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A Phase "0" Review of Elasmobranch Biology, Fisheries, Assessment and Management

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ABSTRACT

Elasmobranch catches in British Columbia (BC) averaged 550 t in the 1970s and 1980s and increased to a maximum of 1850 t in 1997. The average catch between 1998 and 2000 was 1400 t. This trend mirrors the global elasmobranch catches that have risen steadily from an average of 200 000 t in the 1940s to over 800 000 t in recent years. The increased catches reflect the growing interest in directed elasmobranch fisheries that is the result of emerging markets. Fisheries and Oceans Canada (DFO) acknowledges the need for a scientifically defensible approach to the development of new fisheries. A phased approach that is based on the precautionary principle is applied to these fisheries. The available information at each step is utilized for fine tuning management strategies and research needs. There are three steps in the process, designated as Phases 0, 1, and 2. This report is a Phase 0 study that is intended to address questions raised by managers and that will form the basis for subsequent research and management actions. The questions asked are:

1. What is known about the biology and productivity of skates and sharks that are caught in BC waters and/or other jurisdictions?
2. What is known about the biomass and stock size structure of BC skates and sharks and how does this relate to historical stock conditions?
3. What are the appropriate harvest levels, given the biology and status of skates and sharks?
4. What information is available on the bycatch and associated mortalities, of skates and sharks in other fisheries?

There are three species of ray, ten species of skate, and fourteen sharks that are present in BC waters, but only big skate (*Raja binoculata*), longnose skate (*Raja rhina*), black skate (*Bathyraja interrupta*), and sixgill shark (*Hexanchus griseus*) are regularly taken as bycatch in BC fisheries. Of these, big skate is the most important, and represents 70% of the total sorted elasmobranch catch over the past 4 years. The majority of the catches are taken in Hecate Strait. A review of the biology of elasmobranchs is presented and indicates that the largest species are the most vulnerable to exploitation. Based on this, big skate is probably the least resilient BC species.

Research needs that must be addressed for improved assessment and management are: determination of the number and geographical limits of BC elasmobranch populations, the development of aging methods for these species, and obtaining accurate life history parameters for BC elasmobranch species. It is recommended that managers take action to ensure recruitment, and to improve catch statistics. Management recommendations include: species-specific size limits, sorting and accurate reporting of catches from all fisheries, and capping skate catches at the median level of the past four years.

RÉSUMÉ

Les prises d'élasmobranches en Colombie-Britannique (C.-B.) ont été en moyenne de 550 t dans les années 1970 et 1980 et ont augmenté jusqu'à un maximum de 1 850 t en 1997. En moyenne, 1 400 t ont été capturées entre 1998 et 2000. Cette tendance est le reflet des prises globales d'élasmobranches, qui ont progressé régulièrement, passant d'une moyenne de 200 000 t dans les années 1940 à plus de 800 000 t dans les dernières années. Cette hausse des prises témoigne de l'intérêt croissant envers la pêche dirigée des élasmobranches attribuable à l'émergence de marchés. Pêches et Océans Canada (MPO) reconnaît la nécessité d'une démarche valable sur le plan scientifique pour le développement de nouvelles pêches. Une démarche progressive basée sur le principe de précaution est donc utilisée. L'information disponible à chaque étape sert à améliorer les stratégies de gestion et à cerner plus étroitement les besoins en matière de recherche. Le processus comporte trois étapes désignées comme suit : 0, 1 et 2. Le présent rapport est une étude de l'étape 0 qui vise à répondre aux questions soulevées par les gestionnaires et qui servira de base aux recherches et aux mesures de gestion subséquentes. Les questions sont les suivantes :

1. Que sait-on de la biologie et de la productivité des raies et des requins qui sont capturés dans les eaux de la C.-B. ou d'autres régions?
2. Que sait-on de la biomasse et de la structure par taille des stocks de raies et de requins de la C.-B. et du rapport entre ces éléments et les conditions historiques des stocks?
3. Quels sont les niveaux de récolte appropriés, compte tenu de la biologie et de l'état des raies et des requins?
4. De quelle information dispose-t-on sur les prises accessoires et les taux de mortalité connexes des raies et des requins dans les autres pêches?

Il y a trois espèces de raies, dix espèces de pocheteaux et quatorze espèces de requins dans les eaux de la C.-B., mais seuls la raie biocellée (*Raja binoculata*), le pocheteau long-nez (*Raja rhina*), la raie à queue rude (*Bathyraja interrupta*) et le requin griset (*Hexanchus griseus*) font régulièrement partie des prises accessoires des pêches de la C.-B. De ces espèces, la raie biocellée est celle qui est capturée le plus souvent; elle représente 70 % des prises totales d'élasmobranches des 4 dernières années. La majorité des prises sont effectuées dans le détroit d'Hécate. L'examen de la biologie des élasmobranches qui est présenté révèle que les espèces les plus grosses sont les plus vulnérables à l'exploitation. Ainsi, la raie biocellée est probablement l'espèce la moins résiliente de la C.-B.

Les besoins à combler en matière de recherche pour améliorer l'évaluation et la gestion sont les suivants : détermination du nombre et de l'aire de distribution géographique des populations d'élasmobranches de la C.-B., élaboration de méthodes de détermination de l'âge pour ces espèces et obtention de paramètres exacts du cycle biologique des espèces d'élasmobranches de la C.-B. Les gestionnaires devraient prendre des mesures pour assurer le recrutement et améliorer les statistiques relatives aux prises. Les recommandations à cet égard sont les suivantes : limites de taille en fonction de l'espèce, tri et déclaration exacte des prises de toutes les pêches et limite des prises de raies au niveau moyen des quatre dernières années.

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1.0 INTRODUCTION

Since 1996, annual world catches of chondrichthyan fishes have exceeded 800 000 t. This represents 1% of the global fish catch (Bonfil 1994), and continues to increase (Frisk et al. 2001). A small proportion of the catch is composed of ratfish, and the remainder is elasmobranchs, split evenly between sharks and batoid fishes (Anon. 1996). In recent years, shark products (particularly fins) have increased in value. Imports of shark fins to Hong Kong, the centre of world trade for this product, rose 123% between 1980 and 1995 (Phipps 1996). A large proportion of the catch goes unreported, because the carcasses are often discarded at sea after fins are removed, the landings are generally bycatch, and a large portion of the catches occur in countries that lack fisheries monitoring programs (Stevens et al. 2000). The problem is compounded by the migratory nature of many elasmobranch species, which places them outside the jurisdiction of any country and of any international fisheries management organization (Stevens et al. 2000). The end result is that probably less than half of the global elasmobranch catch is reported (Bonfil 1994).

Close to 125 countries are involved in the shark fishery and trade, but only Australia, Canada, New Zealand, South Africa and the United States have instituted management plans for their fisheries (Camhi 1998). In spite of the concerns over the effects of fishing on elasmobranch populations that have developed on an international level, there is no management plan for sharks in international waters. The United Nations Food and Agriculture Organization (FAO), along with other international agencies, such as the International Council for the Exploration of the Sea (ICES) and the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) have prepared action plans regarding the conservation and management of the worlds shark populations (Stevens et al. 2000). FAO developed the International Plan of Action for Conservation and Management of Sharks (IPOA-SHARKS) in 1998.

This report represents the first step taken by Fisheries and Oceans Canada (DFO) to assess elasmobranch populations off the west coast of Canada. A synthesis of the current information on the biology, fisheries, assessment and management of elasmobranchs worldwide is provided and will be a useful guide for elasmobranch management requirements.

The impetus for this report is the recent increase in skate catches in Hecate Strait. Catches of British Columbia elasmobranchs accelerated in the early 1990s, in part the result of emerging markets. Due to a lack of information, no catch limits have been imposed for British Columbia skates or sharks, with the exception of dogfish. DFO acknowledges the need for a scientifically defensible approach to the development of new fisheries. A phased approach that is based on the precautionary principle is applied to developing fisheries (Perry et al. 1999). The available information at each step is utilized for fine tuning management strategies and research needs. There are three steps in the process, designated as Phases 0, 1, and 2.

This report is a Phase 0 study intended to address questions raised by managers as well as form the basis for subsequent research and management actions. The questions asked are:

1. What is known about the biology and productivity of skates and sharks that are caught in BC waters and/or other jurisdictions?
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2.0 BIOLOGY AND LIFE HISTORY

2.1 Chondrichthyes Classification and Common Biology

Chondrichthyan fishes are highly diverse and are characterized by cartilaginous skeletons, hard teeth and well developed jaws (Hart 1973). Their taxonomy is the subject of some dispute. Nelson (1984) divided the Class Chondrichthyes into two Subclasses: the Elasmobranchii, which includes sharks, skates, and rays - fishes that have an upper jaw that is not fused to the braincase and separate slit-like gill openings, and the Holocephali, which includes the chimaeras and ratfish - fishes that have an upper jaw that is fused to the braincase and a flap of skin, the operculum, that covers the single gill slit. Robins et al. (1991) combined elasmobranchs and holocephalians in a single class, the Elasmobranchiomorphi. Eschmeyer (1990) raised the two taxa to full classes, the Elasmobranchii and Holocephali. Our review follows Eschmeyer (1990).

There are 700-800 species of elasmobranch fishes worldwide, and at least half of these species are skates and rays. The skates (Order Rajiformes, Family Rajidae) are the most speciose and are often extremely abundant (Moyle and Cech 2000). In spite of their species diversity, rajids are morphologically conservative, and this poses taxonomic problems (McEachran and Dunn 1998). Skates are unique among the elasmobranchs in their ubiquity, their high species diversity, the fact that they are entirely marine in habit, and because of the restricted ranges of individual species (McEachran and Miyake 1990). Skates are present along the continental shelf and margins of all the worlds oceans but they are not found below 3000m or over hard bottoms. Skates and rays have common adaptations for their benthic habit which are characterized by a dorso-ventrally flat body, ventral gill openings, enlarged pectoral fins attached to the side of the head, no anal fin, and eyes on top of the head (Hart 1973).

Generalizations regarding sharks are difficult to make. Sharks cover a wide spectrum of sizes, ranging from 16cm (the dwarf dogshark, *Etmopterus perryi*) to over 18m (the whale shark, *Rhiniodon spp.*). Additional variety is found in distribution, shape (e.g. the hammerhead, *Sphyrna spp*.), and diet. Sharks such as the white shark (*Carcharodon carcharias*) and the tiger shark (*Galeocerdo cuvieri*) are top predators in the ocean, while others such as the basking shark (*Cetorhinus maximus*) are planktivores (Moyle and Cech, 2000). Most sharks are ectothermic (body temperature dependent on environmental temperature), but some such as members of the Lamniformes are endothermic (generate and maintain their body heat). Sharks are also diverse in terms of dispersal and migration

(Hoenig and Gruber, 1990). Some adult sharks undertake trans-Atlantic and trans-Pacific migrations, while the range of young lemon sharks (*Negaprion brevirostris*) is restricted to about a mile during the first years of life (Gruber et al. 1988). Sharks are long lived fishes. Some of the reported ages are 80+ years for dogfish (*Squalus acanthias*) (McFarlane and Beamish 1987), 43 years for school shark (*G. australis*) (Anon. 1976), and 30 years for lemon sharks (Hoenig 1979). Interestingly, the oldest ages are reported for the smallest sharks (Hoenig and Gruber 1990). The maximum age of the batoid fishes is also high, for example, the maximum age of the bat ray (*Myliobatis californica*) was estimated at 23 years (Martin and Cailliett 1988).

Chondrichthyes are distant relatives of the Osteichthyes, and as such they developed independent adaptations to the marine environment (Moyle and Cech 2000). Specialized characteristics include those related to: (1) buoyancy (oil-filled liver, cartilaginous skeleton, benthic habit); (2) respiration (spiracles, a two-pump respiratory system, constant swimming); (3) placoid scales of one form or another (which increase hydrodynamic efficiency); (4) feeding (distinctive, specialized teeth which are continually shed and replaced, and loose jaws that increase the gape size); (5) mobility (in sharks the heterocercal tail is well adapted for propulsion, steering and stability); and (6) sensory organs and osmoregulation (well developed eyes and sense of smell and efficient osmoregulatory system which enables sharks to adapt quickly to freshwater).

Perhaps the most important difference between the bony and cartilaginous fishes is the reproductive strategy. All chondrichthyans are iteroparous (reproducing more than once) and all produce large young (Hoenig and Gruber 1990). Teleosts rely on specific events or ocean conditions and high fecundity to yield high recruitment, while chondrichthyans rely on long gestation periods (in the live-bearing forms), high survival at all stages, and longevity after maturity (Frisk et al. 2001). The energy expended during reproduction is allocated to a small number of large, active young (Moyle and Cech 2000), meaning that the resulting relationship between stock and recruitment is tight. Therefore, the focus of studies on chondrichthyan reproduction should include the regulating factors of female fecundity (Holden 1977). All elasmobranchs produce relatively few young, but the timing of production varies between species. Skates can produce young throughout the year, while sharks produce young once or twice a year or every second year (Hoenig and Gruber 1990).

A variety of forms of reproduction are observed in the elasmobranchs. Close to half of the species are oviparous (egg laying) – included here are all the skates, all chimaeras, and many sharks. Viviparity, or live bearing, is observed in a variety of forms, for example, ovoviviparity, in which a yolk-sac sustains the embryo that is eventually born live in shallow, protected waters. This form is employed by the Mylobatiformes (the stingrays); while placental-like viviparity, in which all the nutrients for the developing embryos are provided via a placental-like set up, is found in the Carchariniformes (cat sharks and requiem sharks) (Moyle and Cech 2000). Oviparity is considered to be the most primitive form, while placental-like viviparity is considered to be the most advanced, as it is most similar to mammals (Wourms 1993). Viviparity is considered to be an evolutionary advantage in that the young are born at a large size and are better able to obtain food and have few predators (Moyle and Cech 2000).

2.2 Elasmobranch Population Dynamics

Incidental catches of elasmobranchs in fisheries targeting teleosts were (and still are) seldom sorted and recorded (Holden 1977). The recent call for assessment and management of the world's elasmobranch populations has come after years of exploitation, when many stocks are considered to be declining or are maintained at low levels. The immediate challenge facing fisheries scientists is to adapt traditional stock assessment theories and methods for elasmobranchs, and to obtain life history information necessary for their assessment.

2.2.1 Age determination

Accurate estimates of age are required in order to make appropriate management decisions (McFarlane and Beamish 1987). Age is required for describing growth rates, longevity, cohort structure, and the timing of important life stages such as maturity, migration, etc., all of which are important for stock assessment (Gallagher and Nolan 1999). Hoff and Musick (1990) pointed to the lack of age and growth information as a limiting factor in the development of a shark management plan.

Age of elasmobranchs has been estimated using indirect methods such as length-frequency analysis, however, the majority of studies are now focused on determining age from skeletal structures. For example, annuli on the second dorsal spine have been used to age dogfish (*Squalus acanthias*) (Ketchen 1975; McFarlane and Beamish 1987). When length frequency methods are used for age determination, it is most often in conjunction with a more direct method.

Vertebral centra have been used to age a variety of elasmobranch species (Martin and Cailliet 1988), including: big skate (*Raja binoculata*) and longnose skate (*Raja rhina*) (Zeiner and Wolf 1993), bat ray (*Myliobatis californica*) (Martin and Cailliet 1988), lemon shark (*Negaprion brevirostris*) (Brown and Gruber 1988), brown and grey smoothhound sharks (*Mustelus henlei* and *M. californicus*) (Yudin and Cailliet 1990), spinner shark (*Carcharhinus brevipinna*) and tiger shark (*Galeocerdo cuvier*) (Branstetter et al. 1987).

Ageing studies require some method of verification in order to ensure that the age and growth parameters are realistic and agree with estimates obtained via size frequency analysis, back-calculations or similar methods (Cailliet 1990). Additionally, the periodicity of ring deposition must be determined if an ageing method is to be verified. Validation methods that have been used for elasmobranchs include tetracycline injections that provide a distinct mark on the aging structure (Beamish and McFarlane 1983) and radiometric dating (Welden et al. 1987).

