since declined to approximately 4,500 lbs. in recent years. In 1996, trawl fishers reported that access to markets was the limiting factor in the fishery rather than availability of stock.

Limited market sampling was conducted in 1986, and a summary of the results is shown in Table 6. The species composition in six samples from the dive fishery varied from 88 –100 % spiny scallops and 0-12 % pink scallops. Pink scallops were always smaller than the spiny scallops.

In an effort to try and address the concern of fishers of harvesting in some areas, an attempt was made to calculate CPUE (kg./diver hr) in the individual Pacific Fishery Management Areas from the harvest log database, but there are some underlying errors in the data which resulted in unrealistic CPUE values. Fishers expressed concern on the scallop stocks in Pacific Fishery Management sub-area 29-5 in particular. A detailed editing and filtering of the harvest log data was conducted before individual CPUE's were calculated. There were a few obvious errors in the database resulting of a few CPUE's calculated in the 400-600 kg/hr range, and these points were removed as they were considered to be totally unrealistic A summary of the annual effort and landings in sub-area 29-5 is shown in Table 7. In 1995, there was a peak in landings of 50,521 Kg and an increase in CPUE to 71.88 Kg landed/diver hr. By 1997, effort increased to

529.8 hours dive time, but the catch declined to 28, 856 Kg. and the CPUE declined to 52.46 Kg landed/diver hr.

There is presently unlimited entry in both the dive and trawl scallop fishery. In the dive fishery over the past 6 years, there have been 2-3 times more licences issued than have reported landings. In the trawl fishery there have been 5-10 times more licences than there are licences with reported landings. It is not known whether this is an indication of speculative licence buying in order to establish a history in the fishery for qualification in a future licence limitation program, or whether this an indication of a reporting compliance problem.

Management controls include a minimum size limit of 55 mm. shell height. The original size limit was 60 mm. in 1982, but this was changed in 1989 after a limited survey and market sampling. The size of the trawls is limited to a maximum width of 2 m. There are numerous small closures in parks and study areas. In addition, Pacific Fishery Management sub-areas 17-10, 18-1, 19-5, 19-6, 29-4, and 29-5 were closed to the trawl fishery at the request of the dive harvesters. These are most frequently used by the dive fishery, and provide most of the landings for the dive fishery. Sub-area 29-5 was closed for the 1998 fishery due to concerns expressed by fishers on stock abundance.

3.2 Review of Pink and Spiny Scallop Fisheries in Washington

There is a small experimental fishery for spiny scallops in Washington (Sizemore and Palensky 1993). Landings are shown in Table 7. As noted in Table 7, there has been a severe decline in landings, largely due to the single large scallop fisher in Washington leaving the industry. The fishery is confined to a few vessels certified by the Washington State Department of Health operating in restricted areas and subject to weekly PSP monitoring. This fishery is managed by the Department of Health actions on PSP monitoring and closures. The fishery is closed between July 1 and October 1 due to consistently elevated PSP levels during this period. This fishery is limited by PSP closures rather than stock abundance (B. Sizemore, *pers. comm.*).

3.3 Review of Scallop Fisheries in Alaska

The scallop fishery in Alaska targets the weathervane scallop, *Patinopecten caurinus*. The fishery is a dredge fishery, with large vessels, consisting of a maximum crew of 12.

Commercial scallop landings in Alaska started in 1967, and quickly expanded to the highest landings, exceeding 800 metric tons in 1969. Effort steadily declined from 1970 to 1978 when no vessels participated in the fishery. A smaller more stable fishery evolved from 1979 to 1989, followed by an expansion from 1990 to 1993 (Shirley and Kruse 1995). Access to scallop landings in Alaska is difficult to obtain due to confidentiality issues in some areas. In 1996, the most recent year where the most information is available shows over 330,000 pounds were harvested with an exvessel value of $1.94 million (Alaska Department of Fish and Game 1999a)

The Alaska Scallop Fishery Management Plan specifies that dredges used cannot be more than 15 feet wide, with rings having an inside diameter of 4 inches or more and a maximum of two dredges may be used at any one time. The management plan establishes nine Scallop Registration Areas, and a vessel is limited to fish in one registration area at a time. There are Guideline Harvest Limits in each registration area. There are also seasonal and area closures. In addition, there are provisions for location and duration of harvests; gear limitations and other harvest procedures; periodic reporting, including logbook requirements; requirements for onboard observers; and catch or bycatch limits (Alaska Department of Fish and Game 1999b). Crab bycatch is an issue in the scallop dredge fishery, In some areas the scallop fishery has been closed early before the TAC has been reached, when the crab bycatch exceeded permissible levels.

There have been a number of management measures implemented to reduce effort, and some were drastic measures. In 1995, the National Marine Fisheries Service closed all scallop fishing in federal waters off Alaska for 1 year (National Marine Fisheries Service 1995). A vessel moratorium program was implemented in 1997 (Federal Register 1997), and there have been drastic reductions in TACs in some areas (National Marine Fisheries Service 1997).

3.4 Review of Scallop Fisheries in Québec

In Québec, there has been commercial scallop harvesting since the mid-1960s. It is an inshore fishery, targeting on two species indiscriminately, the sea scallop, *Placopecten magellanicus*, and the Iceland scallop, *Chlamys islandica*, with a Digby-type scallop drag. In the Gulf of St. Lawrence, the Iceland scallop occurs in the northern gulf, on the North Shore, Anticosti Island and the north shore of the Gaspé. The sea scallop is primarily found in the southern gulf around the Îles-de-la-Madeleine, Bay of Chaleur, and occasionally on the Lower North Shore. The sea scallop grows considerably faster than the Iceland scallop. The commercial size is reached at age 5 for sea scallops, and age 8 for Iceland scallops (DFO 1999a).

Landings are usually reported as muscle (meat) weight. The scallop fishery in the Gulf of St. Lawrence started in the Îles-de-la-Madeleine, where landings have fluctuated widely, from over 350 t of meat in 1969 to 41 t of meat in 1998. Landings on the North Shore rose rapidly between 1984 and 1990, and have since levelled off since 1991 due to the introduction of individual quotas on the Middle North Shore.

In Area 20, Îles-de-la-Madeleine, and 16E, a small area of the North Shore, research surveys are conducted. Assessments are based on indices measured during the surveys, as well as an analysis of catch data. In all other areas, assessments are based on an analysis of catch data alone.

In the Îles-de-la-Madeleine, there are serious concerns for the conservation of the stocks, and the most recent recommendation is a cessation of all scallop fishing in the area. In the Gaspé, a reduction of effort has been recommended for the north shore of the Gaspé. In other areas, fishing effort has declined to sufficiently low levels to alleviate any concerns. On the North

Shore, there are concerns due to the lack of information available in some areas, and more stringent management measures may be recommended. There is evidence of localized overfishing in some areas.

3.5 Review of Scallop Fisheries in the Maritimes

The sea scallop, *Placopecten magellanicus*, is harvested in the Maritimes region by inshore fisheries and offshore fisheries. The inshore fleet tows 7 to 9 Digby-type drags off the starboard side, while the offshore fleet uses two New Bedford offshore scallop rakes or drags, 4 to 4.9 m width, towed on each side of the vessel simultaneously.

MacPhail (1954) describes details of the Digby drag design. The original Digby drag has an angle-iron frame with openings 20.32 cm high and 78.1 cm wide. The drag consists of wire ring nets approximately 0.6 m deep. A gang of 7 Digby drags will sweep an area almost 5.5 m wide, and a gang of 9 will sweep an area of 7 m wide. There are several local modifications to this type of drag, including the number of drag in a gang, the ring diameter, and the addition of teeth to the scrapping surface, but the overall design is basically the same. Details of the offshore drag are described by Bourne (1964). The offshore drag consists of a heavy metal frame made of ½-inch to 1 ¾-inch steel plate. A net bag knit of steel rings is attached to the frame. There is a sloping pressure plate at the top of the frame to help keep the drag on the bottom. At the bottom of the frame, the net bag is not attached directly to the frame, but to a sweep chain, which is preceded by a tickler chain. A 3.65 m wide drag weighs 600-750 kg. In the typical configuration of the offshore fishery of towing 2 offshore drags, the area swept is 8–10 m wide.