Cailliet et al. (1983) showed that the extent of calcification in the vertebral centra of some of the deep water sharks is too poor to provide adequate growth information. The reasons might be related to their habitat - these species inhabit dark, cold, deep water which may be low in calcium, or to the fact that they are from relatively primitive families (Cailliet

1990). Alternate structures have been identified as possible sources of age estimates. A recent study by McFarlane et al. (*In press*) showed distinct bands on the neural arches of sixgill sharks. The bands appeared to be regularly deposited, and the number of bands increased with the size of the shark. McFarlane et al. (*In press*) note that although more research into the method is required, these results point to the potential for neural arches to be used to age deepwater and primitive elasmobranch species. The potential for aging skates and rays using caudal thorns was recently identified by Gallagher and Nolan (1999). Similar to dorsal fin spines, caudal thorns are modified placoid scales that serve a defensive purpose, and they are securely anchored within the caudal tissue.

3.0 FISHERIES

3.1 Global Catch Statistics

Recent increases in demand for shark products (including fins) and sport fisheries for a number of species have contributed to the current increases in global catches of elasmobranchs. The official catch statistics of many countries comprise records from directed fisheries and incidental catches from multispecies fisheries. However, Bonfil (1994) points out that in many fisheries, elasmobranch catches are discarded and seldom reported. The official FAO catch statistics therefore only approximate the catch from many countries. Data used in this section were obtained from the FAO statistical database that is available online at www.fao.org and that is currently updated to 1999. Statistics are reported in FAO database as “sharks, skates, rays, and chimaeras” but for the purpose of this report, and because catches of chimaeras are minimal (Anon. 1996), they are grouped together as elasmobranchs.

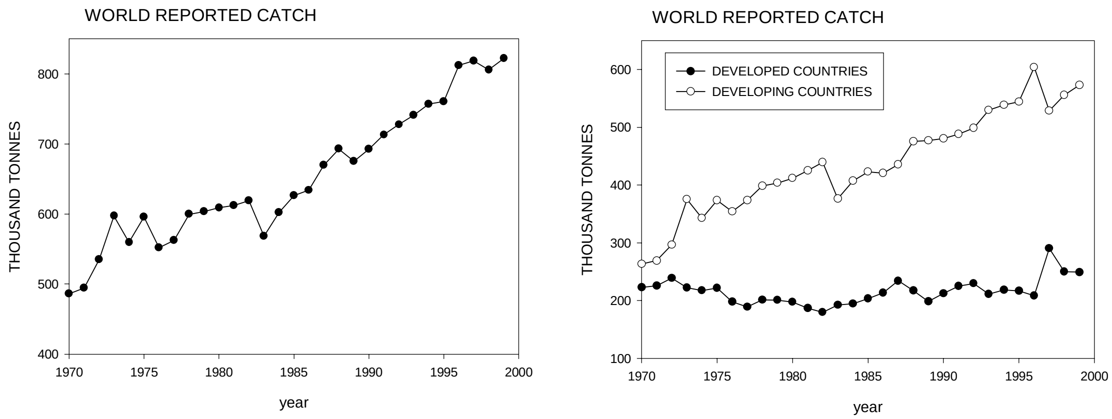

Figure 1 World reported elasmobranch catch 1970-1999.
(Data from FAO fishery catch database).

Bonfil (1994) identified four periods of trends in world elasmobranch catch. The catch grew slowly from an average of 200 000t to just under 300 000 t between 1947 and 1954, increased to approximately 580 000 t between 1955-1973, and slowed again for most of the 1970s with catches averaging approximately 600 000 t. A period of rapid growth began in the 1980s and continues to the present day (Figure 1). The dramatic increase in catches can be attributed to fisheries in developing countries. Of the major shark fishing countries (ones that harvest over 10 000 t/yr) Japan, Indonesia, India, Taiwan, and Pakistan have the highest catches, with yearly records ranging between 36 000 t and 116 000 t in 1999, the latter value is from Indonesia, where annual catches have soared from 10 100 t in 1970. There is no sign of a slowdown. Catches from Japan, once the largest fishing nation, have declined from 62 000 t in 1970 to 36 000 t in 1999. Within Europe, France, the UK and Norway were traditionally the major fishing countries with annual yields ranging between 21 000 t and 27 000 t (Bonfil 1994). Recently, catches have declined, totaling 23 000 t, 17 500 t, and 2 300 t for each respective country in 1999. The USA, Australia, and New Zealand are part of a group of major fishing countries that traditionally yielded the lowest catches (between 4000 and 10 000 t/yr (Bonfil 1994), but catches in 1999 were reported at 38 000 t, 10 200 t, and 19 810 t, respectively. Including Canada, these countries are the only ones that have management plans for their fisheries (Camhi 1998).

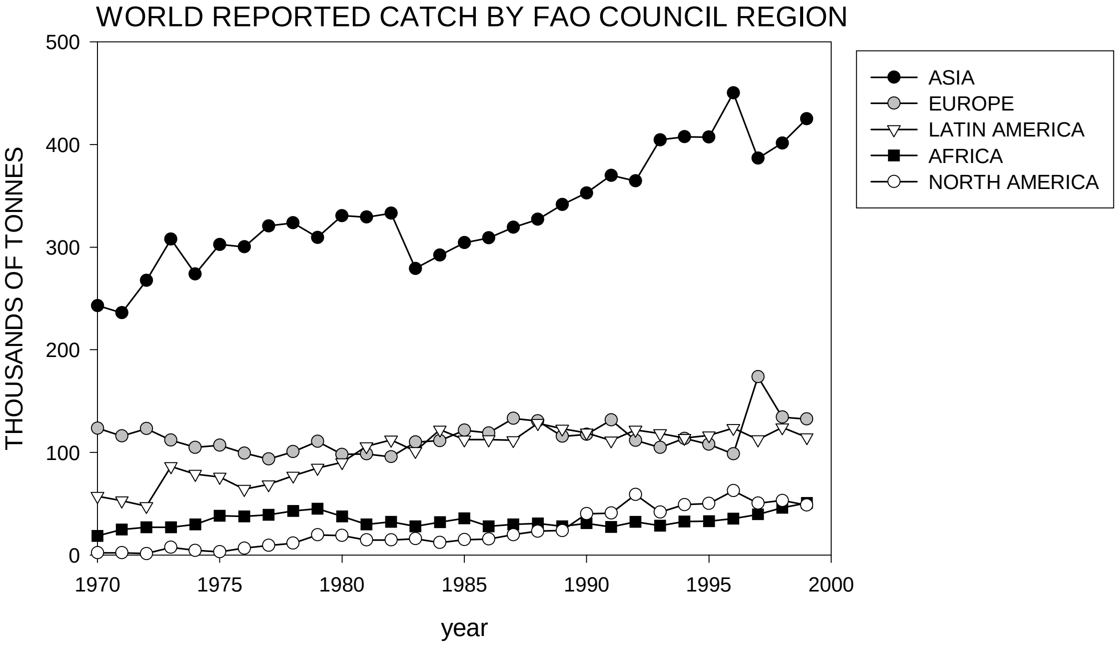

Figure 2 World reported elasmobranch catch by the FAO council regions 1970-1999. (Data from FAO fishery catch database). Catches are shown for the regions that catch the most elasmobranchs, catches from the Southwest Pacific, Near East, and “other” are not shown.

An increasing trend in catches is most evident in the Asian countries for the 1990s (Figure 2). North American catches show the same trend, although on a much smaller scale. With the exception of the last 4 years, European catches appear to have leveled off, as have those in Latin America and Africa. This may indicate that these fisheries are being exploited at maximum levels, and no further growth should be expected (Bonfil

1994). Elasmobranch species in the families Carcharhinidae (requiem sharks), Rajidae (skates), and Squalidae (dogfish) are the most important to fisheries. Catch trends for the Carcharhinidae and Rajidae are shown in Figures 3 and 4 respectively; dogfish (Squalidae) are not the focus of the present review. North America is not a major region of Carcharhinid shark catch, but has become a major skate fishing region over the past 10 years.

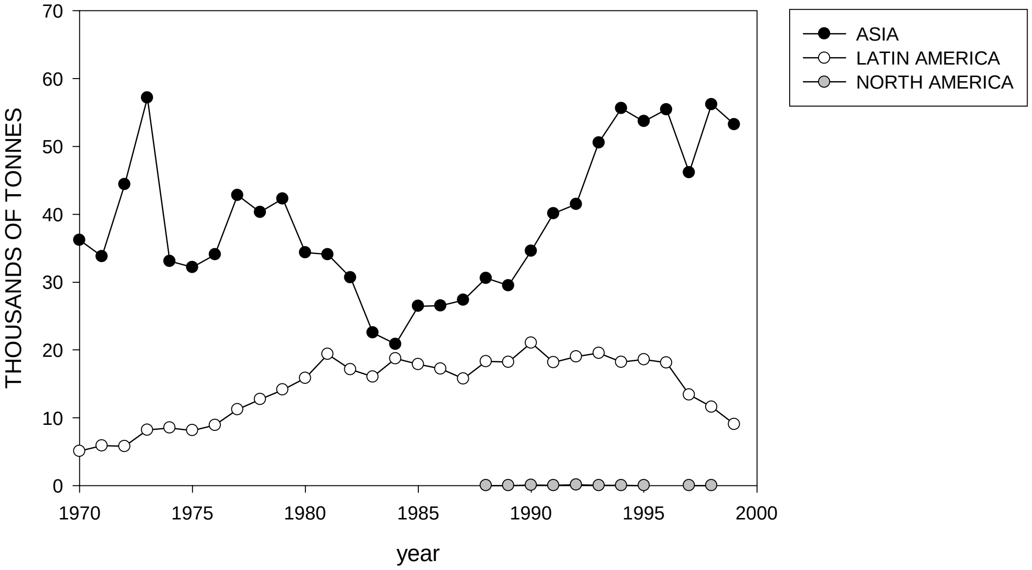

Figure 3 Carcharhinid shark catches by major fishing region from 1970-1999.
North American catches shown for comparison. (Data from FAO fishery catch database).

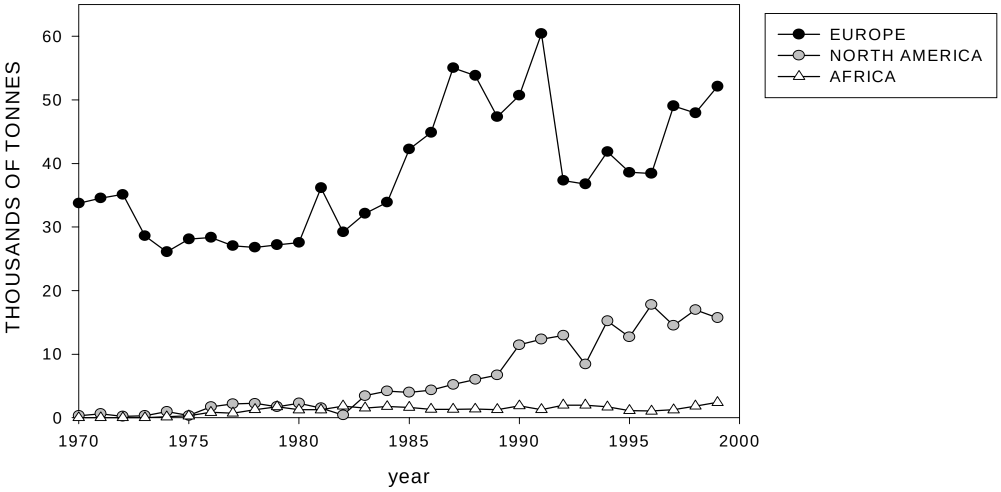

Figure 4 Rajidae catches for the major fishing regions from 1970-1999.
(Data from FAO fishery catch database).

Sharks and skates are the target of recreational as well as large scale industrial and artisanal (non-industrial) fisheries. Walker (1998) notes that the distinction between industrial and non-industrial fisheries is not well defined because some artisanal fisheries employ spears, canoes and row boats, while others such as the Mexican subsistence shark fishery use powerboats and fish using gillnets and longline (Holts et al. 1998). In recent years the vessel size in many artisanal fisheries has increased, and this represents a gradual transition to more industrialized methods (Walker 1998). Large scale fisheries use mainly driftnets (Holts 1988), gillnets (Francis 1998), longline (Hurley, 1998), and trawl gear (Dulvy et al. 2000). The large scale fisheries are generally multispecies fisheries, such as the California drift gillnet fishery for pelagic sharks (thresher, mako, blue shark) and swordfish (Hanan et al. 1993) and the Falkland Islands skate and ray fishery (Agnew et al. 2000). These fisheries occur along the coast and continental margins of the world, and the species involved appear to be the most heavily exploited (Walker 1998). Large scale, high seas fisheries also take a substantial incidental catch of elasmobranchs, particularly blue sharks (ca. 6.5 million caught per year) (Bonfil 1994). Catch, discard, and mortality rates in these fisheries are unknown, but are assumed to be high, with discards estimated at approximately 250 000 t annually.

Due to extensive coverage in international waters, the largest source of shark mortality on the high seas is longline gear. Drift gillnet fisheries were ranked second in terms of catch prior to being phased out in 1992 because of large catches of non-target species. Other high seas fisheries include the tuna purse seine, pole and line, and the Australian orange roughy deepwater trawl fishery, all of which catch relatively minor amounts of elasmobranchs (Bonfil 1994).

4.0 STOCK ASSESSMENT

4.1 Stock Assessment Models

Early elasmobranch stock assessment methods were developed during periods in which targeted fisheries were rare, and where catches were seldom sorted by species. Because of these problems, the assessment methods developed around a minimum of data. A method to quickly assess the ability of an elasmobranch stock to withstand exploitation was developed by Holden (1974), who calculated the relationship between the rate of reproduction and the total mortality rate (Z) at which constant recruitment will be maintained:

$$Z = xe^{(-Z'tm)}$$

where x is the average number of female young produced per female, and t_m is the mean age at maturity. Brander (1981) modified the expression to:

$$Z_m = xe^{(-Zi\ tm)}$$

in order to demonstrate the distinction in the mortality rates between mature fish (Z_m) and immature fish (Z_i), and to show that the rate of recruitment is determined as much by fecundity as by mortality at the immature ages (Brander 1988). Walker and Hislop (1998) obtained estimates of Z using a length converted catch curve that was based on length frequency data from North Sea skate and ray species.

Species with a high Z should in theory be able to withstand high levels of exploitation because of a presumed density dependent response in fecundity (Holden 1977). If females in a stock can be shown to have reached their maximum fecundity at a given Z, then this value can be taken as the maximum mortality rate the stock can withstand if it is to remain at equilibrium (replacement mortality). Brander (1981) and Walker and Hislop (1998) presented estimates of replacement mortality for several skate and ray species. The results of both studies show that the mortality is largely dependent on the age at maturity. For example, *Raja clavata*, a species that matures around age 8, could sustain a Z between 0.45 and $0.55 \cdot \text{year}^{-1}$, while *Raja batis*, which matures around age 11, can withstand a much lower Z of $0.35 \cdot \text{year}^{-1}$. Holden (1977) pointed out that the method is problematic in that Z is the average total mortality over the life span, and therefore provides no guidance regarding the fishing mortality or exploitation rate that the population can withstand.

4.1.1 Surplus Production Models

Surplus production models (e.g. Shaefer and Gulland biomass models) have been applied to elasmobranch stocks with little success (Holden 1977, Anderson 1980, Anderson 1990). The data requirements are minimal: catch, stock biomass and fishing effort, however, the assumptions of the methods mean that they can not be applied with any confidence to most elasmobranch fisheries (Anderson 1990). The assumptions are that the CPUE is reliable, the catches are from a unit stock, there are no time lags operating in the system (i.e. biomass regeneration occurs at the same time as fishing), and the age composition does not affect production. Holden (1977) applied the models to dogfish catch statistics and found that surplus production models did not accurately describe the history of the fishery because the slow reproductive cycle of dogfish (and all elasmobranchs) means that there are considerable lags in the system. Additionally, surplus production models are likely inappropriate for the assessment of elasmobranchs because density dependent growth and fecundity responses may be absent (Musick et al., 2000) and because CPUE is likely to be unreliable due to non-reporting of catches.