In the southern Gulf of St. Lawrence, reported landings have dropped from over 600 mt annually from 1968 to 1971, to an average of less than 300 mt since 1981. There has not been any commercial sampling since 1988, therefore the size and age-structure of the commercial catch is unknown. A research survey conducted in 1997 suggests weak incoming recruitment and low abundance in Northumberland Strait. The overall conclusion is the southern Gulf of St. Lawrence scallop fishery is overexploited, and effort should be reduced (DFO 1998a).

In the Bay of Fundy, scallop landings have declined from 1993 to 1996, the most recent year data is available (Table 9)(DFO 1997a). There has a sharp decline since 1995. An area based management plan was implemented in 1997, due to declining catches and concerns over the long-term viability of the fishery. The Bay of Fundy was divided into seven Scallop Production Areas (SPA) for management purposes (Smith and Lundy 1998). Each SPA has a management plan that includes a Total Allowable Catch (TAC), meat count (/500 g), minimum meat weight (often voluntary), minimum shell height, and seasonal openings. Logbooks or dockside monitoring programs are used to monitor fleet activity (DFO 1999b). Assessments include resource surveys, analysis of commercial catch data, and commercial catch sampling in most areas. In many areas, the incidence of clappers (dead paired shells) has increased substantially, reflecting an increase in natural mortality and incidental fishing mortalities (DFO 1997b). Recruitment levels are expected to remain low in most areas, and recommendations have been made to substantially reduce exploitation rates to allow full growth potential. Many lobster fishers have expressed concerns on the potential damage scallop gear may have on lobster habitat (DFO 1997c).

Sea scallops are also harvested in offshore fisheries on the Eastern Scotian shelf, and on German Bank, Browns Bank, and Georges Bank of southwestern Nova Scotia. On the Eastern Scotian shelf, landings declined by 50% from 1992 to 1993. In 1994, a catch limit was imposed based on the low end of catches over the 1980-1994 period. Assessments include logbooks, dockside monitoring and resource surveys. Recruitment and biomass is expected to slowly increase in the Sable Island/Western Banks area. Recruitment in the Middle grounds area appears to be sporadic and there is limited potential in this area (DFO 1997d).

On German Bank, scallop catches declined steadily until 1985, when the fishery closed for 7 years. The fishery resumed in 1993, as seasonal fishery, to avoid gear conflicts with the lobster fishery, with a 200 t TAC. The TAC was increased to 600 t in 1994, and then reduced to 400 t in 1995, and further to 100 t in 1996, due to rapidly declining catch rates and increasing meat counts. Assessments include logbooks, dockside monitoring and resource surveys. It is unlikely that this fishery is sustainable over a 100 t TAC (DFO 1997e).

Scallop catches on Browns Bank was the highest on record (2002 t) in 1995. There was a rapid expansion since 1989, as new areas of Brown Bank were exploited. However, 1996 and 1997 catches have declined to levels comparable to the early 1990's. Assessments include logbooks, dockside monitoring and resource surveys. Due the extreme patchiness and low overall abundance of prerecruits, the TAC will likely be reduced from the 1997 level (DFO 1998b).

The Georges Bank area supports a major scallop fishery. The 1980-89 average landings were 5,100 t. In 1992 and 1993, a 6,200 t TAC was implemented, which was reduced to 5,000 t in 1994, 2,000 t in 1995 and increased to 3,000 t in 1996. Assessments include logbooks, dockside monitoring and resource surveys. Exploitation rates on directed ages (4 to 7) were 23% in 1995 and 31% in 1996. A 3,000 t TAC in 1997 would result in a 19% exploitation rate on an estimated biomass of 11,300 t (DFO 1997f).

3.6 Review of Scallop Fisheries in Newfoundland

The Iceland scallop in Newfoundland started in 1969 in the Strait of Belle Isle, and expanded to St. Pierre Bank in 1989 and the Grand Banks in 1993. In the Straits of Belle Isle, there are four strong peaks in landings: 1972-73; 1980-81; 1984-86; and 1992-94. The 1972-73 peak is attributed to a smaller ring size in the scallop rakes, and the changeover to more efficient gear, the Labrador rake, in the mid 1980s contributed to higher landings along with higher prices and new exploitation areas. There is a repeating pattern in this fishery of sharp increases to very high landings (1500 t to over 2000 t round wt.) followed by several consecutive years of poor catches. The 1995 survey showed no evidence of new recruitment (DFO 1997g)

The Grand Banks fishery has had steadily increasing landings (measured as round weight) of 817 t in 1993, to 9,454 t in 1996. A variety of gear was first used in the fishery, and the fleet has changed from the large heavy New Bedford rakes to the smaller Digby drags. In 1996, this was the largest Iceland scallop fishery in Canada. Periodic research vessel surveys long with an analysis of fishery performance are used in the assessments. Analysis of survey data suggests an increase in annual natural mortality from pre-exploitation values of 0.05 to 0.13-0.19. The higher rates have been attributed to non-yield gear-related mortality, or collateral damage (DFO 1997g).

4. Discussion

The pink and spiny scallop fishery has been an unlimited fishery since its inception. There is a minimum size limit of 55 mm shell height to allow spawning at least once before recruitment to the fishery. Both species reach maturity at 35 mm. shell height. There are some small closures around parks and study areas, and some areas are closed to the net fishery, but open to the dive fishery. There is unlimited entry, but a comparatively low participation rate. There is no catch ceiling, such as total allowable catch or maximum harvest rate. The target of this fishery is two different species, and there are two methods of fishing: diving and trawling with a small trawl.

The dive fishery is concentrated in the exposed areas of Georgia Strait in Pacific Fishery Management Areas 17, 18 and 29. The dive fishery lands an estimated 85% of the total scallop landings from British Columbia waters.

The only other fishery that is similar to the British Columbia pink and spiny scallop fishery is the small spiny scallop fishery in Washington State. The Washington Department of Health manages this fishery due to PSP levels. Other scallop fisheries that were reviewed have considerably different species and fishery characteristics in comparison to the pink and spiny scallop fishery in British Columbia. Most other scallop fisheries have similar characteristics, harvesting by dredges, a very rapid expansion of the fishery with very sharp increase in landings that can only be sustained for a year or two, followed by rapid declines to very poor catches for several consecutive years. Some fisheries have closed completely for a few years due to poor recruitment and production.

4.1 Biological Considerations

In British Columbia, pink and spiny scallops are managed as one species and one stock. There are considerable differences in the growth rates and maximum size of each species. Spiny scallops are faster growing, and reach a larger maximum size than pink scallops. The minimum shell height was originally set for spiny scallops, which precludes most pink scallops. The original intention was to permit animals to spawn at least once before they were recruited to the fishery (Bourne 1987). However, reproductive effort in spiny scallops is considerably higher than in pink scallops, and increases with age and size, when gamete production exceeds somatic production in the final year. Reproductive potential of spiny scallops may be better protected by minimum and maximum sizes. There are also considerable differences in other reproductive characteristics. Pink scallops first spawn from March to April and again from September to early October in southern British Columbia. Spiny scallops only spawn from July to August.

There is no specific information available on the effects of the small trawls used in the British Columbia fishery on the target species, co-occurring species or on the habitat. The size selectivity, bycatch characteristics and the fate of discards from this trawl fishery have not been assessed, nor have there been any habitat assessments done on the effects of the trawl fishery. However, fishing with trawls, dredges and drags generally reduces habitat complexity by smoothing the sediment surface, removing emergent epifauna, and removing species that produce structures such as pits and burrows (Auster 1998). There is also extensive information on scallop drags on the East Coast, including habitat damage, fishing inefficiency, incidental mortalities and collateral damage.

A close examination of the effect of scallop drags on the East Coast (Caddy 1973) showed sediment alteration by siltation, gravel and rock displacement, as well as predator aggregations in the drag tracks at densities 3-30 times densities outside the tracks. Wating and Norse (1998) cite several experimental studies on habitat alteration by scallop drags, including removal of the upper 4 cm of sediment, loss of surface labile organic matter, coarsening of the sediments, and changes in species composition and diversity. Observational studies cited by Wating and Norse (1998) show scallop dragging reduces the number of organisms, biomass, species diversity, and structural complexity. Benthic microalgae, hydroids and shrimp were eliminated in scallop drag paths. Wating and Norse (1998) rate the severity of scallop dragging as falling between hydraulic clam dredging and bottom trawling, but overall the severity of mobile fishing gear is rated as high. While there is no specific information on the impacts of the trawl used in the West Coast scallop fishery, information from the impacts of other scallop drags shows severe impacts on habitat alteration and collateral damage.

Caddy (1973) estimates incidental mortality incurred by scallop drags of 13-17% per tow, which is similar to fishing efficiency estimates of the drags. Original estimates of drag efficiency range from 5-12% for the Digby drag and 8-10% for the Bedford drag (Dickie 1955). Several other types of drags evaluated world-wide range from 6-35%, with majority ranging from 10-20%. (McLoughlin *et al* 1991). In many cases cited by McLoughlin *et al* (1991), the incidental fishing mortality exceeded the efficiency of the scallop drags. While there are no estimates of efficiency or incidental mortalities for the small trawl used on the West Coast, it appears that from other scallop fisheries, the actual fishing mortalities are at least twice the catch.

Due to the relatively low efficiencies of scallop drags, considerable effort is required to harvest a stock, resulting in several passes to harvest all the available stock. However, with increasing effort, there is an expected decline in habitat complexity, and the threshold effort levels which may produce large changes are unknown (Auster 1998). These drags used in the East Coast fishery are considerably larger and heavier than the small trawls used in the British Columbia fishery. The area swept by the East Coast drag fisheries on each pass is 3 – 6 times wider than the trawls used on the West Coast. The West coast trawls have a rigid steel frame opening, and the potential biological damage is likely similar to that found on the East Coast, but it would occur over a smaller area and maybe with less severity for each pass. However, repeated passes to harvest all the available stock in a given area would likely result in damage similar in magnitude to that found on the East Coast.

It is very difficult to determine appropriate precautionary threshold levels for this type of fishery. Often threshold levels are only determined after they have been exceeded and the damage is apparent. It appears that from a number of scallop drag fisheries that have been reviewed in Alaska and the Canadian East Coast, the threshold effort levels have been exceeded, resulting in a severe decline in the fisheries, and large areas of habitat destruction.

4.2 Stock Assessment Considerations

The U.S. National research Council publication on Improving Fish Stock Assessments (1998), gives a checklist of four basic topics that should be included in a stock assessment: (1) stock definition; (2) data; (3) assessment model; (4) policy evaluation.

4.2.1 Stock Definition

In order for the pink and spiny scallop fishery to continue or expand, an understanding of the stock distribution is required. A distributional survey and habitat assessment with must be spatially structured to determine the individual species distribution, as well as habitat requirements, preferences and partitioning. There is conflicting evidence on the habitats of each species, likely due to a lack of sufficient data.

4.2.2 Data

There is very little available information on the status of the stocks of pink and spiny scallops in British Columbia waters. There is data on reported effort and landings. In some cases, fluctuations in effort and landings is driven by lack of markets rather than stock abundance, or fishing opportunities have been constrained by PSP blooms, but in other cases, a historically very productive fishing area has been closed to concerns expressed by fishers on stock abundance. Assessment of stock status by monitoring effort and landings is not sufficient or appropriate for this fishery.

There has not been any structured survey or biomass estimate of pink and/or spiny scallops in British Columbia. The last market sampling was conducted in 1986. These are two basic tools that are used in most other scallop fisheries such as in Alaska, Québec, the Maritimes, and Newfoundland.

Caddy and Gulland (1983) classified stocks into four groups using their fluctuation patterns: (1) Steady stocks, which remain the same from year to year, and variations remain within 20-30% of the long-term average. Some boreal or arctic populations of long-lived species have this type of pattern. (2) Cyclical stocks, which show a repeated pattern of high and low abundance, often with uneven periods. These patterns may result from climatic fluctuations, predator-prey interactions, and other factors affecting year-class strength. A *Placopecten* stock in the Bay of Fundy is an example (Caddy 1979). (3) Irregular stocks, which fluctuate widely from year to year without any clear pattern, and often dependent on hydrographic conditions. Georges Bank stocks are examples with this pattern. (4) Spasmodic stocks, which have irregular pulses of high abundance, followed by very low abundance periods or near collapses. Most scallop species show this pattern (Orensanz *et al* 1991). It is very important to determine the natural fluctuation patterns of the stocks being assessed and managed, in order to put any biomass estimates into perspective. It is also important to know the potential magnitude and periodicity of the natural fluctuation pattern, as well as the current position within the fluctuation cycle when determining a risk averse exploitation rate.

Fisheries independent surveys are the most reliable method of determining biomass and distribution. These need to be repeated annually to determine recruitment events and fluctuation patterns. Abundance estimates at index sites give relative estimates of abundance, which used with catch data, information on recruitment and estimates of natural mortality. CPUE as an index of abundance is not adequate, due to problems with hyperstability, unstandardized effort and change in catchability (Hilborn and Walters 1992).

In addition to fishery independent surveys, an estimate of all removals is required, including the catch, bycatch, discards and their subsequent mortalities and collateral damage by fishing gear. Information on age, size and sex is required from both the fishery independent surveys and from market samples, in order to determine recruitment patterns and the effect of the fishery on the populations.

Biological information can be collected immediately and inexpensively from the fishery by repeating the market sampling in 1986, by examining differences in size and age composition, growth, sex ratio, and reproductive activity.

4.2.3 Assessment Models

An estimate of important parameters such as natural mortality (M), vulnerability, fishing mortality (F), and catchability are required in order to make preliminary estimates of appropriate exploitation level. Exploitation rates are usually based on a proportion of estimated natural mortality. Applying experimental exploitation rates in limited areas can test the performance of a fishery and its effect on the sustainability on stocks.

There are empirical alternatives to age-based assessment techniques, which warrant investigation for this fishery. Some East Coast scallop fisheries use a size-based analysis, which is quite accurate and are not as data or assumption dependent as other analytical techniques (M. Hanson, *pers. comm*.).

4.2.4 Policy Evaluation

Policy evaluation is a topic that needs to be addressed by stock assessment considerations and management strategies. This fishery is presently being managed as one species and one stock. While there are distinct differences between the two species that may require changes in the management of the fishery, it is not known whether there is one large stock within Georgia Strait, or whether there are several smaller discreet stocks. There are areas of concentrated fishing effort that appear to be adversely affecting stocks, which has resulted in a closure. A rotational fishery would move concentrated effort around to allow stocks to recover. Stock delineation would be instrumental in the design of a rotational fishery.

This fishery is being passively managed by a minimum size limit, which has been shown to be ineffective at insuring sustainable fisheries for species with highly variable recruitment. The recruitment pattern of these two species is not known. Depending on the stock definition, and recruitment patterns of the pink and spiny scallops, an area based TAC may be a more appropriate management tool. The use of rotational fisheries rather than an overall TAC may be more appropriate, and this should examined more closely.