The 1993 U.S. Fisheries Management Plan (FMP) for sharks of the Atlantic Ocean was a mixed species assessment based on a modified surplus production model based on four years of data (Cortez 1998). The FMP grossly overestimated (by approximately 30%) the fishing mortality that large coastal sharks such as lemon and sandbar sharks could withstand. According to Cortez (1998), this was because the biology of the individual species was not incorporated, and therefore the analysis did not account for differential productivity and life histories between species.

4.1.2 Age Structured Models

Age structured models incorporate biological information such as growth, mortality, and recruitment in population assessment. These types of models have been applied with some success to marine mammal populations, and because of similar life history strategies, they may also be appropriate for elasmobranch assessment (Anderson 1990). The early versions of these models provided little more information than MSY, but later versions were more complex and allowed for an examination of the internal dynamics of the stock (Anderson 1990).

Demographic methods are fully age structured models that make extensive use of the available biological data on age, growth, fecundity, and mortality (Cortes 1998). Demographic analyses have been used for lemon shark (*Negaprion brevirostris*) (Hoenig and Gruber 1990), sandbar shark (*Carcharhinus plumbeus*) (Hoff 1990; Sminkey and Musick 1996; Cortes 1999), school shark (*Galeorhinus galeus*) (Punt and Walker 1998), skates and rays in the North Sea (Walker and Hislop 1998), and dusky shark (*Carcharhinus obscurus*) (Simpfendorfer 1999a). The advantage to these models is that they provide detailed information on the effect of exploitation on population growth, they allow for species-specific assessment, and also for an examination of the effects that life history traits have on the response to fishing (Sminkey and Musick 1996). Additionally, they can help to prioritize research by identifying the parameters (e.g. natural mortality or age at maturity) that produce the most uncertainty in the results (Anderson 1990; Simpfendorfer 1999a).

Traditional demographic studies are limited in that they are deterministic and do not provide for the inclusion of a density dependent recruitment response or emigration and immigration. (Cortes 1998; Simpfendorfer 1999a). In an attempt to better apply age structured models to shark fisheries, researchers have made improvements such as using the model along with tagging data to obtain age-specific exploitation rates (Simpfendorfer 1999a), incorporating stochasticity in the vital rates (fecundity, mortality) used in the model (Cortes 1999), and using a Bayesian estimation approach to determine prior 'realistic' distributions for life history parameters, that may not be realistically estimated using maximum likelihood methods (Punt and Walker 1998). A further benefit of the Bayesian approach is that the assessment includes an estimation of the level of risk associated with various levels of fishing.

The single largest limiting factor in the use of species-specific, age structured models in assessing elasmobranch stocks is the lack of appropriate data. Problems such as non-reporting of catches, unsorted catches, and low research priorities of elasmobranchs preclude the use of detailed models for most elasmobranch species (Hoenig and Gruber 1990). An additional problem is that most elasmobranchs are caught as bycatch. Traditional fisheries statistics such as catch per unit effort (CPUE) are seldom appropriate for the analysis of bycatch species, because catch and effort can be affected by complex stock structuring and by fishers targeting different species (Holden 1977; Holts et al. 1998; Walker 1998). What is required for accurate assessment is a simple approach to monitoring stocks that can be applied to individual species as well as larger species groups.

4.2 Life History Studies

The mandate for fast and effective management of elasmobranch populations exists in spite of the absence of large amounts of data and resources. Faced with these limitations, and the low probability of extensive study of all elasmobranch species, fisheries scientists must determine a species' ability to withstand exploitation within a comparative framework. The study of life history strategies can prove useful in this regard, and in providing the baseline data for the demographic models discussed above. "Life history" refers to the patterns of growth, maturation, and reproduction, and to the longevity of a species (Beverton 1992). The theory centers around trade offs between demographic traits (how fast a population can grow and the generation time of a population) and reproductive traits (physiological limitations to fecundity and behaviors such as parental care), while the interest for management lies in the performance of a population in response to perturbations such as fishing. These responses are governed by life history traits (Winemiller and Rose 1992). Further, evidence is mounting that the relationships between life history and population dynamics can be used to prioritize species for conservation (Jennings et al. 1998).

The life history traits of small, fast growing fish differ from those of large, slow growing species. Beverton (1963) noted that a tradeoff exists between growth and mortality such that species that grow quickly toward their maximum size tend to die at younger ages than slow growing species, and that, in order to ensure reproductive success, a short lived species must reach maturity at a young age. The "slow" and "fast" types of life history strategies are observed in all terrestrial and marine phyla. Species are classified as either "r-selected" or "K-selected" based on their life history parameters, where r (the per capita rate of population increase) and K (carrying capacity) are parameters in the familiar logistic growth model: $dN/dt = rN((K-N)/K)$. In this model growth, recruitment, and natural mortality are summed up in a single measure (r). r-strategists are selected for extreme and highly variable conditions. They exhibit fast growth, high fecundity, small size, and high rates of natural mortality, while K-selected species are long lived, of large size, low natural mortality, and low fecundity (Wilson and Bossert 1971). This classification can be useful for making general predictions regarding a species' response to exploitation. Due to their "fast" life histories, r-selected fish species are able to recover faster and sustain higher yields than K-selected species (Adams 1980). Elasmobranchs are generally K-selected, and like other long-lived marine animals such as turtles and whales, they have a poor record of sustainable harvest (Stevens 1999). Long lived species require careful management, because once depleted, the populations can take decades to recover (Musick 1999a).

The slow life history strategy of sharks, skates and rays has worked well for millennia, but the accumulating evidence indicates that it may become their undoing when faced with the recent (evolutionarily speaking) introduction of predation in the form of fisheries. Many elasmobranchs stocks worldwide have collapsed under unsustainable levels of harvest (Moyle and Cech 2000). However, according to Walker (1998) the poor track record does not mean that the harvest of shark resources should be avoided entirely because recent studies have shown otherwise.

In spite of their common life-history patterns, all elasmobranch species do not exhibit the same response to exploitation. For example, the school shark (*Galeorhinus galeus*) and the gummy shark (*Mustelus antarcticus*), both members of the Triakidae, are taken in the Australian southern shark fishery, and as such, both are exposed to the same fishing regime (Stevens 1999). Recent stock assessments indicate that the catches of gummy shark are sustainable while the school shark is overfished (Caton et al. 1997, in Stevens 1999). In the North Sea, a change in species composition of the skate and ray populations has occurred since 1930 in response to fishing. Species such as the common skate (*Raja batis*) and the thornback ray (*R. clavata*) have decreased in abundance and have been replaced by starry ray (*R. radiata*) and cuckoo ray (*R. naevus*) (Walker and Hislop 1998). On the eastern Canadian continental shelf, the barndoor skate (*Raja laevis*), once one of the most numerous species (estimated at 0.6 million individuals in the 1950s), decreased to just 500 individuals in the 1970s as the result of large catches in the trawl fishery (Casey and Myers 1998). Over the same period of time, thorny skate (*R. radiata*) and smooth skate (*R. senta*) increased in abundance.

Why would one species be able to withstand exploitation while a similar species can not? First, gear selectivity and the ability to survive in the fishing gear differ between species. Demersal species such as the skates and rays are more vulnerable to bottom trawling than are the pelagic sharks (members of the Carchariniformes and Lamniformes), which are highly vulnerable to gillnets and hooks (Walker 1998). Additionally, the ability to survive in the gear (when caught as bycatch) is closely linked to anatomy and behavior. Fast swimming species such as the tope shark (*Galeorhinus galeus*) need to keep swimming in order to breathe. Therefore, when caught in fixed gear, they tend to die more quickly than species with well developed spiracles, which can better ventilate their gills (Walker 1998).

In addition to species-specific vulnerability to fishing gear, biological attributes and life history patterns vary between species, and govern the response to exploitation. For example, in the Australian southern shark fishery discussed above, the vulnerability of gummy shark and school shark to the fishing gear is similar, but the gummy shark is more productive and is therefore more resilient to exploitation. The gummy shark reaches maturity at 4-5yr, lives up to 16yr, gives birth every year, and the average litter size is 14 pups, but can be as high as 40 pups, depending on the size of the female (Walker 1992). School sharks reach maturity at 8-10yr (Moulton et al. 1992), live as long as 60yr, give birth every 2-3 yr, and the litter size averages 30 pups. Similar differences are observed in the skates and rays of the North Sea, which exhibit considerable variability in their total size and age and length at maturity (Holden 1975). It is this variety that accounts for the different response to exploitation in the rajid community.

Walker and Hislop (1998) noted that in the North Sea, the largest species of skates and rays were replaced by smaller species after 20 years of fishing. The smaller species fared better than the larger species because they grow faster and are therefore able to sustain a higher fishing pressure (Jennings et al. 1998) and/or because they are less vulnerable to size-selective fishing gear (Jennings et al. 1999). Similarly, on the eastern Canadian continental shelf, the smaller skate species increased in abundance while the large barndoor skate declined (Casey and Myers 1998).

The response to exploitation can also vary between populations or subpopulations of the same species. Between the 1950s and 1970s, barndoor skate was driven to near extinction in several areas on the continental shelf (Casey and Myers 1998). Today, small numbers of barndoor skate are present only in deep water (a refuge from the trawl fishery) and on Browns Bank and Georges Bank, which are on average 6°C warmer than the northern areas of the continental shelf. The warmer temperatures are likely associated with faster growth rates which may be a factor in the survival of barndoor skates in this region (Casey and Myers 1998).

The r- and K-selection classification can provide some insight into the potential response of a species to exploitation, however, due to the variety of responses observed in the K-selected elasmobranchs, a more accurate method is required in order to assess the risk of depletion in response to exploitation.

4.2.1 Resilience to Exploitation

Certain life history traits have been identified as indicators of resilience to exploitation. According to Pratt and Casey (1990), the calculations of population age structure and von Bertalanffy growth coefficient k are central to understanding the response of a population to exploitation. k has been used as an indicator of vulnerability in a variety of marine animals. Musick (1999b) notes that fish, turtles and elasmobranch species with a k value at or below 0.1 exhibit extreme vulnerability to exploitation. k provides a measure of the potential yield in a population (a high rate of increase in the somatic tissue of an individual fish, averaged over an entire population indicates high production), and can also provide information on other life history parameters. Beverton and Holt (1959) demonstrated that the growth coefficient, k, and natural mortality, M, are positively related, and therefore, k can be used as a predictor of M (Beverton 1992).

Growth data are not easily obtained for elasmobranchs, in large part due to the difficulties encountered in ageing (see previous section) and of obtaining sufficient numbers of individuals at each size and age (Pratt and Casey 1990). As a starting point, Holden (1974) modified the von Bertalanffy equation to solve for k independent of age data such that:

$$L_{t+T} - l_t = (L_\infty - l_t)(1-e^{-kT}) \quad \text{which becomes} \quad (l_{t+T})/L_{max} = 1-e^{-kT}$$

where: k = growth coefficient
l_t = length at fertilization = zero at t_o
l_{t+T} = length at birth
T = gestation time
$L_\infty \equiv L_{max}$ = maximum reported length

The fundamental assumption of Holden's (1974) method is that the growth rate *in utero* (or in the egg) is the same as that postpartum. Holden (1977) notes that the assumption can not be made for some ray species, in which embryonic growth is faster than postpartum growth. Based on the results of his analysis, Holden (1974) concluded that the k values for sharks fell between 0.1 and 0.2 and for skates and rays between 0.2 and 0.3. However, Holden (1974) lacked estimates of the gestation time. He went on to estimate it by manipulating the kT exponent so that the resultant k values fell in the predetermined range (Pratt and Casey 1990). The problems associated with Holden's method are reviewed extensively by Pratt and Casey (1990). The parameters on which the method is based - the gestation period, size at birth, size at maturity and even maximum size (more correctly the maximum *reported* size) are difficult to determine for many species. Additionally, the assumption that embryonic growth is the same as postpartum growth does not hold for many elasmobranch species. Pratt and Casey (1990) conclude that the uncertainty associated with the method indicates that it should be used with caution, and only when it can be verified with growth data.

Another means of assessing the resilience of a species to exploitation is ranking species according to the level of total mortality (Z) the population can withstand without collapse (Brander 1981; Walker and Hislop 1998). Methods of obtaining Z were described earlier in this chapter. The methods [especially those of Walker and Hislop (1998)] require extensive amounts of data for fecundity, age, and length at maturity, and growth, all of which are difficult to obtain and are available for relatively few species (Smith et al. 1998). Fecundity has also been considered an indicator of resilience. Holden (1977) noted that elasmobranchs are particularly vulnerable to fishing because of their direct stock-recruitment relationship, and that, within the elasmobranchs, the most fecund species should be able to withstand the highest rates of fishing. However, subsequent analyses have shown that fecundity is not an important indicator of response to exploitation (Heppell et al. 1999; Jennings et al. 1999).

Frisk et al. (2001) categorized the resilience to harvest of elasmobranch species based on maximum body size (L_{max} or L_{∞}) because it is related to the majority of life history parameters (Frisk et al. 2001), it is easily measured and available for most elasmobranch species (e.g. Hart 1973, Campagno 1984), and because large size has been related to vulnerability to exploitation for some elasmobranch species (Jennings et al. 1998; Walker and Hislop 1998; Dulvy et al. 2000). However, according to Stevens et al. (2000) the evidence supporting a body size-vulnerability relationship for elasmobranchs as a whole is only suggestive. The group for which there is the most evidence of a relationship is the skates (Walker and Hislop 1998; Dulvy et al. 2000). Stevens et al. (2000) propose that the reason for this may lie in the fact that they are morphologically conservative when compared to most other elasmobranch groups.

Maximum size can be used along with other life history traits to provide a basis for the comparison of life history patterns of species. Beverton and Holt (1956) showed that the proportion of the total growth span covered prior to maturation (L_{mat}/L_{∞}) is relatively invariant among fish species. The same is true for the age at maturity T_{mat} and life span T_{max} (Beverton 1963, 1992). Using the invariant L_m/L_{∞} and k/M ratios, Beverton (1992) quantified the relationship between the patterns of growth, maturity, and longevity (GML) for four orders of teleosts, which included both short lived and long lived species. More correctly, Beverton used $1/T_{max}$ as a surrogate for M, as did Beverton and Holt

(1959), because true values for M are seldom known. The values for species within a given order tend to cluster in predictable areas of the plot such that fast growing species tend to mature faster (lower L_m/L_∞) than slow growing species. Variability in the GML plot for a group can be attributed to differences in geographic location and environmental conditions experienced by a population or species (Beverton 1992). For example, for wide-ranging species, those populations that are located at the cold end of the range will not grow as fast as species in the warmer areas. A promising feature of GML plots is that they include an optimal strategy zone which indicates the size/age at which a cohort biomass is maximum, and therefore provides some harvesting guidelines. Additionally, GML plots might be used to gain insight into the resilience of little known species by comparing the plots and identifying similar species for which the response to exploitation is known. Using this method, Beverton (1992) found that the life history patterns of long-lived *Sebastes spp*. of the Pacific Ocean are similar to higher vertebrates such as the minke whale (*Balaenoptera acutorostrata*) and the African elephant (*Loxodonta africana*). A similar life history implies a similar response to exploitation.