4.3 Management Strategies

Fisheries independent stock assessments, is the most reliable method to monitor and manage scallop fisheries. This is done in the vast majority of the scallop fisheries reviewed on the East and West Coast. Due to the wide range of depths and substrates inhabited by pink and spiny scallops in British Columbia, both dive and trawl surveys will be required for all scallop beds fished, or at least at representative index sites. Surveys of areas currently open will be costly in relation to the value of this fishery. Estimates of scallop biomass and estimates of mortality will result in the management of areas (or scallop beds) by harvest quotas (by species), and calculated through a fixed exploitation rate, or by a fixed escapement goal. Controlling catch by quotas will require DFO and industry to develop more timely and accurate reporting requirements for harvest activities.

Minimum size limit regulations (55 mm) are currently in effect for both the pink and spiny scallops in British Columbia. Size limits may be effective in the dive fishery, where animals are selected underwater and smaller scallops are relatively undisturbed. Size limits are not effective for animals harvested within trawls, where mortality of smaller scallops due to trawl damage and handling may undermine the perceived protection. In addition, there is little biological evidence that the 55 mm minimum size limit currently in effect provides sufficient protection. While protecting sexually mature spawning animals for 1 to 2 years before allowing commercial harvest, the current size limit may not be able to protect enough animals to provide adequate recruitment to maintain a viable, healthy population. There is evidence that size limits based on age at first maturity have been ineffective in intertidal clam fisheries without other management actions (G. Gillespie, *pers. comm*.). It has been shown that reproductive effort in pink and spiny scallops increases with age, with varying degree in each species (Fig 5). There should be a re-assessment of size limit based on reproductive potential of each species, and not on size at first maturity. Size limits should be determined based on an acceptable level of reduced egg production. There is anecdotal information from fishers to suggest that scallop populations in some areas of the BC coast are severely depleted from previous years. A rotational fishery would ensure that effort is moved around beds of known scallop beds, and diverting concentrated effort would prevent stock depletion in localized areas, as has been seen in the fishery recently.

Sex specific selection in commercial harvesting, such as is currently in effect for the BC crab fishery, is not a viable option for the scallop fishery. Sex determination is not possible by external inspection or by size selection. There is no evidence to suggest that females make a disproportionate contribution to reproduction; as fertilization for scallops is external.

In the absence of other fishing effort controls, seasonal closures provide little real protection to a fished population. The timing of fishing effort around the spawning season and settlement periods may provide increased benefits to spawning stocks and improves recruitment success.

Permanent closures, or refugia, for a portion of the pink and spiny scallop populations will provide protection to these animals from commercial harvest. Implementing closures will require knowledge of the distribution of these animals, or at least of previously fished beds. With limited knowledge of population size and structure, closures represent the easiest and least expensive option to help maintain risk adverse management of the scallop fishery. Closures will only be an effective tool, if in effect for both the dive and trawl fisheries, and bathymetric and horizontal movement of these animals is taken in to account.

Arbitrary quotas assigned to fishing areas may provide some protection against further escalation in fishing effort, but provides limited assurance against over harvesting.

4.4 Management Considerations

1. The scallop by dive fishery currently has unlimited licence entry, and few controls on fishing effort. Currently maximum sustainable harvest levels cannot be determined and estimates or indices of population size cannot be determined due to a lack of data. Effort limitation should be considered as a logical step towards reducing potential future fishing over capacity. Fisheries and Oceans could better assess stocks through scientific licences.

2. The scallop by trawl fishery is also currently an unlimited entry fishery. There is no specific information on the habitat impacts of the trawl fishery, trawl efficiency, incidental mortalities, bycatch and collateral damage. However, some areas have been closed to the trawl fishery at the request of the dive fishery due to perceived damage and overfishing. Information from other scallop fisheries using larger heavier gear indicates that there are severe impacts attributed to scallop drags. Closing the scallop trawl fishery should be seriously considered

until the impacts of the trawl fishery are assessed in detail. Otherwise 100% observer coverage and bycatch reporting should be considered in the trawl fishery.

3. Biological sampling programs should be established in order to collect species, age, size, and sex information on the catch.

4. Fishing opportunities for licence holders should be restricted to areas currently open for fishing until assessments of stocks can be completed. Future expansion of fishing opportunities may be considered following assessments of stocks in an area.

5. Collaborative agreements should be established with licence holders to fund and conduct stock assessment activities in areas presently open to fishing.

6. Consideration should be given to closing areas with known scallop beds within Johnston Strait and Georgia Straight to act as refugia from commercial harvest. In 1999, most of PFMA 13 through 18, and area 20 are accessible for commercial harvest.

7. Consideration should be given to attempting experimental management of fishing areas through manipulation of fishing controls.

8. Consideration should be given to reviewing the current size limit for both pink and spiny scallops, as there are considerable differences in reproductive characteristics between the two species. An increase of the limit will decrease the proportion of the population vulnerable to removal.

9. Consideration should be given to implementing a rotational fishery in order to divert concentrated effort and prevent localized stock depletion.

5. Conclusions

There is anecdotal evidence as well as limited scientific evidence that there is a localized depletion of pink and spiny scallops stocks in some areas of the British Columbia scallop fishery. The present management system is not appropriate, as two species are being managed as one species/one stock, and there is no indication as to the number of possible discrete stocks that may require unique management measures. The only monitoring systems in place are landings from harvest logs and sales slips, and a calculation of catch per unit effort (CPUE). This is not adequate for stock assessment requirements in order to implement a risk averse management system.

The following measures are required to collect sufficient information for a sound biologically based management system:

- strict enforcement of catch reporting as a condition of licence;
- accurate estimates of total fishing mortality including discards and collateral damage;

- fishery independent surveys of pink and spiny scallop populations to determine distribution, density, availability of suitable stock to the fishery, recruitment rates, and potential community interactions;
- habitat assessments in proposed fishing areas to ensure sensitive habitats are protected from harvesting and related activities;
- exploratory fisheries, in consultation with stakeholders, to determine the distribution of accessible and suitable stocks, and to collect detailed catch information;
- collect biological samples from key index sites (both fished and unfished) to monitor the effects of fishing on population structure, and to develop an understanding of recruitment;
- investigate the appropriateness of critical threshold levels.

Effort limitation should be considered as an interim measure to protect stocks, and reduce potential future fishing over capacity, prior to implementing a stock assessment program and adoption of a sound biologically based management system.

6. Acknowledgements

Our thanks go to Graham Gillespie of the Pacific Biological Station and Mark Hanson of the Gulf Fisheries Centre who reviewed the draft manuscript and provided many useful and helpful suggestions, thereby improving the paper. Rick Harbo provided the files on earlier work conducted on pink and spiny scallops by Fisheries and Oceans, as well as a historical background and some very helpful suggestions on the management aspects of the fishery. Jim Morrison provided editorial advice and suggestions. Klaus Schallie of the Canadian Food Inspection Agency provided the data on PSP concentration in scallops, and valuable anecdotal information on incidents of illness attributed to toxic scallops. Bob Sizemore and Alex Bradbury of the Washington Department of Fish and Wildlife provided information on the spiny scallop fishery in Washington. Annie Smith provided assistance in the literature search at the Pacific Biological Station library.

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Table 1. Scallop species with geographic range reported from British Columbia waters, after Bernard (1983).

Species	Geographic Range
Chlamys albida	54°N-71°N
Chlamys behringiana	53°N-71°N
Chlamys hastata	33°N-60°N
Chlamys jordani	48°N-52°N
Chlamys rubida	33°N-58°N
Crassadoma gigantea	25°N-60°N
Cyclopecten argenteus	44°N-53°N
Cyclopecten carlottensis	53°N-54°N
Cyclopecten knudseni	44°N-50°N
Cyclopecten squamiformis	45°N-49°N
Delectopecten randolphi	28°N-58°N
Delectopecten vancouverensis	27°N-60°N
Patinopecten caurinus	36°N-59°N

Table 2. PSP toxin in pink and spiny scallops exceeding regulatory level (80 µg/100g) sampled by Canadian Food Inspection Agency (formerly DFO Inspection Branch) in selected British Columbia waters from 1993 to early 1999.