The intrinsic rate of increase, r, was considered useful by Hoenig and Gruber (1990) for determining relative capacities to withstand exploitation among the elasmobranchs. r is the scale parameter in the logistic growth model and controls the rate of population increase from low levels to K (Wilson and Bossert 1971). High r values are associated with a fast rate of population increase. The intrinsic rate of increase is a complex function of individual body growth rates, natural mortality and reproduction (Hoenig and Gruber 1990), and is therefore a synthesis of several life history processes. Similar to other life history traits, r can provide information regarding vulnerability to exploitation, but is particularly useful in that it summarizes the response of a population to an extreme reduction in size. In a comparison of r values for cetaceans, sharks, turtles and birds, Musick (1999b) found that those species with r values less than 0.1 are extremely vulnerable to increased mortality. Hoenig and Gruber (1990) point out an additional benefit of r – it can be used to estimate the maximum sustainable yield (MSY): $MSY = rK/4$ (Ricker, 1975).

Values for r are not easily obtained. Pauly (1982) suggested the use of the regression model: $r = 0.025^{w-26}$, where w is the mean weight at maturity. More accurate estimates can be generated using fisheries data and surplus production models, and using methods such as life table and Leslie matrix analyses (Hoenig and Gruber 1990). Because of the extensive data requirements of such methods (e.g. life table analysis requires age-specific survivorship, fecundity and maturity (Heppell et al. 1999)), they are unlikely to be widely applied to elasmobranchs. Smith et al. (1998) modified the life table methodology by incorporating standard density-dependent relationships, where fecundity, survival and growth increase as a population declined. They then estimated r at a mortality level which yielded maximum sustainable yield (r_{2M}) for 26 shark species. They found that when compared to teleosts, sharks have lower productivities, and that the smaller shark species have higher r_{2M} values than larger species. The parameters used by Smith et al. (1998) were: age at maturity, maximum age, and fecundity. The maximum age was used to obtain M using Hoenig's (1983) formula ($\ln M = 1.44 - 0.982\ln(\text{max. age})$). The productivity values were strongly affected only by the age at maturity. This method may be flawed, however, as there is little supporting evidence for density dependent change in population parameters of chondrichthyan fishes (Stevens et al. 2000).

Jennings et al. (1999) obtained estimates of the potential rate of population increase *r′*, an analogue of *r* (Jennings et al. 1998) for 9 fish and 1 shark species in the North Sea, using estimates of fecundity and length and age at maturity: *r′ = (log fecundity at Lm)/Tm.* Unlike *r*, the potential rate of population increase is a function of fecundity – a doubling of fecundity will double the rate, however, Jennings et al. (1999) found no direct relationship between population decline and fecundity. Nonetheless, those species that declined during a period of intensive fishing activity had lower *r′* values. The authors note that *r′* is preferred over *r* when there are few data, because of the relatively small amount of data required in the calculation.

4.2.2 Predicting Elasmobranch Life History Parameters

Due to the considerable evidence that life history studies can help to identify species that are most threatened by exploitation, and because of strong relationships between many demographic and life history parameters, Frisk et al (2001) developed models to predict important life history parameters that are difficult to measure or have yet to be determined in elasmobranch species. They used the available data from the major oceans of the world in their analyses and found that the length and age at maturity were related to maximum length in a predictive way for the Rajidae and Carcharhinidae. Additionally, the L_{mat}/L_{max} (mean 0.73) and the T_{mat}/T_{max} (mean 0.38) ratios for elasmobranchs did not differ from the values for other fish groups (Beverton and Holt 1959; Beverton1992). It appears that elasmobranchs are selected for extreme iteroparity, living as much as 62% of their life span after maturation.

Charnov et al. (1993) found that the *M/k* ratio does not differ between fish and reptiles, which indicates that the life history patterns of the two groups are similar. Frisk et al. (2001) found that although *M* and *k* are significantly related in elasmobranchs, the ratio is significantly lower than that of fish and reptiles. The difference can be attributed to the large, long lived species, because the ratio for Rajidae is similar to fish and reptiles. Frisk et al. generated GML plots for elasmobranchs and found that skates matured later or larger than indicated by the location of the optimal yield zone, whereas the requiem sharks fell below their calculated optimum, indicating they are maturing at a smaller size than is predicted for maximum yield. These results may indicate that using GML plots to estimate potential yield is inappropriate for certain elasmobranchs.

Using the method described by Jennings et al. (1998), Frisk et al. (2001) estimated *r′* for elasmobranchs. The values ranged from lows of 0.03 and 0.04 (Angel shark, *Squatina californica,* and Pacific spiny dogfish, *Squalus acanthias*)) to a high of 0.68 (little skate, *Leucoraja erinacea*). Although the skate value is very high compared to the previous values, and suggests that little skate can withstand exploitation better than the other species, all elasmobranch values are very low when compared values for teleosts. The values for groundfish in the western Atlantic and North Sea obtained by Frisk et al. ranged between 2.08 for halibut (*Hippoglossus hippoglossus*) and 7.56 for whiting (*Merlangus merlangus*).

Frisk et al. (2001) found a significant relationship between maximum total length and *r* for elasmobranchs, which supports Hoenig and Gruber's (1990) finding of a negative relationship between *r* and adult body size. Frisk et al. (2001) additionally divided elasmobranch species into three categories based on size (0-99cm, 100-199cm, and 200+cm) and estimated r' values. The results add to the importance of body size as an indicator of vulnerability to exploitation, with an r' value of 0.41 for the smallest group and 0.21 and 0.19 for the intermediate and largest groups respectively. The smallest group includes most of the skates, rays, and dogfish, and as such, supports the previously discussed findings (Walker and Hislop 1998; Dulvy et al. 2000; Stevens et al. 2000) that size is an important indicator of vulnerability to exploitation in skates. The predictive models from Frisk et al. (2001) are summarized and applied to skate and shark species caught in British Columbia fisheries in sections 6.2.2 and 7.2.2 respectively.

Life history parameters are immediately important to managers as inputs to assessment models, but they can also be informative when the data required by the models are incomplete or inadequate. Understanding the life histories is unlikely to increase the yield from a fishery, but it will improve regulation by providing information on factors other than fishing mortality that affect fisheries (Pratt and Casey 1990). Hoenig and Gruber (1990) suggested that changes over time in the value of certain life history parameters might indicate that the level of exploitation is excessive, and provide an incentive to reduce effort. A list describing the symptoms of overexploitation of elasmobranchs has yet to be developed but it would likely include: increase in growth rates and fecundity, reduction of mean size and age in the population, reduction in the age at maturity, and a reduction in the proportion of breeding females in the population (Hoenig and Gruber 1990). A further symptom overexploitation might be added for multispecies fisheries - a change in the catch composition that can reflect a change in community structure (Agnew et al. 2000).

5.0 MANAGEMENT

Management of elasmobranchs is a low priority in most areas of the world, and where management and assessments are implemented, the available data are generally inadequate (Shotton 1999). Management is complicated by the fact that the fisheries are often depleted prior to the implementation of management recommendations (Pratt and Casey 1990), many species are highly migratory and travel through several management jurisdictions (Daves and Nammack 1998), and a large portion of the catch is either unreported and/or is combined as either "sharks" or "skates" (Musick et al. 2000).

Details of management methods are available primarily for elasmobranch species that are the focus of directed fisheries, or multispecies fisheries. Less information is available solely for bycatch species. Within the targeted fisheries, assessment and management efforts differ from country to country. In the Southern Gulf of Mexico and Caribbean, for example, there are no specific assessment or management measures implemented (Bonfil 1997), while in the U.S. EEZ in the Atlantic Ocean, Gulf of Mexico, and Caribbean, 39 species of sharks are managed by the Highly Migratory Species Management Division of

NMFS (Stone et al. 1998). Management measures implemented include: commercial quotas, trip limits, fishery closures, mandatory reporting, prohibition of finning, and closure of nursery and breeding areas during mating and pupping seasons (Carrier and Pratt 1998; Stone et al. 1998). New Zealand manages a few shark and skate species using a quota system and gear restrictions such as limits on the length of the net and the mesh size (Francis 1998). The success has been limited because the quotas, at least for skates, have been exceeded by approximately 50-100% every year, meaning the skates are essentially unmanaged (Francis 1998). Further, the shark species that are not managed under the quota system are prohibited as target species for commercial fishers, but can be caught in unlimited numbers as bycatch in other fisheries (Francis 1998).

An example of an elasmobranch fishery that warrants discussion because of its longevity is the Western Australia shark fishery. This fishery exhibits marked success in many areas: it is a 50 year old, multispecies fishery that targets several demersal shark species, some of which are locally endemic (e.g. the gummy shark *Furgaleus macki*) and others such as the dusky shark (*Carcharhinus obscurus*) that have a circum-global distribution. Additionally, there is a high level of utilization of the catch, and there is very little bycatch of marine mammals, sea birds, and turtles in the fishery (Simpfendorfer 1999b). The Australian shark fisheries are among the most heavily researched and strictly managed in the world and are an excellent example of successful management (Shotton 1999).

The collection of catch data in the Western Australia shark fishery began in the 1940s, and annual data are available since 1951. Beginning in 1975, catches and fishing effort became available for individual species. Presently, fishers provide catch, effort, and area data on a monthly basis (Simpfendorfer and Donohue 1998). Research on the biology, distribution, and physiology of the shark populations dates back to the early 1970s and continues to this day (Simpfendorfer and Donohue 1998). Due to the availability of large amounts of data, the assessment of the fishery is very detailed. The assessments have evolved from simple examination of catch rates to age structured models, to stochastic models and risk assessments. Recently, concerns have developed regarding the validity of the age structured models for the long lived species because the 22yr long CPUE time series is too short to provide information regarding the response of the stock to fishing (Simpfendorfer and Donohue 1998). To overcome these limitations, age-specific exploitation rates obtained from tagging studies are now included in the models.

The target reference point is 40% of the virgin biomass. This was chosen because teleost and invertebrate stocks typically collapse between 15-20%, and the level for sharks is expected to be much higher (Simpfendorfer 1999b). Recognizing the multispecies nature of the fishery means that optimal yield from some species may not be achieved in order to meet the conservation goals of others. Effort is limited to the level that will provide sustainable catches from the least productive stock (Simpfendorfer and Donohue 1998). Effort is limited using monthly time-gear units – the effort equivalent of ITQs. Each unit entitles a fisher to a specified length of net in a given month (Simpfendorfer 1999b). There is extensive industry consultation in the management of the fishery, which increases the time of decision making and implementation, however, there is also a high degree of support for management measures in the fishery (Simpfendorfer 1999b).

The Western Australia shark fishery is anticipated to be sustainable over the long term as the result of extensive research and implementation of management programs. It is therefore a useful example of the benefits of species-specific research, monitoring and management. However, most managers are faced with a lack of the critical data for stock assessment of elasmobranchs. This is a serious impediment to management (Hoff and Musick 1990).

5.1 Effective Management of Elasmobranch Fisheries

Holden (1977) suggested that even the most fecund and abundant elasmobranch species are unable to withstand intensive fisheries, because most of the fisheries have collapsed during a short period of time. According to Pratt and Casey (1990), elasmobranch fisheries would be sustainable if they developed once a suitable population was identified (e.g. one with a growth rate exceeding 0.20 and that is naturally abundant). However, the reasons for which fisheries develop are not related to the life history of the species. According to Bedford (1987) and Pratt and Casey (1990), the ‘real world’ requirement of intensive regulation and management at both national and international levels means that most large-scale fisheries are doomed to failure. Bedford (1987) observed that management of the California pelagic shark fishery failed because it was treated “in the same manner as other (teleost) fisheries” in that the managers expected the stocks to rebuild rapidly after fishing was reduced in response to overfishing. Managers of both teleost and elasmobranch stocks are confronted with similar problems, but the result of mismanagement or late management of elasmobranchs is a pronounced and persistent population decline (Bedford 1987).

Not all researchers have a pessimistic view of the future of elasmobranch fisheries. Walker (1998) argues that the same life history characteristics that make elasmobranchs vulnerable to overexploitation make them good candidates for sustainable fisheries. The large size and high survival rate of juveniles means that recruitment is not variable and that the population size is stable from year to year. A stable population means that low-level but sustained catches can be removed over time. Therefore, managers must consider that fishing can be sustainable at low levels. Walker (1998) notes that the key to sustainable harvest of elasmobranchs lies in the relative productivity of the stocks. A larger proportion of the biomass can be removed from a more productive stock compared to a less productive stock.

Production rates of individual species must be considered by managers when the fishery under consideration is a multispecies fishery. In those fisheries, the species that have the highest productivity continue to support the fishery while species with lower productivity decline (Walker 1998; Musick 1999b). This problem is exacerbated when the catch is not sorted, because the aggregated catch records mask the decline of the less productive species (Musick et al. 2000). The larger, slow growing species can decrease to extremely low levels, and may be driven to near extinction (Dulvy et al. 2000). Therefore, the usual belief that a fishery will become economically extinct before the target species become biologically extinct may be incorrect (Musick et al. 2000). One way to deal with this problem is to limit fishing effort to the level that can be sustained by the species with the lowest rate of population increase, as is the case in the Western Australia shark fishery (Simpfendorfer and Donohue 1998).

The American Fisheries Society recently recommended the following actions in order to improve the management of elasmobranch fisheries (Musick et al. 2000):

- management must be given high priority due to the high vulnerability of most elasmobranchs to exploitation
- management should be conservative and predicated on the precautionary principle when faced with uncertainty
- management should be focused at the lowest level, such as genus and the unit stock
- when faced with sparse data, groups of species with similar life history traits should be identified
- when possible, age-based models or Bayesian techniques should be used in the assessment. Surplus production models are likely inappropriate for long-lived species.
- the biomass must be maintained well above the levels that would provide MSY
- full utilization of the catch should be encouraged in order to minimize waste and to improve catch statistics, because landing only parts such as fins, make identification impossible
- mandatory release of all unwanted live species
- explicit, precautionary quotas for bycatch species

In terms of regulations, Frisk et al. (2001) recommend that managers implement size-based limits for species that mature at a large size or old age. Musick et al. (2000) propose that in order to avoid recruitment overfishing, these limits should be set at a level that guarantees recruitment. Frisk et al. (2001) advocate the close monitoring and conservative management of large species (>100cm) because large size is associated with increased vulnerability to exploitation. They further recommend the maintenance of adult biomass, as Winemiller and Rose (1992) suggested for all K-strategist species, because juvenile survival depends on the condition of the adults in the stock. When managing a multispecies fishery (such as most skate fisheries), Agnew et al. (2000) recommend minimizing the proportion of the catch composed of large, late maturing species using time and area closures.

In order to effectively manage elasmobranch fisheries, research in several key areas is required. In terms of life history studies, more information on fecundity, age, mortality, and growth rates for different species as well as different populations of the same species is required (Frisk et al. 2001). Additionally, in order to improve catch statistics, uncertainty regarding taxonomy and stock delineation must be addressed (Walker 1998). The examination of fishing methods that can reduce elasmobranch bycatch and increase the post-release survival is also required (Musick et al. 2000).

5.2 Ecological Considerations

The development of ecosystem based management hinges on understanding the implications of indirect and direct impacts on ecosystem structure and function (Fogarty and Murawski 1998). The direct effects (changes in species composition and life history parameters) of fishing on elasmobranch populations have been discussed in some detail in this report. What is less clear is how the removal of large amounts of sharks and rays will affect ecosystems. The increasing calls for conservative, ecosystem based management means that these effects must be examined.

In order to predict changes in ecosystem dynamics that would result from the depletion of shark resources, Stevens et al. (2000) utilized ECOPATH models from three areas including the Gulf of Alaska. Sharks were a separate component of each model, but were grouped generally as "sharks". The Gulf of Alaska group included mainly salmon sharks and blue sharks. The predictions of the models indicate that shark depletion could result in dramatic and unforeseen changes in the abundance of many species. Interestingly, the results suggest that the affected species are not necessarily the major prey of sharks. For example, in the Gulf of Alaska model, most species increased initially once sharks were depleted, but some decreased below the baseline biomass over extended (100 year) periods. These species were the salmonids, which are unimportant prey items, and the "large fish" group, which decreased to 50% of the original biomass. Two of the most important prey items, mesopelagic and small pelagic fishes, increased slightly and remained constant thereafter.

In comparing the responses across ecosystems, Stevens et al. (2000) note that the most apparent outcome is that the reactions of ecosystems to the removal of sharks are complex. The common response across all ecosystems was an increase in the biomass of unimportant prey species shortly after shark removal and decreases in some important prey species. This result means that the main prey items in shark diets will not provide much insight into ecosystem responses. The key to understanding ecosystem responses lies in the role the sharks play in controlling the prey, not how important the prey is in the diet (Stevens et al. 2000). The authors conclude that the effects of shark depletion on ecosystems are likely to be persistent, and to have significant ecological and economic effects. Elasmobranchs must therefore be studied in an ecosystem context because the effects of removing significant numbers of the top predators in the system remain essentially unexamined, and because an understanding of trophic interactions is required for ecosystem management.

6.0 SKATES OF BRITISH COLUMBIA

Five species of skates were identified by Hart (1973) as present in British Columbia waters: big skate (*Raja binoculata*), longnose skate (*Raja rhina*), deepsea skate (*Raja abyssicola*), black (or sandpaper) skate (*Bathyraja interrupta*) and starry skate (*Raja stellulata*). Roughtail skate (*Raja trachura*), broad skate (*Raja badia*), and California skate (*Raja inornata*) were subsequently identified as fishes of British Columbia (B.C.)

(Gillespie 1993). The classification of skates and rays occurring off British Columbia is shown in Table 1; the distribution is summarized in Table 2.

Table 1 Classification of the skates and rays of the British Columbia coast.
Table based on Gillespie (1993). Asterisk denotes those species caught in BC commercial fisheries 1954-2000.

CLASS	ORDER	FAMILY	GENUS	COMMON NAME
Elasmobranchii	Torpediniformes	Torpedinidae	Subfamily Torpedininae	
		-electric rays	*Torpedo californica*	Pacific electric ray*[1]
	Rajiformes	Rajidae - skates	Subfamily Rajinae	
			Bathyraja abyssicola	deepsea skate*
			Bathyraja interrupta	black skate*
			Bathyraja trachura	roughtail skate*
			Bathyraja aleutica	Aleutian skate
			Bathyraja rosispinis	flathead skate[2]
			Raja badia	broad skate*
			Raja binoculata	big skate*
			Raja rhina	longnose skate*
			Raja stellulata	starry skate*
			Raja inornata	California skate[3]
	Mylobatiformes	Dasyatidae	Subfamily Dasyatinae	
		- stingrays	*Dasyatis violacea*	pelagic stingray
			Dasyatis brevis	diamond stingray

[1] small numbers of Pacific electric ray have been caught in the domestic and J/V trawl fisheries yearly since 1991.

[2] taken August 2001 off South West Vancouver Island (Gillespie, pers. comm.)

[3] California skate has been reported from Juan de Fuca Strait (Gillespie, 1993)

Table 2 Distribution of British Columbia skate species.
Table based on Hart (1973).

SPECIES	GEOGRAPHIC RANGE	DEPTH
Deepsea skate	Northern Oregon to Bering Sea	deep sea: 1460-2910m
Big skate	Southern California to Alaska	moderate depths
Black skate	Southern California to Alaska	400-825m
Longnose skate	Southern California to Alaska	370m
Starry skate	Southern California to Alaska	366m
Broad skate	-	-
Roughtail skate	-	-
Aleutian skate**	Bering Sea/Alaska to Canada?	-
Flathead skate	-	-
California skate*	Baja California to Juan de Fuca Strait	670m

* information from Zeiner and Wolf (1993) ** information from Gillespie (1993)

6.1 BC Skate Fishery

6.1.1 Catch

Records of skate catches from B.C. waters date back to 1954. Skate catches are reported either as wings or round weight. Catches from the troll, longline, and hand line fisheries prior to 1976, and landed catches from the trawl fishery during 1954-1995 were reported as wing weights. All other catches were recorded as round weight. Differences in reporting have been accounted for in the totals reported below using a conversion factor of 2.5 (obtained from K. Rutherford, pers. comm.). All catches are reported as round weight. The trawl fishery is responsible for the largest amount of bycatch (Table 3). Big and longnose skates have been targeted by the trawl fishery since 1996, and since that time, at sea observers have been placed on most trawlers. As a result, catches have been more accurately reported, which probably accounts for some of the increase in total catch in recent years. It is interesting to observe that records of discards have been negligible since observers were placed onboard the vessels. Species identification improved after 1996, prior to which catches were reported simply as “skates”. Big skate and longnose skate comprise the majority of the catch (Table 4), and the largest catches are from area 5D (northern Hecate Strait). Neither species has been reported from area 4B (Strait of Georgia), but catches of varying size have been reported from all other areas. In 1996 a directed longline fishery developed for big skate in Canadian waters. The initial catch was 198t, but declined in subsequent years to an average of 83t - compared to the average bycatch of 1424t from the trawl fishery for the same period of time (Table 3).

Records of total skate indicate that catches increased in the late 1970s in areas 5B, 5C, and 5D (Figure 5). Species-specific time series are available from 1996 to 2000, and are presented for big, black, and longnose skate in Figure 6-8, respectively. Although unidentified skate catches were reported from area 4B dating back to 1954, only longnose skate has been reported from this area since 1996, and only in trace amounts (Figure 8). Additionally, catches of longnose skate have been increasing steadily in area 3C. All 7 of the currently known skate species have been caught off the west coast of Vancouver Island (areas 3C and 3D), Queen Charlotte Sound and Hecate Strait (areas 5B, 5C, and 5D).

6.1.2 Observed and Predicted Catch

Ninety-six percent of the trawl fishery catches in area 5D are taken at depths between 50 and 150m. In order to compensate for under reporting in the trawl fishery prior to 1996, the historical skate catch was estimated using observed catch per unit effort data from 1996-2000. Skate catches in these years were reported by observers and are therefore assumed to be better catch estimates than those in non-observed years. The focus was on area 5D since this is the area with the largest catches (Figure 5). Skate CPUE (tonnes/hr) was 0.11, 0.20, 0.10, 0.16, 0.15 in 1996, 1997, 1998, 1999, and 2000 respectively. The predicted total skate catch in area 5D for 1954-1995 was generated by applying the average to the annual total number of hours spent trawling between 50 and 150m. The average for the period is 0.15 tonnes/hr. The time series of the observed and predicted skate catch in depths between 50 and 150m is shown in Figure 9. Trawl effort varied substantially between 1954 and 2000, but tended to increase over the time period (Table 3). The number of hours spent trawling increased steadily from 1227 to 7795 hours between 1954 and 1979, and decreased to a minimum of 3123 hours in 1986. A dramatic increase in effort began in the late 1980s and reached a maximum of 11061 hours in 1993, after which effort decreased to an average of 5722 hours. The reported catches follow a similar pattern to the effort until the beginning of the period of rapid increase in the late 1980s, but not after (Figure 9). This is most likely a function of under-reporting. If the predicted catches are taken to be more realistic than the observed catches, the skate catches in area 5D more than doubled between 1988 and 1993, and declined thereafter to an average of 840 tonnes.

Table 3 British Columbia reported skate catch (tonnes) by gear type and utilization. “Other” includes hand line, troll, and unknown. Trawl effort shown for 50-150m in area 5D.

	TRAWL				LONGLINE				OTHER	**TOTAL**
YEAR	discards	retained	unknown	total	discards	retained	unknown	total		
1954	-	218.73	-	218.73	-	-	0.17	0.17	0.25	**219.15**
1955	-	141.18	-	141.18	-	-	-	-	0.27	**141.46**
1956	-	134.01	-	134.01	-	-	0.23	0.23	0.05	**134.28**
1957	-	153.04	-	153.04	-	-	0.00	0.00	0.98	**154.01**
1958	-	135.63	-	135.63	-	-	0.23	0.23	0.86	**136.72**
1959	-	150.56	-	150.56	-	-	0.91	0.91	0.11	**151.58**
1960	-	199.86	-	199.86	-	-	1.93	1.93	0.09	**201.87**
1961	-	171.41	-	171.41	-	-	0.34	0.34	0.45	**172.20**
1962	-	175.65	-	175.65	-	-	-	-	-	**175.65**
1963	-	148.69	-	148.69	-	-	1.93	1.93	-	**148.69**
1964	-	156.56	-	156.56	-	-	0.45	0.45	0.57	**157.58**
1965	-	160.48	-	160.48	-	-	0.91	0.91	0.18	**161.57**
1966	22.75	110.39	-	133.14	-	-	1.13	1.13	0.79	**135.06**
1967	1.36	126.79	-	128.15	-	-	0.45	0.45	0.23	**128.83**
1968	-	130.15	-	130.15	-	-	0.34	0.34	-	**130.49**
1969	31.30	213.24	-	244.54	-	-	0.68	0.68	-	**245.22**
1970	12.70	211.11	-	223.82	-	-	0.34	0.34	0.11	**224.27**

1971	-	163.96	-	163.96	-	-	-	-	-	**163.96**
1972	-	206.19	-	206.19	-	-	0.06	0.06	0.07	**206.32**
1973	4.99	202.01	-	206.99	-	-	-	-	0.05	**207.04**
1974	4.54	169.95	-	174.48	-	-	-	-	0.27	**174.76**
1975	30.84	398.34	-	429.19	-	-	-	-	0.09	**429.28**
1976	-	461.10	-	461.10	-	-	0.09	0.09	0.18	**461.37**
1977	43.77	590.56	-	634.33	-	-	-	-	0.27	**634.60**
1978	162.91	369.19	-	532.09	-	-	-	-	2.00	**534.09**
1979	160.50	427.05	-	587.55	-	-	-	-	5.00	**592.55**
1980	284.05	637.68	-	921.72	-	-	-	-	8.00	**929.72**
1981	51.85	600.46	-	652.31	-	-	-	-	-	**652.31**
1982	67.72	322.65	-	390.37	-	-	0.59	0.59	-	**390.37**
1983	129.62	342.84	-	472.46	-	-	0.47	0.47	0.32	**473.25**
1984	37.14	388.15	0.44	425.72	-	-	8.65	8.65	0.55	**434.92**
1985	50.00	361.41	0.32	411.73	-	-	6.28	6.28	0.82	**418.83**
1986	13.70	498.02	1.26	512.98	-	-	13.60	13.60	4.06	**530.63**
1987	44.52	728.23	0.36	773.12	-	-	18.71	18.71	3.65	**795.48**
1988	117.19	569.72	0.01	686.93	-	-	20.22	20.22	1.82	**708.97**
1989	97.32	341.03	0.05	438.41	-	1.18	9.70	10.88	2.10	**451.38**
1990	172.09	167.89	-	339.98	-	8.06	8.74	16.80	2.16	**358.94**
1991	388.98	234.85	0.03	623.86	-	4.87	11.10	15.97	0.34	**640.17**
1992	242.22	285.09	-	527.31	-	1.64	15.81	17.45	2.23	**547.00**
1993	229.64	267.28	-	496.92	-	0.01	4.77	4.78	0.56	**502.26**
1994	321.29	500.70	-	821.99	-	0.05	17.38	17.43	1.00	**840.42**
1995	94.13	966.94	0.01	1061.09	-	0.02	70.71	70.74	3.07	**1134.90**
1996	13.83	1118.49	-	1132.32	-	-	197.56	197.56	6.21	**1336.10**
1997	0.35	1752.26	-	1752.61	-	-	90.84	90.84	3.03	**1846.48**
1998	0.07	992.87	-	992.95	-	-	55.80	55.80	0.38	**1049.13**
1999	-	1547.20	-	1547.20	6.85	0.10	58.42	65.38	2.81	**1615.39**
2000	0.14	1403.18	-	1403.32	13.07	2.86	104.61	120.53	10.63	**1534.48**

Table 4 British Columbia reported skate catch (tonnes) by year.

year	BIG SKATE	BLACK SKATE	BROAD SKATE	DEEPSEA SKATE	LONGNOSE SKATE	ROUGHTAIL SKATE	STARRY SKATE	UNIDENTIFIED SKATES
1954	-	-	-	-	-	-	-	219.15
1955	-	-	-	-	-	-	-	141.46
1956	-	-	-	-	-	-	-	134.28
1957	-	-	-	-	-	-	-	154.01
1958	-	-	-	-	-	-	-	136.72
1959	-	-	-	-	-	-	-	151.58
1960	-	-	-	-	-	-	-	201.87
1961	-	-	-	-	-	-	-	172.20
1962	-	-	-	-	-	-	-	175.65
1963	-	-	-	-	-	-	-	150.62
1964	-	-	-	-	-	-	-	157.58
1965	-	-	-	-	-	-	-	161.57
1966	-	-	-	-	-	-	-	135.06
1967	-	-	-	-	-	-	-	128.83
1968	-	-	-	-	-	-	-	130.49
1969	-	-	-	-	-	-	-	245.22
1970	-	-	-	-	-	-	-	224.27
1971	-	-	-	-	-	-	-	163.96
1972	-	-	-	-	-	-	-	206.32
1973	-	-	-	-	-	-	-	207.04
1974	-	-	-	-	-	-	-	174.76
1975	-	-	-	-	-	-	-	429.28
1976	-	-	-	-	-	-	-	461.37
1977	-	-	-	-	-	-	-	634.60
1978	-	-	-	-	-	-	-	534.09
1979	-	-	-	-	-	-	-	592.55
1980	-	-	-	-	-	-	-	929.72

1981	-	-	-	-	-	-	-	652.31
1982	-	-	-	-	-	-	-	390.96
1983	-	-	-	-	-	-	-	473.25
1984	-	-	-	-	-	-	-	434.92
1985	-	-	-	-	-	-	-	418.83
1986	-	-	-	-	-	-	-	530.63
1987	-	-	-	-	-	-	-	795.48
1988	-	-	-	-	-	-	-	708.97
1989	-	-	-	-	-	-	-	451.38
1990	-	-	-	-	-	-	-	358.94
1991	-	-	-	-	-	-	-	640.17
1992	-	-	-	-	-	-	-	547.00
1993	-	-	-	-	-	-	-	502.26
1994	0.06	0.01	1.38	-	3.53	0.00	0.02	835.41
1995	2.75	-	-	-	-	-	-	1132.14
1996	416.11	3.80	-	0.19	348.80	0.05	0.07	567.09
1997	1224.94	3.52	-	0.19	403.63	-	2.09	212.12
1998	583.74	4.45	0.01	1.08	318.33	-	0.60	140.93
1999	1011.25	17.25	-	4.48	415.00	-	1.80	165.61
2000	1008.87	24.16	-	1.44	265.82	4.74	1.03	228.41