Area	**Sub-Area**	**Location Name**	**PSP mg/100g**	**Domoic Acid ppm**	**Date Harvested**
13	17	Quadra Island	90	ND	21/06/94
17	10	Thrasher Rock	570	ND	02/12/97
18	1	Georgina Shoals	198	ND	24/11/97
18	1	Georgina Shoals	140	ND	05/12/97
18	1	Georgina Shoals	110	ND	06/01/98
19	4	Juan de Fuca	450	ND	02/08/95
20	5	Muir Point	110	ND	07/01/93
20	5	Muir Point	96	ND	18/02/93
20	5	Muir Point	270	ND	06/07/95
20	5	Muir Point	710	ND	25/09/95
24	7	Cypress Bay	95	ND	19/08/94
29	5	Valdes Island	170	ND	13/10/97
29	5	Valdes Island	930	ND	14/10/97

Table 3. Summary of parameters and 95% confidence intervals for the relationship between shell height (mm) and age (yr.) fitted to the von Bertalanffy model (from MacDonald *et al* 1991).

	H_∞	K	T_0	N	R^2
Spiny scallops	93.7±5.2	0.32±0.05	0.46±0.11	301	0.88
Pink scallops	67.0±2.4	0.41±0.07	-0.19±0.31	697	0.97

Table 4. Annual landings (tonnes), value and effort for pink and spiny scallops, 1982 to 1998, as reported on fish slips and harvest logs.

Year	Type and # of Licences Issued Dive	Type and # of Licences Issued Trawl	# of Vessels with Landings From Slips Dive	# of Vessels with Landings From Slips Trawl	Total Vessel Fishing Days From Slips Dive	Total Vessel Fishing Days From Slips Trawl	Coastwide Landings From Slips (t)	Dive Gear Landings From Slips (t)	Trawl Gear Landings From Slips (t)	Landed Value From Slips ($·10³)	Whole Landed Value ($/t)	Diver CPUE[1] From Logs (kg/diver hr)
1982			8				8			19	2,375	54
1983	Z 11		6				11			45	4,091	36
1984	Z 17		14				20			56	2,800	61
1985	Z 22		15				53			139	2,623	56
1986	Z 24		18		703		68			212	3,118	63
1987	ZI 29		11		601		66			244	3,697	50
1988	ZI 17		20		925		67			289	4,313	75
1989	ZI 43		13		784		75	75		316	4,213	68
1990	ZI 57		11		383		69	69		317	4,594	74
1991	ZI 61		9	12	485	199	82	59	23	387	4,700	49
1992	ZI 83		7	11	473	206	91	72	19	420	4,638	59
1993	ZI 35	ZR 44	9	10	1,016	91	90	82	8	423	4,700	76
1994	ZI 37	ZR 32	17	4	1,287	63	104	99	5	490	4,712	65
1995	ZI 29	ZR 43	14	8	969	133	96	86	10	476	4,958	74
1996*	ZI 39	ZR 40	12	5	1,364	81	102	95	7	503	4,931	64
1997*	ZI 41	ZR 38	13	3	1,101	66	73	70	3	376	5,151	58
1998*	ZI 20	ZR 34	6	3	613	59	54	50	4	290	5,370	49

[1]CPUE [ ] from harvest log data – log format changed in 1988

*preliminary data for 1996,1997,1998

Note: The catch databases were reviewed in 1999 & some historic data have been changed from previous updates

Table 5. Proportion of total cumulative scallop landings by Pacific Fishery Management Area in the dive fishery and in the trawl fishery

Scallop by Dive Fishery		**Scallop by Trawl Fishery**	
Pacific Fishery Management Area	Landings as % of total dive fishery	Pacific Fishery Management Area	Landings as % of total trawl fishery
12	0.2	13	6.5
13	0.4	14	45.7
14	1.6	17	0.9
15	0.3	18	10.1
16	0.5	19	1.7
17	26.0	20	33.5
18	35.8	25	0.1
19	1.2		
20	0.1		
29	33.9		

Table 6. Summary of species composition and size from market samples of pink and spiny scallops. From Bourne and Harbo (1987)

Date Sampled	Harvest Location		Species Composition			Size % ≥ 60 mm			Size % ≥ 55 mm		
	Area	S-Area	Ttl (n)	Pink (n)(%)	Spiny (n)(%)	Ttl	Pink	Spiny	Ttl	Pink	Spiny
05/06/86	29	01	230	25(12%)	202(88%)	83%	11%	93%	95%	68%	99%
18/06/86	17	10	160	10(6%)	150(94%)	88%	10%	93%	98%	70%	99%
18/06/86	17	10	143	3(2%)	140(98%)	86%	0%	88%	94%	33%	96%
19/06/86	14	07	200	0(0%)	200(100%)	74%	0%	74%	91%	0%	91%
09/07/86	17	10	200	0(0%)	200(100%)	91%	0%	91%	98%	0%	98%
14/08/86	14	07	200	0(0%)	200(100%)	60%	0%	60%	96%	0%	96%

Table 7. Annual effort and landings in Pacific Fishery Management Subarea 29-5

Year	Hrs. Dive Time	Kg. Landed	Avg. CPUE (Kg/Diver Hr)
1987	232.3	14,679	48.19
1988	321.7	18,554	60.84
1989	63.7	10,498	74.87
1990	21	11,545	89.27
1991	226.1	10,574	48.08
1992	274.5	18,060	66.66
1993	306.4	33,815	70.15
1994	376.7	38,677	62.63
1995	387.1	50,521	71.88
1996	241.0	22,112	64.58
1997	529.8	28,856	52.46

Table 8. Pink and Spiny Scallop Landings in Washington State

Year	Landings (Kgs)
1989	24,515
1990	20,598
1991	23,876
1992	10,831
1993	20,484
1994	26,460
1995	38,700
1996	15,253
1997	4,938
1998	3,628

NOTE: The large decline in landings is largely due to the single major scallop fisher in Washington State leaving the industry in 1997. Declines are also attributed to health restrictions on areas open to fishing and PSP reporting requirements.

Table 9. Bay of Fundy scallop landings (metric tons)