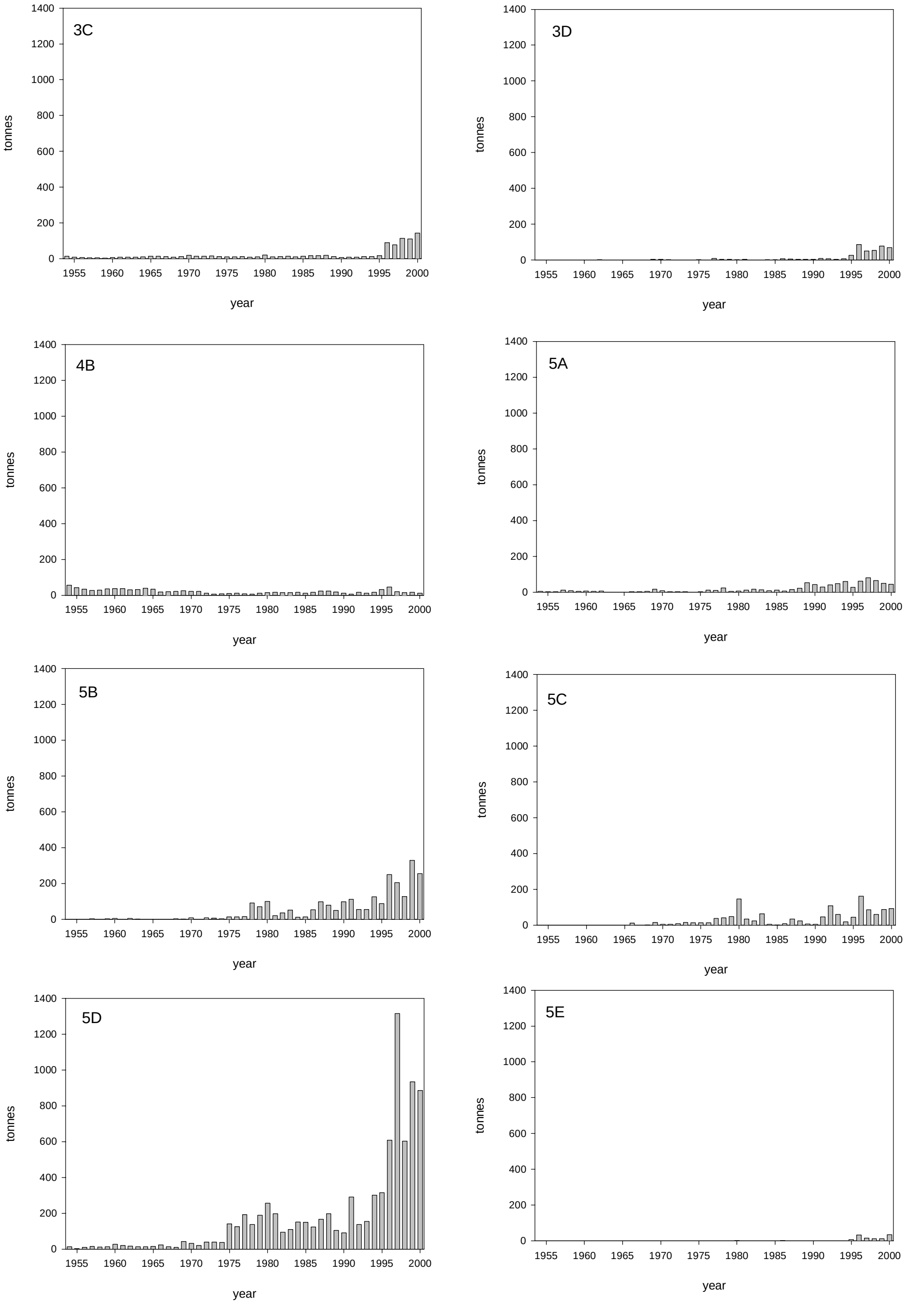

Figure 5 British Columbia total reported skate catch by area and year.

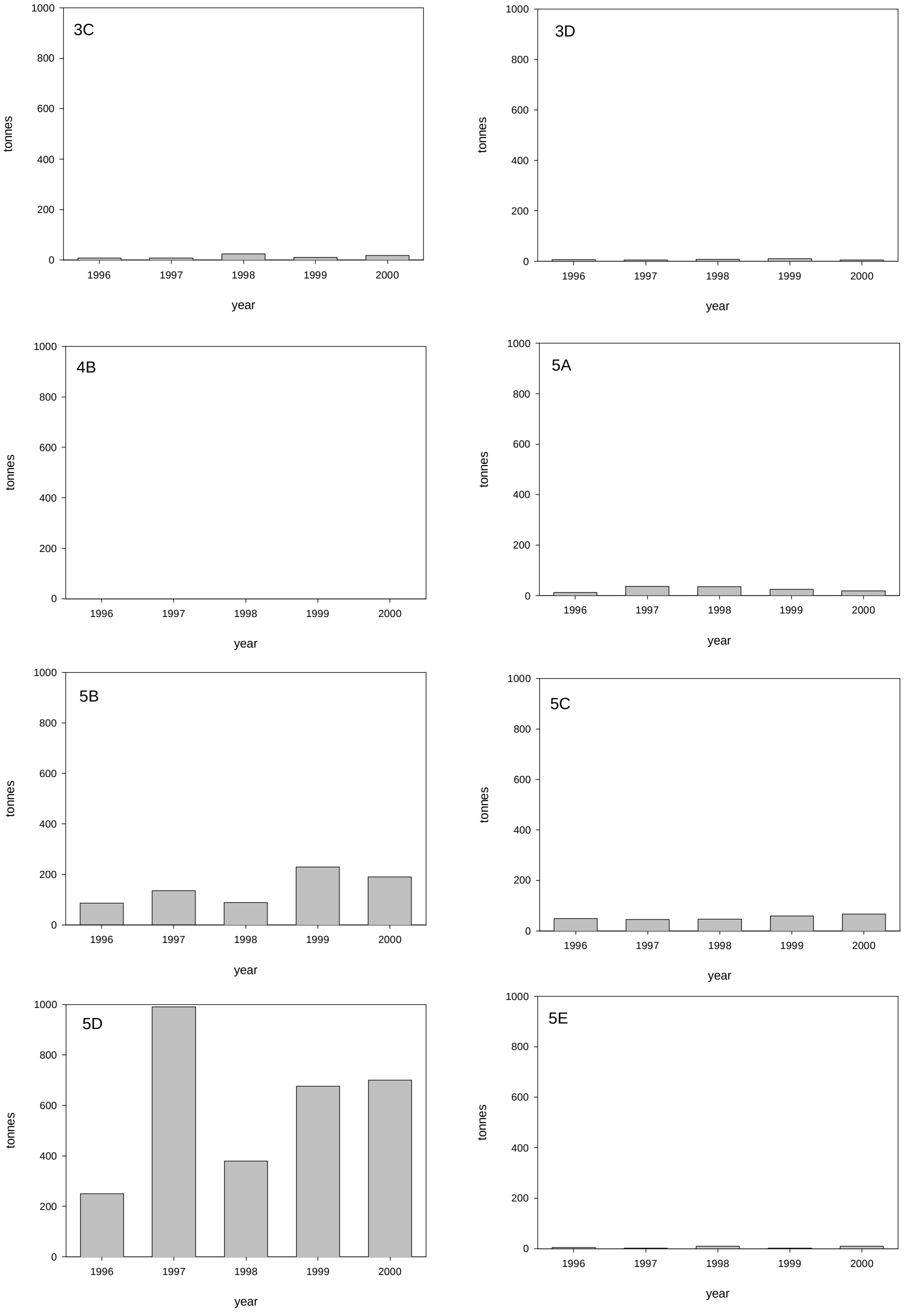

Figure 6 British Columbia reported big skate catch by area and year.

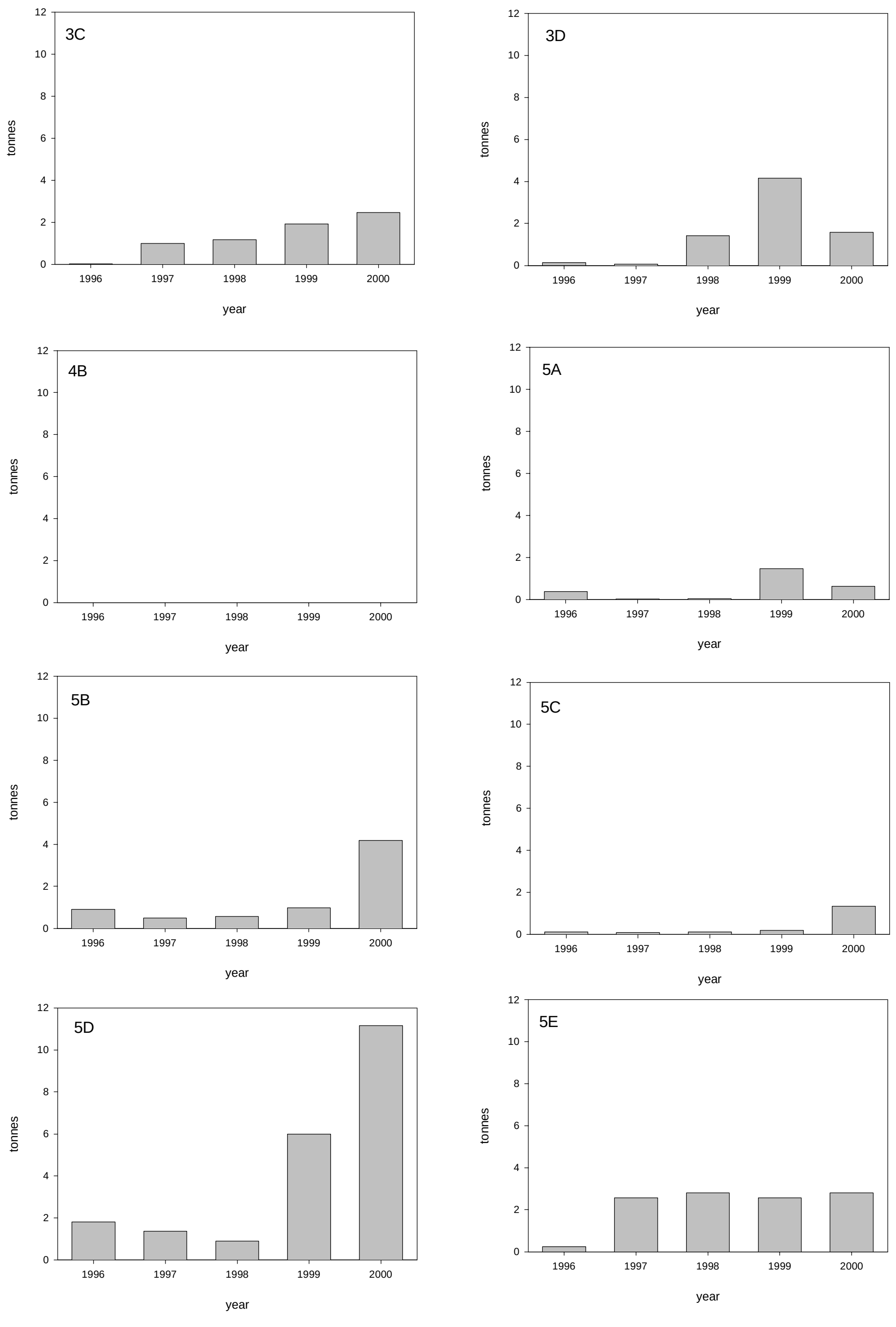

Figure 7 British Columbia reported black skate catch by area and year.

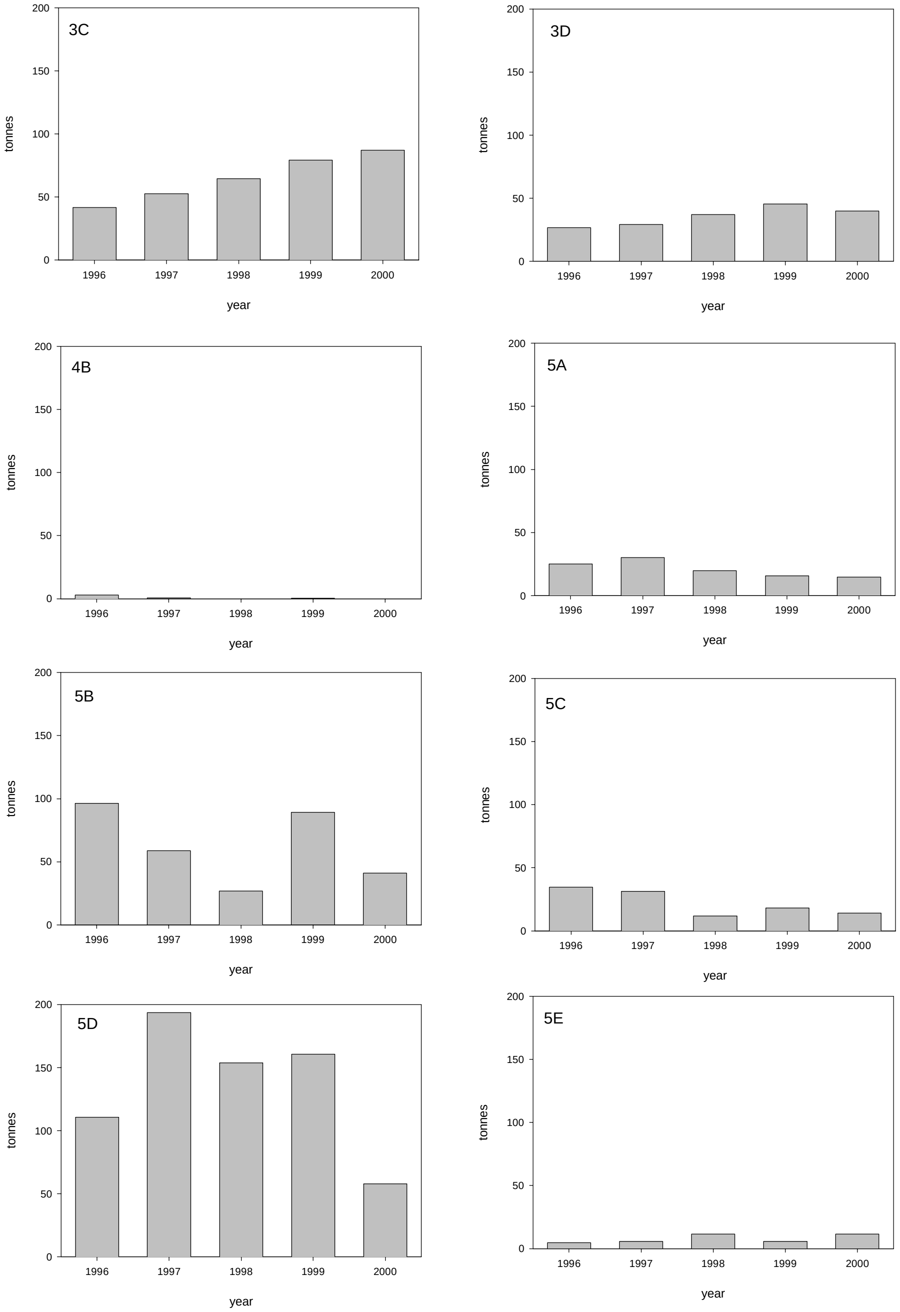

Figure 8 British Columbia reported longnose skate catch by area and year.

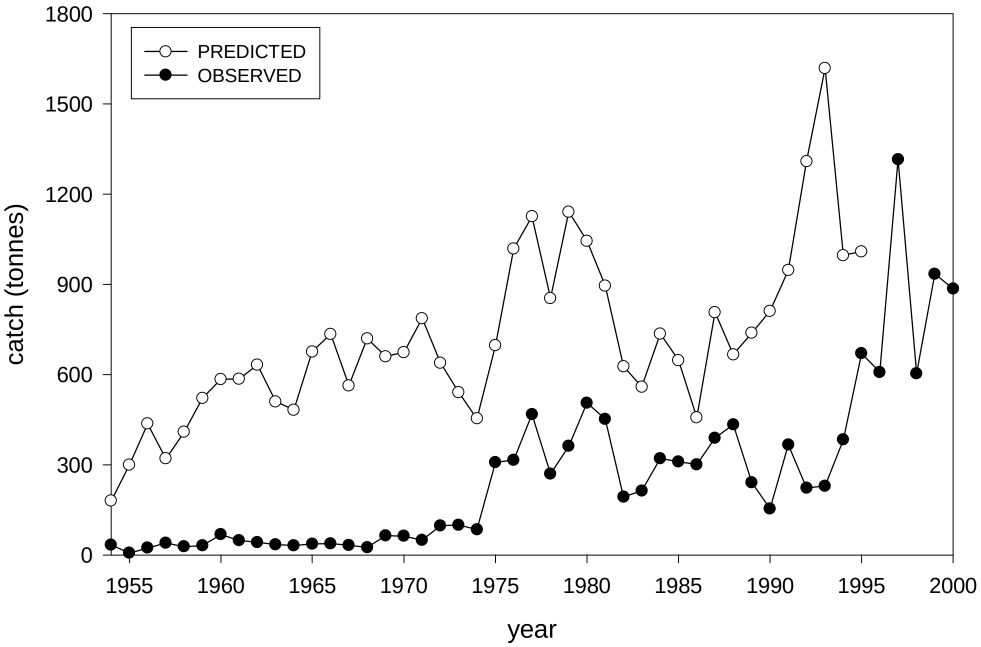

Figure 9 Observed (1954-2000) and predicted (1954-1995) total British Columbia skate catch in area 5D. Between 1996 and 2000, 96% of the catches were taken at depths between 50 and 150m. Historical trawl effort and the 1996-2000 average CPUE (0.15 tonnes/hr) at these depths were used to estimate historical catches. Observed catches between 1954 and 1995 are not available by depth, therefore they are presented for all depths.