Avg 85-90	1991	1992	1993	1994	1995	1996*
2319	2304	2443	2429	2254	1754	900

*preliminary

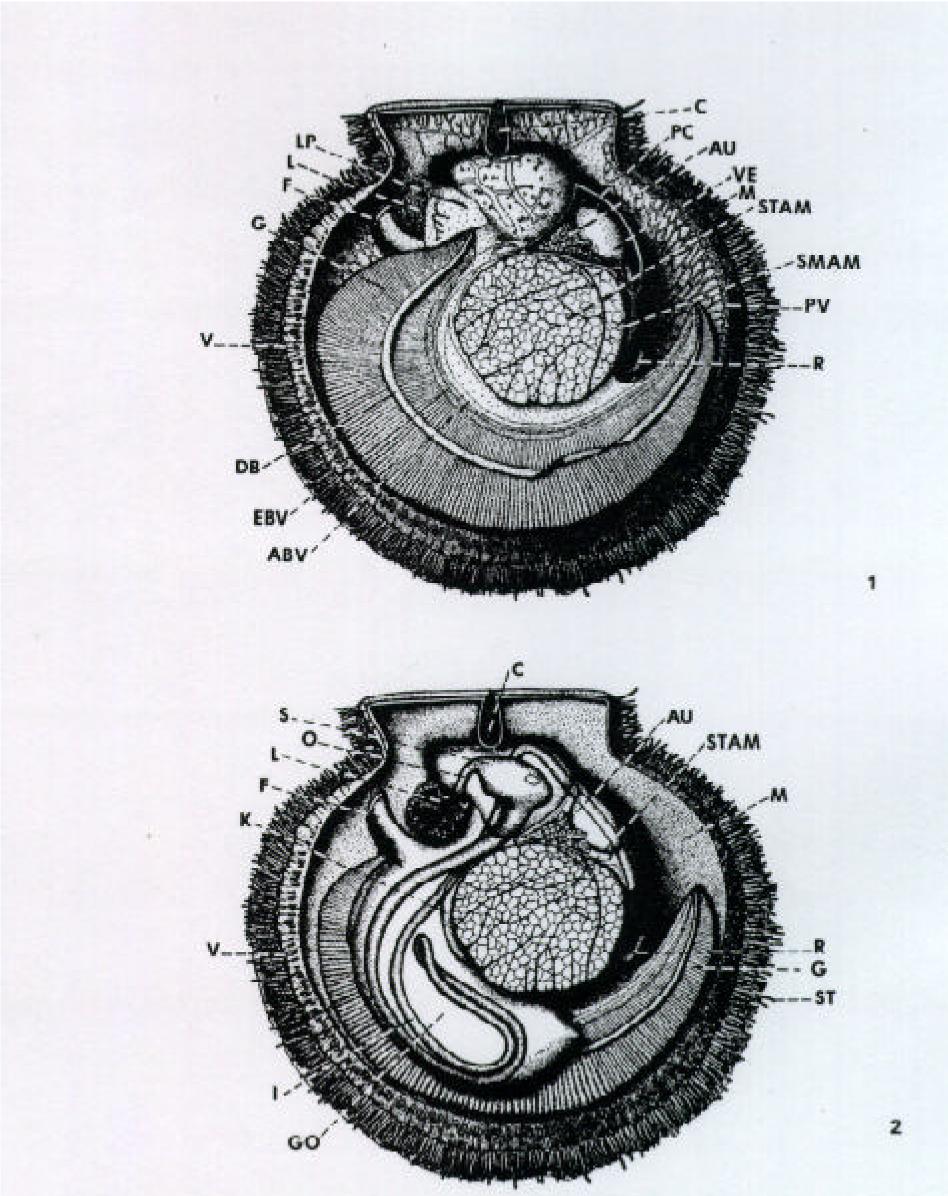

Fig. 1. General anatomy of a representative scallop, the sea scallop, *Placopecten magellanicus*. (1) Left valve and mantle removed. (2) Left valve, mantle and gill removed. Abbreviations: ABV, afferent branchial vessel; AU, auricle; C, chondophore; DB, dorsal bend of gill filaments; EBV, efferent branchial vessel; F, foot; G, gill; GO, gonad; I, intestine; K, kidney; L, lips; LP, labial palps; M, mantle; O, oesophagus; PC, pericardium; PV, pallial vessels; R, rectum; S, stomach; ST, sensory tentacles; SMAM, smooth adductor muscle; STAM, striated adductor muscle; V, velum; VE, ventricle After Drew (1906) Cited in Beninger and Le Pennec (1991)

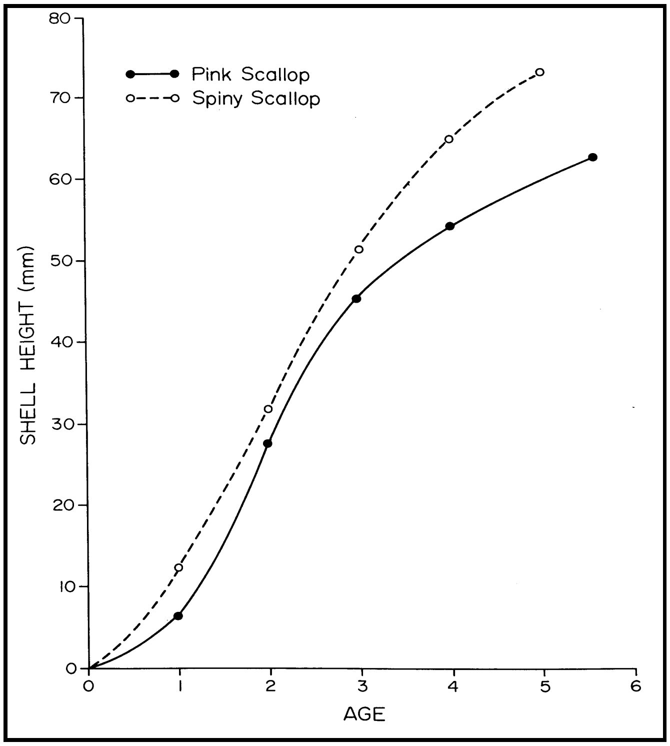

Fig. 2. Growth of pink and spiny scallops from British Columbia. From Bourne and Harbo (1987)

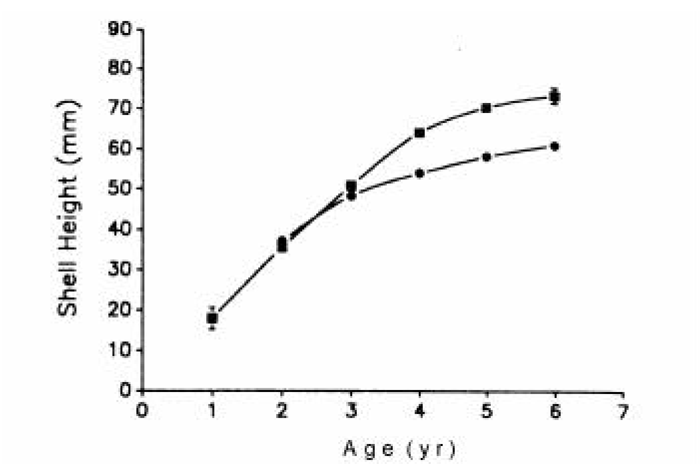

Fig. 3. Shell height (mm) for each age class of spiny scallops (■) and pink scallops (●). Fitted line in is von Bertalanffy model $H_t=H_\infty[1-e^{-k\,(t-t0)}]$ from MacDonald *et al* (1991).

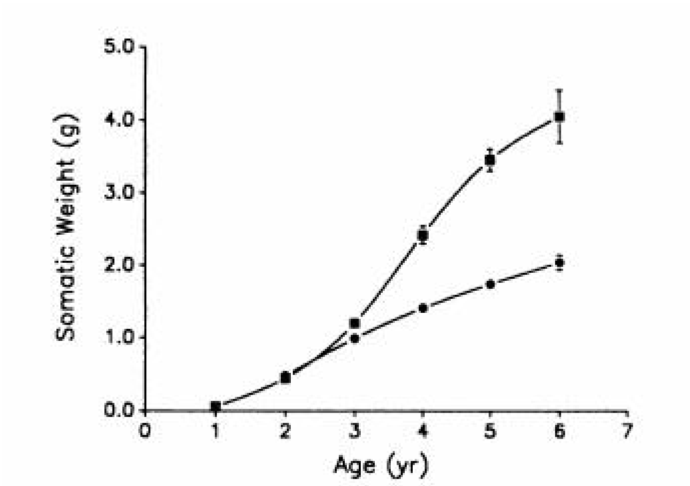

Fig. 4. Dry weight somatic tissue (g) for each age class of spiny scallops (■)
and pink scallops (●). from MacDonald *et al* 1991.