6.1.3 CPUE

The Department of Fisheries and Oceans has conducted research surveys approximately every two years since 1984 using bottom and mid-water trawl gear in areas 5C and 5D (southern and northern Hecate Strait, respectively). Skates are captured incidentally in the surveys, and big skate represents the majority of the bycatch. In an effort to determine if directed fishing on big skate has affected the population, survey CPUE was examined. No trend is evident in the time series (Figure 10).

Because CPUE for bycatch species is less reliable than that for targeted species, we examined monthly total skate (mostly big and longnose) CPUE from the trawl fishery in areas 5C and 5D during 1996-2000 (Figures 11 and 12). Effort by mesh size (which would provide information on the sets that targeted skate using the “skate codend”) is unavailable, therefore total effort was used in the calculation. The CPUE varies without trend over the time period, however, there are indications of seasonality in the time series. Catches in area 5C are highest during the spring and summer, and in area 5D during the fall and winter. This may reflect seasonal movement between adjacent areas by the fishery or by the skates. Another possibility is seasonal movement between depths within an area, which was not possible to examine in the present study. However, there are indications of seasonal depth changes by thorny skate on the Grand Banks, where catches are highest in the late fall in shallow depths (Kulka and Mowbray 1998).

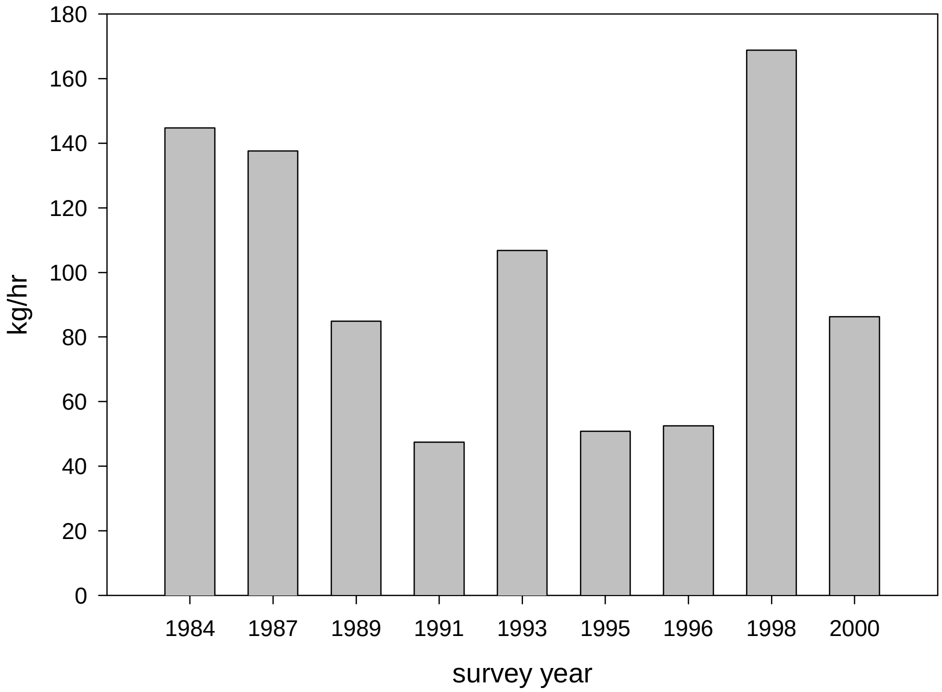

Figure 10 Big skate CPUE (kg/hr) in the Hecate Strait spring research surveys 1984-2000.

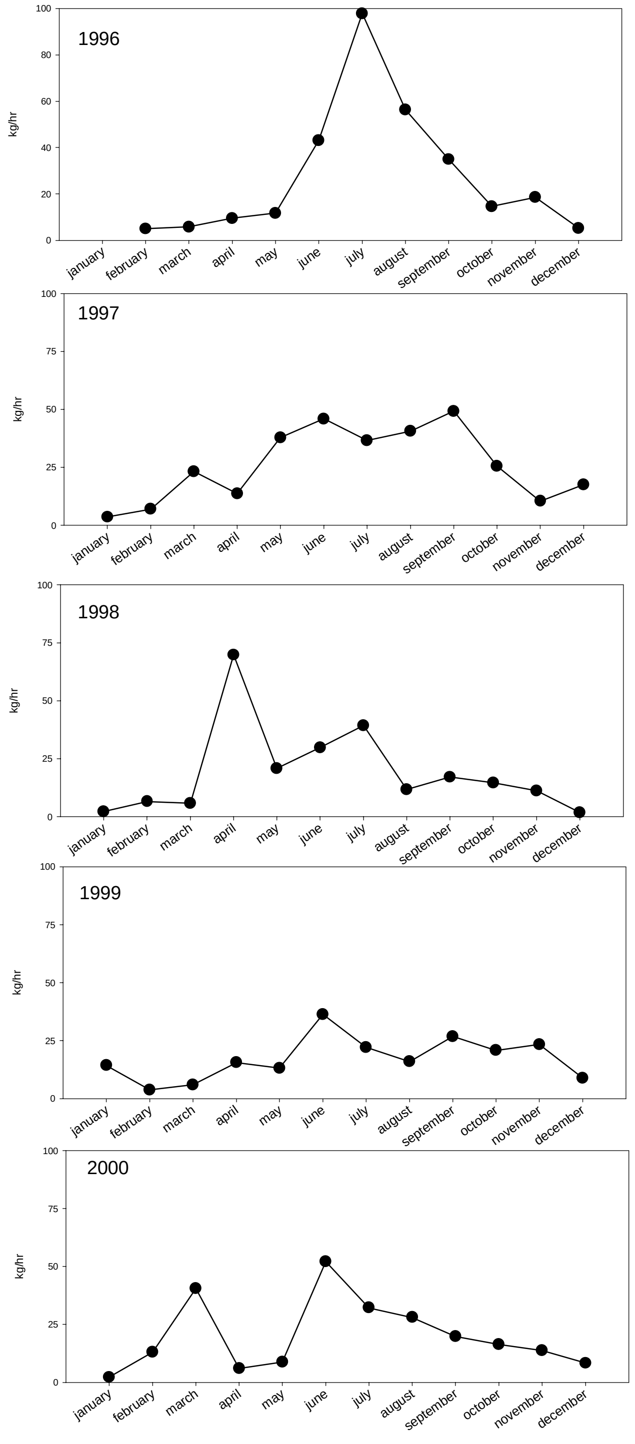

Figure 11 Area 5C total skate monthly CPUE (kg/hr) in the trawl fishery 1996-2000.

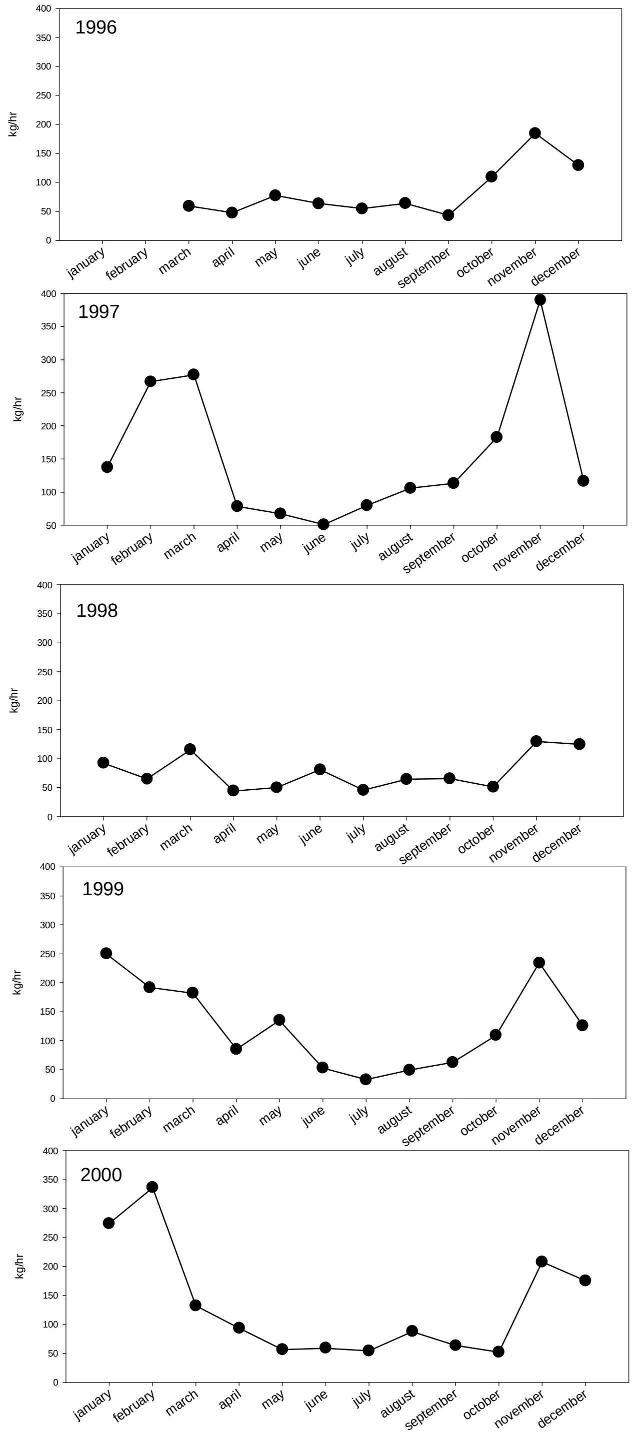

Figure 12 Area 5D total skate monthly CPUE (kg/hr) in the trawl fishery 1996-2000.

6.2 Biology

6.2.1 Biological Data

There are currently a total of 700 big skates, 160 longnose skates, 111 black skates, and 1 deepsea skate from the Hecate Strait surveys in the biological database. The deepsea skate measured 60cm in total length. There were more samples taken in area 5D (440 big skates, 109 longnose skates, and 76 black skates) than in area 5C (229, 45, and 29 for each species respectively). In addition to the survey samples, a total of 30 skates were caught in longline gear and sampled in area 5E (west coast of the Queen Charlotte Islands) in 2000. There are 6 big skates, 21 longnose skates, 1 black skate (total length 117cm) and 2 unidentified skate (total lengths 78 and 99cm) samples from this area. Length frequencies of all available big skate, longnose skate, and black skate specimens are presented in Figure 10.

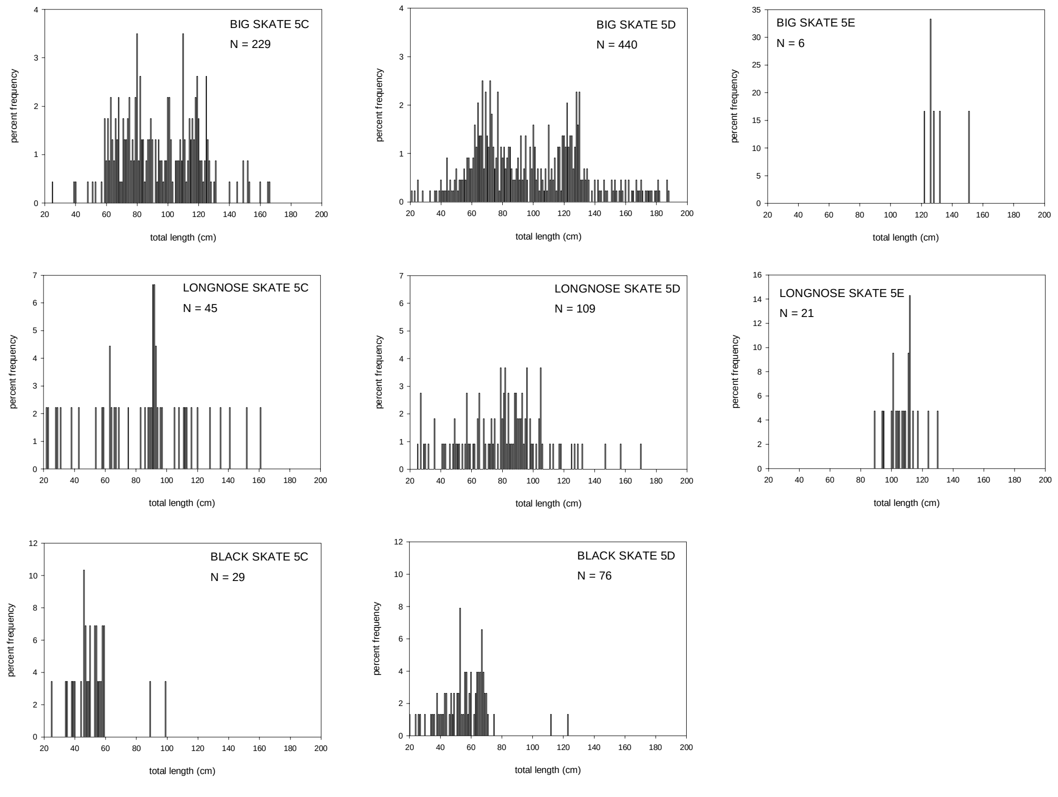

Figure 13 Length frequency of big skate, longnose skate, and black skate by area.

The sizes reported for big skate are well under the maximum reported size of 240cm (Hart 1973). Zeiner and Wolf (1993) estimated the length at maturity for California big skate as 110cm (age 7-8) for males and 130cm (age 12) for females. Of the sexed specimens, 19 of 30 (63%) male big skate exceeded 110cm, and 11 of 35 (31%) females exceeded 130cm in length. The big skate length frequency distributions are the only ones that are bimodal, with peaks occurring between 70 and 90 cm and again between 110 and130cm. The range of sizes of big skates in both areas of Hecate Strait are similar, however, there are more of the largest (140+ cm) skates in the north. All big skates sampled from 5E were l20cm or longer. Sample sizes of big skates vary between years. The largest samples (over one hundred individuals) were taken in 1989, 1991, and 1993. A comparison of these years shows a virtual elimination of the largest (>140cm) individuals in 1991 and 1993, although small numbers in this size range were caught again in 1998 and 2000.

The sizes of 6 longnose skates exceed the maximum (140cm) reported in the literature. Male longnose skates larger than 60cm (age 5) and females larger than 70cm (age 8) are considered to be mature (Zeiner and Wolf 1993). 19 of 23 (83%) male longnose skates and 11 of 16 (69%) female longnose skates exceeded the size of maturity. The mode of the longnose skate length frequency lies between 85 and 95cm in 5C, between 80 and 100cm in area 5D, and at 112cm in area 5E. Sample sizes of longnose skate are all small (Figure 10). Longnose skates larger than 120cm were sampled in 3 years: 1984 (11 of 44), 1989 (2 of 26), and 2000 (2 of 35). The reduction in numbers of the largest skates in the samples may indicate a reduction in large sizes in the population, which is of concern because fecundity is related to female body size in skates (Holden 1977). However, there are substantial numbers of longnose skates larger than 60 and 70cm in all years, which suggests that there are large numbers of mature longnose skates in the population.

The size of 4 black skates exceeded the reported maximum (84cm). No information exists for the size and age at maturity of black skate. A greater number of black skates larger than 60cm were captured in area 5D than in area 5C. The single specimen from area 5E was 117cm long, a size of black skate that is rare in the inside waters. There are few of the larger black skates in the samples, the frequency distribution ends abruptly at 59cm in area 5C, and at 75cm in area 5D. Black skates larger than 70cm are rare, but were caught in 1984 (2) and 1989 (4). No black skates larger than 70cm were sampled in 1991 and 1993, and no black skates were sampled in 2000.