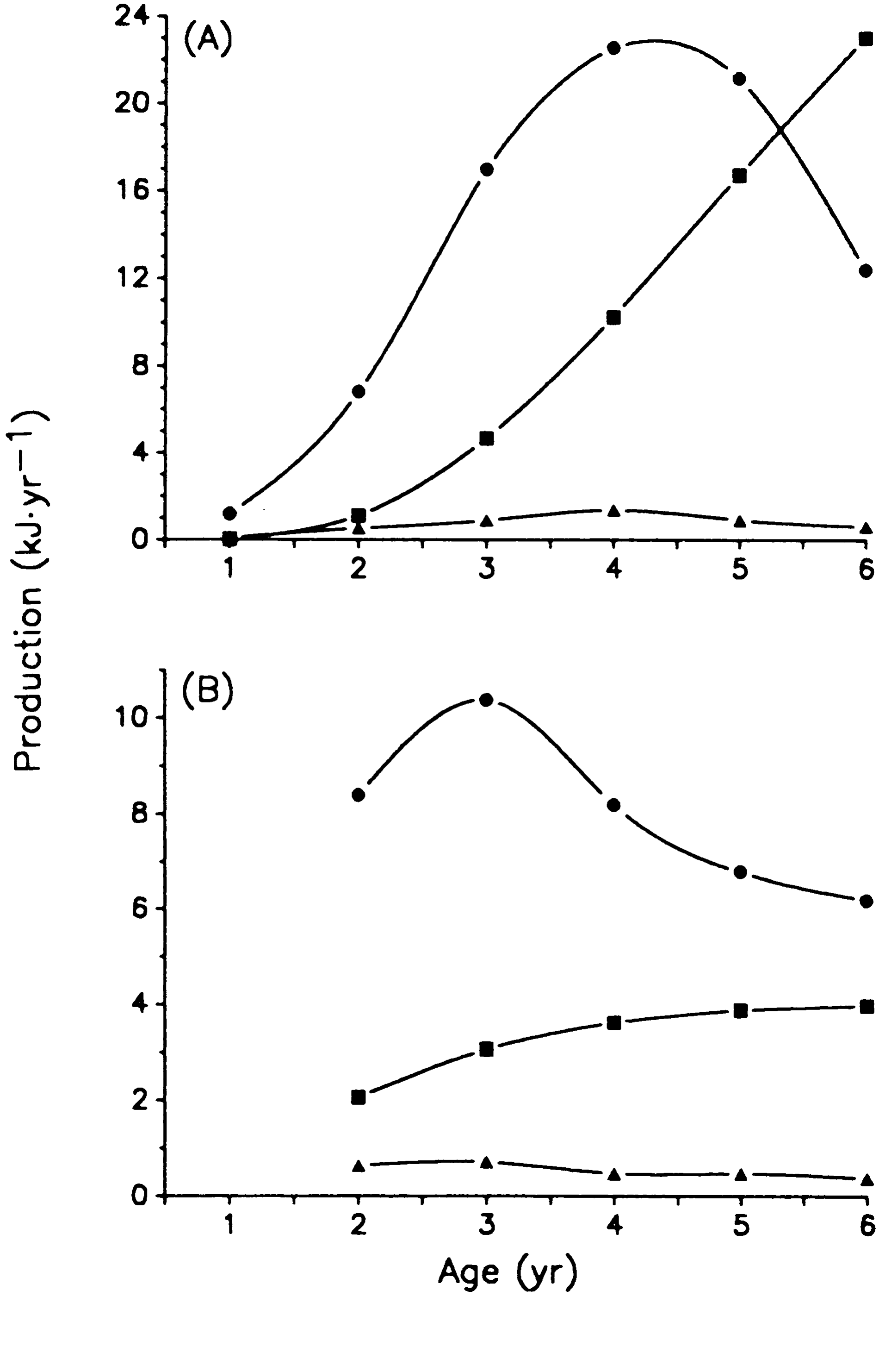

Fig. 5. Annual production of somatic tissue (P_g ,●), shell (P_s , ▲), and gametes (P_r ,■) for each age class of **(A)** spiny scallops and **(B)** pink scallops. from MacDonald *et al* 1991

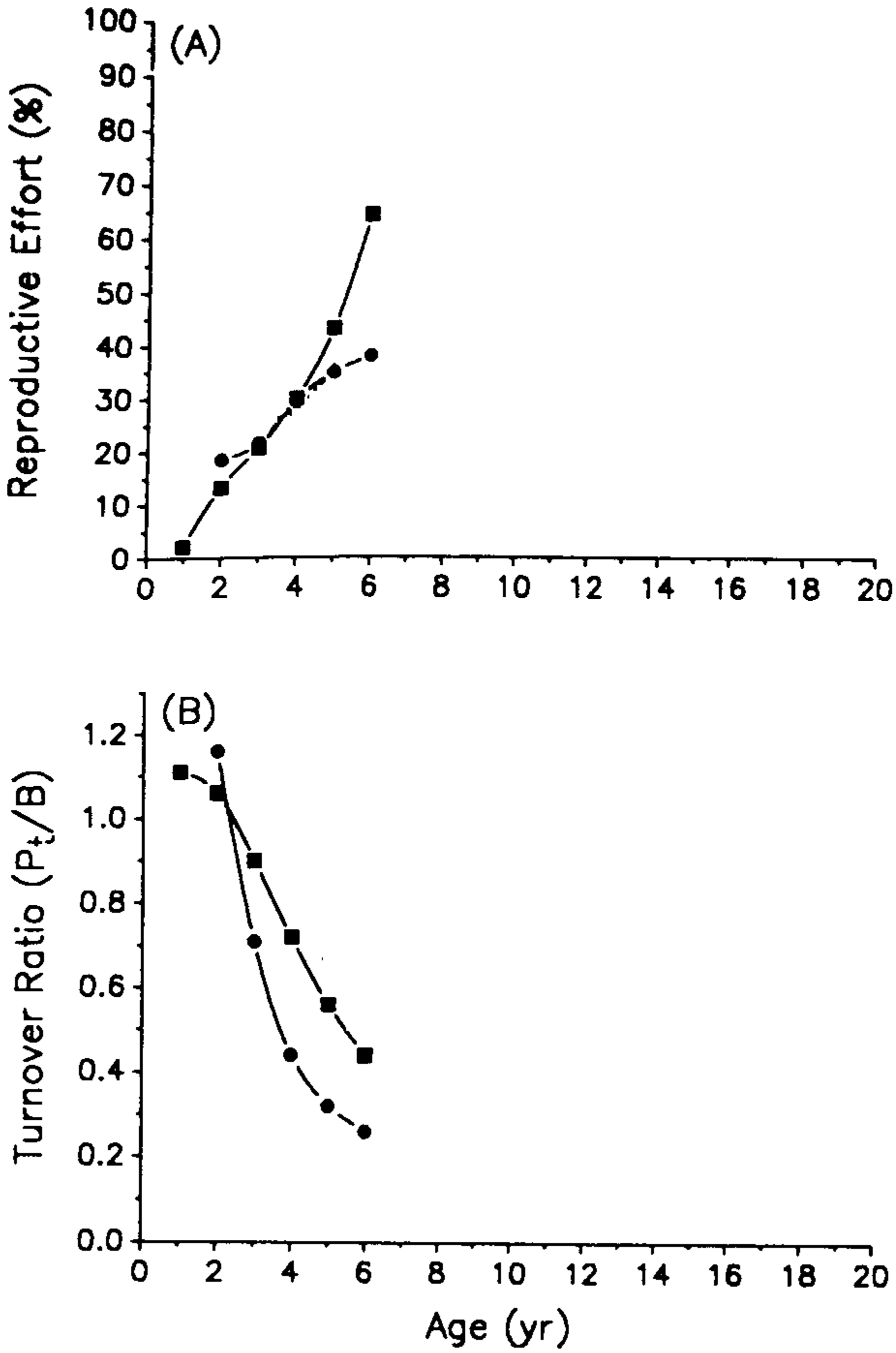

Fig. 6. (A) Age-specific reproductive effort in spiny scallops (■) and pink scallops (●). (B) Mean turnover ratios (($P_g + P_r + P_s$)/B) where B = somatic biomass) for each age-class in the two species.
from MacDonald *et al* 1991

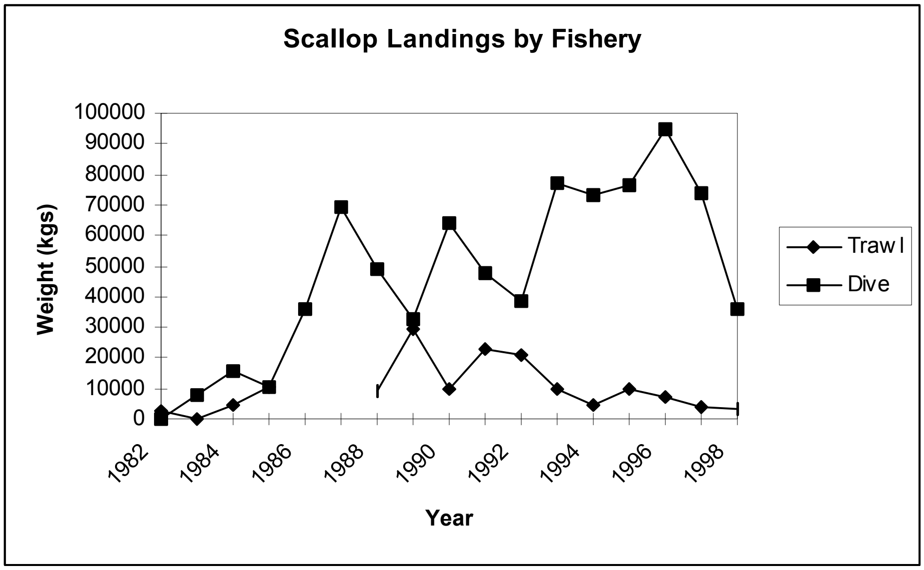

Fig. 7. Total pink and spiny scallop landings by fishery (◆- trawl; ■ - dive) from British Columbia waters

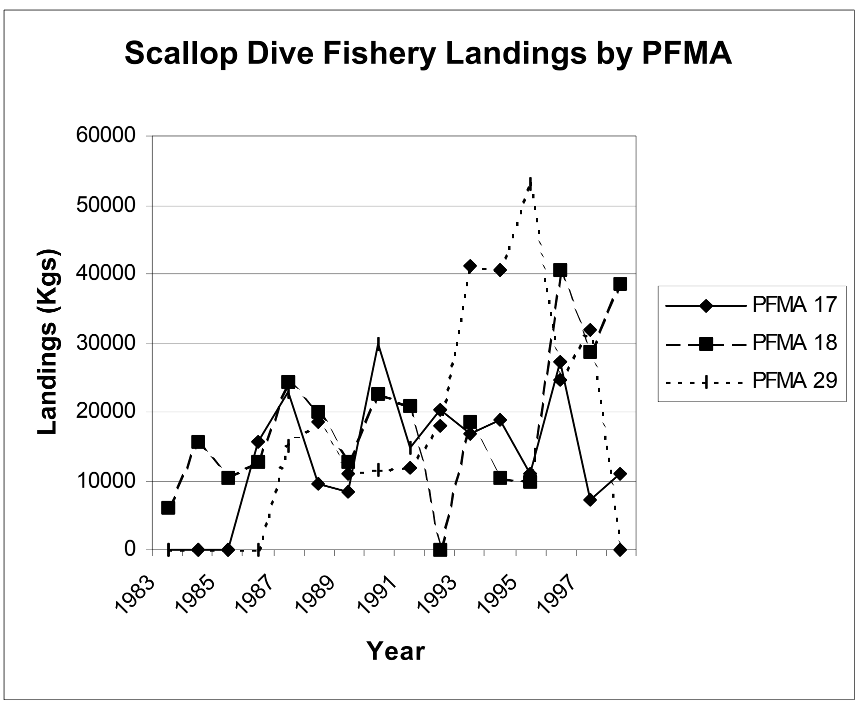

Fig. 8. Scallop dive fishery annual landings (Kgs.) by Pacific Fishery Management Area

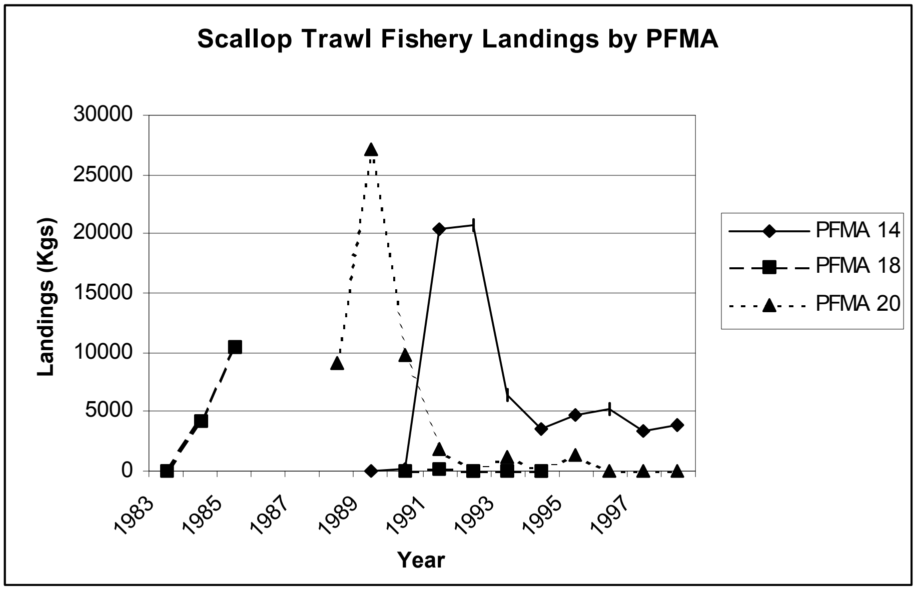

Fig. 9. Scallop trawl fishery annual landings (lbs.) by Pacific Fishery Management Area

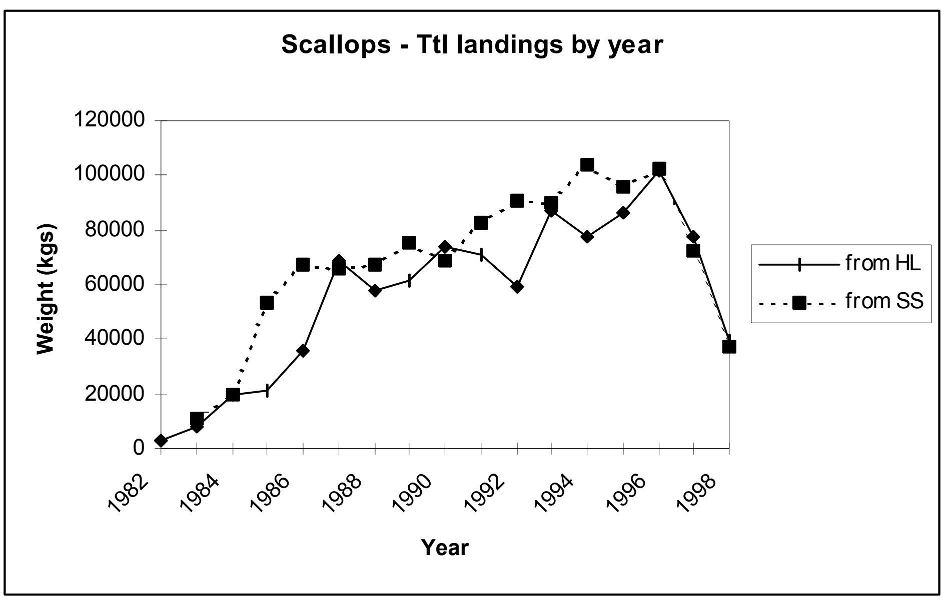

Fig. 10. Total scallop landings reported from dive and trawl fisheries by (◆) harvest logs and (■) sales slips.