6.2.2 Life History Parameters

Members of the Rajidae exhibit considerable variation in their life history characteristics (Walker and Hislop 1998), and this variety is reflected in the British Columbia skate species (Table 5). The range of life history characteristics within this family has been linked to varying degrees of resilience to exploitation between species (Stevens et al. 2000). The skate species with the lowest length/age at maturity are expected to have the highest probability of survival at high levels of exploitation because they are more likely to reproduce before being fished (Walker and Hislop 1998).

No studies on skate life history have been conducted in Canadian waters, however, growth characteristics (von Bertalanffy K and L_∞) and age and length at maturity estimates exist for big skate and longnose skate in Monterey Bay (Zeiner and Wolf 1993). Zeiner and Wolf collected skates from commercial trawl vessels. Total length (TL), sex, maturity, and age were recorded. Female stage of maturity was based on ovary condition, while sexual maturity of males was determined by an abrupt change in the relationship between clasper length and TL, coupled with hardening of the claspers. The 10th through the 20th vertebral central were used to age the skates. These results are summarized in Table 5.

Empirical relationships between several life history parameters of elasmobranchs were recently generated (Table 5, Frisk et al. 2001). Using these relationships values of age at maturity, length at maturity, *K*, *M*, and *r'* (potential rate of population increase) were predicted for deepsea, big, longnose, black, and starry skate using the empirical relationships. The estimates are based on maximum length, L_{max}, values taken from Hart (1973). No data are available for broad and roughtail skates. The estimates are summarized in Table 5, and the models used are presented in Table 6.

Table 5 Estimates of biological parameters for British Columbia skates.
Values in parentheses from Zeiner and Wolf (1993). L_{max} values, excepting those in parentheses, are from Hart (1973).

Species	Sex	Lmax (cm)	Lmat	Amat	K	M	r'
Deepsea skate	All	137	102	9	0.13	0.05	0.29
Big skate	M	(139)	104 (105)	9 (7.5)	0.13 (0.40)	0.05	0.29
	F	(168)	125 (130)	10 (12)	0.10 (0.40)	0.04	0.26
	All	240	176	12	0.04	0.01	0.22
Longnose skate	M	(95)	73 (60)	7 (5)	0.20 (0.30)	0.07	0.34
	F	(107)	81 (70)	8 (8)	0.18 (0.20)	0.07	0.32
	All	140	105	9	0.13	0.05	0.29
Black skate	All	84	65	7	0.22	0.08	0.35
Starry skate	All	76	59	6	0.23	0.09	0.37

Table 6 Summary of the empirical relationships used to generate life history parameters for British Columbia skates.
Relationships from Frisk et al. (2001).

	Estimated Parameter	Model
Rajidae	Length at maturity	$Lmat = 0.71*L_{max}+5.17$
Rajidae	Age at maturity	$Amat = 5.06*\ln(L_{max})-15.70$
Rajidae	K	$K = -0.17*\ln(L_{max})+0.97$
Rajidae	M	$\ln M = 1.10*\ln K-0.8$
Elasmobranchs	r'	$r' = -0.13*\ln(L_{max})+0.93$

A comparison of the life history parameters obtained by Zeiner and Wolf (1993) with those predicted using the relationships of Frisk et al. (2001) reveals that the agreement ranges from good (L_{mat} for big skate males) to very poor (*K* for male big skate). It is unclear which parameters are most realistic, considering that the maximum lengths reported for both big and longnose skate by Zeiner and Wolf (1993) are much lower than those reported by Hart (1973). It should be noted that the former values are the result of questionable fits of the von Bertalanffy curve (Zeiner and Wolf 1993), while the latter are actual observed sizes.

An examination of the life history parameters in Table 5 suggests that big skate, longnose skate, and deepsea skate are the least resilient species in the BC skate community. This prediction is based on the association between large size and increased vulnerability to exploitation, but also holds when the *r′* values are examined, because low values are associated with low resilience to exploitation (Jennings et al. 1999).

6.3 Skates in Other Jurisdictions

In this section, case studies of two fisheries are provided for comparison with the British Columbia (BC) fishery. The California fishery is discussed first because it captures the same species as the BC fishery, and similar to BC, it is an essentially unmanaged fishery. It would be ideal to present several examples of skate fisheries that are well researched, assessed and managed in this section, but unfortunately no examples exist. Some, such as the Falkland Islands fishery are relatively old, but the details of management and assessment are not particularly informative (Agnew et al. 2000). The problems that have been identified in the management of elasmobranchs apply equally well to this fishery – skates are managed as an aggregate, stock assessment models can not be applied due to a lack of biological data, and the catch limits are set using surplus production models, the underlying assumptions of which are not applicable to elasmobranchs.

6.3.1 Pacific United States

Landings of skates from California to Alaska have increased in recent years, and as a result, improved management of skates in the eastern North Pacific has been listed as a priority by the American Fisheries Society (Musick et al. 2000). Skates and rays are captured incidentally in California trawl fisheries. Similar to British Columbia, big skate and longnose skate are important commercial species, but big skates are also taken in recreational shark derbies. California skate is also an important component of the commercial catch (Martin and Zorzi 1993). Landings of skate in California, particularly from the trawl fishery, increased from 504 tonnes in 1989 to approximately 4200 tonnes in 1999, but increased landings of fish that were previously discarded may be a factor in the apparent increase in catch (Zorzi and Martin *In press*).

A lack of data has restricted assessment of the status, distribution and dynamics of the California skate populations (Zorzi and Martin *In press*). Information on size, sex, species composition, survival rates after release, and life history parameters are required in order to produce an effective management plan. Because little is known of the population distributions, Zorzi and Martin (*In press*) advocate the coordination of management of skates within the Pacific states. Canada might be added to the coordinated effort because the same species are captured along the B.C. coast and the distribution and delineation of the stocks have yet to be determined.

6.3.2 Grand Banks Skate Fishery

Large amounts of skates were caught and retained by foreign fishing vessels on the Grand Banks beginning in the 1940s and ending in the 1980s, when foreign fishing in the area was phased out. In contrast, catches in the Canadian fishery were not considered to be valuable, and as much as 5000 t was discarded annually until the mid-1990s, when the collapse of major groundfish fisheries turned attention to non-traditional species (Kulka and Mowbray 1998). Canada established a regulated skate fishery on both the Grand Banks and the adjacent Scotian Shelf in 1994. The fishery outside the 200 mile limit is presently unregulated. Both the Grand Banks and Scotian Shelf fisheries are managed as separate stocks in spite of the fact that the distributions of some species overlap (Kulka and Mowbray 1999). Less than 1% of Canadian licensees direct their fishing toward skate, but the number of vessels actively fishing skate has shown some increase since 1994. Just over 50% of the catch is taken by trawl gear, close to 30% is taken by gillnets, and the remainder is taken predominantly by longline (Kulka and Mowbray 1998).

The thirteen Atlantic Canada species of skate are present in commercial trawl hauls in varying abundance, but thorny skate (*Raja radiata*) comprises the majority of the catches (Kulka et al. 1996). The other common species are: spinytail (*R. spinicauda*), barndoor (*R. laevis*), smooth (*R. senta*), and winter skate (*R. ocellata*) (Kulka and Mowbray 1999). According to Casey and Myers (1998) barndoor skate, one of the larger species, was once second in abundance to thorny skate, but since 1970 it has been driven to near extinction. During this period the smaller species such as thorny and smooth skate increased in abundance. Casey and Myers (1998) propose that the change in the composition of the skate community is the result of large incidental catches in groundfish fisheries. The results of Casey and Myers' study are the subject of some debate, however, as the records from the groundfish fisheries for the 1980s and 1990s apparently do not agree with their results (Kulka et al. 1996).

Kulka and Mowbray (1999) summarize the assessment and management of the Grand Banks skate fishery: it is a limited entry fishery, with only groundfish license holders allowed to participate. All skates are managed as a unit stock because the landings are aggregated. Minimum mesh size is imposed for trawls and gillnets, and minimum hook sizes are imposed for longlines. Management targets (e.g. TACs) are recommended annually by the extra-governmental Fisheries Resource Conservation Council (FRCC). The TACs have not been met in any year.

Catch and effort are provided from the commercial catches, but because skates are landed as wings, no biological data have been collected from the fishery. Limited biological data (length frequencies by species and sex) have been collected since 1965 in DFO groundfish surveys. Because the fishery is new and there is relatively little biological data, traditional stock evaluation methods are not used. Instead, the strength of the stock is monitored using indices such as minimum biomass estimates, length and weight composition of the catches, spatial distribution, and commercial catch statistics. A rough estimate of fishing mortality is obtained using total catch and minimum survey biomass, but the rate of renewal of the stock is not estimated.

Although the present state of the stock is uncertain, the extended time series (>20yr) of research data has shown that over the past 20 years, the Grand Banks skates decreased in size, underwent a contraction in their distribution, and became less abundant – all signs of a stressed population. The required data are lacking to determine whether management has been effective for all species, and there is no recognition among fishers and government of the need to treat each species independently.

The skate fisheries in California, on the east coast of Canada, and in British Columbia are similar in they are all multispecies fisheries and they all lack sufficient data for stock delineation, assessment, and management. However, the Grand Banks fishery stands out because of the extended time series of size frequency and distribution available from research surveys, and because some form of management has been in place since 1994. However, the management is geared toward the thorny skate, which may be one of the more resilient species, given the long history of exploitation. This does not bode well for species such as the barndoor skate that may be more vulnerable to exploitation. Another reason the Grand Banks fishery stands out is that the distribution of many species extends out beyond the 200 mile limit, and skate fishing is unregulated beyond that point. Because the continental shelf is relatively narrow along the west coast of North America, the potential exists for all skate fisheries to be regulated and managed under federal jurisdiction. This is especially true in British Columbia, where skates are mainly captured in the inside waters of Hecate Strait.

6.4 Assessment and Management of Skates in British Columbia

Decreased abundance, range contraction, and decreases in average size are all indications of stressed skate populations (Kulka and Mowbray 1999; Walker and Hislop 1998). No information is available on the distribution or abundance of BC skates, however, the fact that the largest species (big, longnose and black skates) make up the largest proportion of the catch, combined with the fact that the largest individuals of the species are relatively abundant, may be an indication that the stocks are healthy.

The distribution of most skate species captured in BC fisheries extends from California to Alaska (Hart 1973), but there are indications that the relative abundance of the species changes with latitude. Teshima and Wilderbauer (1990) describe the distribution and abundance of skates caught in groundfish surveys in the eastern Bering Sea, Gulf of Alaska, and the Aleutian Islands between 1976 and 1986. Seven species were identified in the surveys. In decreasing order of importance in terms of biomass, the species were: Alaska skate (*Bathyraja rosispinus*) (32%), Aleutian skate (*B. aleutica*) (27%), black skate (20%), big skate (9%), starry skate (7%), deepsea skate (<5%), and roughtail skate (<5%). Although the abundance and distribution of the various skates along the west coast of North America has yet to be quantified, it may be that species such as black skate increase in importance with latitude, while big and longnose skate decrease in importance. Coordinating Canadian research efforts with those in the Pacific United States could answer this important question.

The distribution and species composition of BC skate populations must be determined in order to effectively manage the fishery. Agnew et al. (2000) demonstrated that there are two adjacent, distinct rajid communities in the Falkland Islands, each of which have different sustainable yields. Additionally, after only 6 years of fishing near the Islands, a change in species composition to smaller, late-maturing species was evident. The relative abundance and size of the largest BC skate species should therefore be monitored closely and used as an index of stock status. Based on the results of Frisk et al. (2001) the largest species should be the most conservatively managed. This should work well for managing the B.C. skate fishery, because big skate is both the largest and the most important species caught in the fishery. Because rajid species are closely associated ecologically, it is next to impossible to harvest one species without harvesting others (Fahy 1991), and management via species specific catch limits is therefore inappropriate (Agnew et al. 2000). However, gearing management toward big skate should result in conservative management of all skate species, because the recommended yields for big skate will necessarily be conservative. This situation differs from that in the Grand Banks because in that area, management is focused on thorny skate which is relatively small and may be more resilient to exploitation than the other species, notably barndoor skate.

The problem of combined catches, observed in the Grand Banks skate fishery, can be avoided in the British Columbia fishery. Aggregated landings provide gross abundance indices for skates, but mask underlying changes in species composition and distribution. Species specific information would enable early detection of changes in abundance, and prevent near extinctions of the most vulnerable species (e.g. barndoor skate). The barndoor skate example is particularly relevant for fisheries in B.C. and California, because barndoor skate is similar in its biology to big skate (Musick et al. 2000). All landings in the British Columbia fishery have been recorded by species since 1996. Where possible, skates should be landed whole for proper identification. Observers must be trained to properly identify skate species, which can be difficult due to the similar morphology of most skate species.

7.0 SHARKS OF BRITISH COLUMBIA

Four shark Orders, the Hexanchiformes (cow sharks), Lamniformes (mackerel, basking and thresher sharks), Carchariniformes (cat sharks, houndsharks and requiem sharks) and the Squaliformes (dogfish sharks) are present in British Columbia waters (Gillespie 1993, Table 7). Gillespie’s classification system differs from Hart (1973), who identified two Orders, the Hexanchiformes and Squaliformes. Hart separated the Orders based on the number of gill openings present. Sixgill and sevengill sharks (cowsharks) were placed in the Hexanchiformes while all other “higher” sharks, with five gill openings were placed in the Squaliformes. Information on the distribution of B.C. sharks is presented in Table 8.

Table 7 Classification of the sharks of British Columbia.
Asterisk denotes those species caught in British Columbia fisheries 1984-2000. Table based on Gillespie (1993).

CLASS	ORDER	FAMILY	GENUS	COMMON NAME
Elasmobranchii	Hexanchiformes	Hexanchidae		
		-cow sharks	*Hexanchus griseus*	sixgill shark*
			Notorynchus cepedianus	sevengill shark*
	Lamniformes	Lamnidae		
		-mackerel sharks	*Carcharodon carcharias*	great white shark
			Isurus oxyrinchus	shortfin mako
			Lamna ditropis	salmon shark*
		Cetorhinidae		
		-basking sharks	*Cetorhinus maximus*	basking shark*
		Alopiidae		
		-thresher sharks	*Alopias vulpinus*	thresher shark*
			Alopias superciliosus	bigeye thresher shark*
	Carchariniformes	Scyliorhinidae		
		-cat sharks	*Apristurus brunneus*	brown cat shark*
		Triakidae		
		-hound sharks	Subfamily Galeorhininae	
			Galeorhinus galeus	soupfin shark*
		Carcharhinidae		
		-requiem sharks	*Prionace glauca*	blue shark*
	Squaliformes	Squalidae		
		-dogfish sharks	*Squalus acanthias*	spiny dogfish*
			Somniosus pacificus	Pacific sleeper shark*
			Etmopterus spp.	green-eye shark*

Within the four Orders, there are twelve species of shark that have been confirmed as present in B.C. waters. Two additional species that had not been previously considered to be B.C. species, the green-eye shark (*Etmopterus spp.*) and bigeye thresher shark (*Alopias superciliosus*), are now being captured in B.C. fisheries. Small numbers of green-eye shark were caught in joint-venture trawl surveys in 1991 and 1994. These specimens were identified to the genus level, but according to Campagno (1984) *E. villosus* is the only species present in the Pacific Ocean. Trace amounts of bigeye thresher were reported from observed domestic and joint-venture trawl fisheries in 1992, 1993 and in 1996 through to 2000. The focus of this report is the shark species for which a formal assessment has not been made. Spiny dogfish (*Squalus acanthias*) is therefore not discussed in any detail.

Table 8 Distribution of British Columbia shark species.
Table based on Compagno (1984).

SPECIES	GEOGRAPHIC RANGE	DEPTH
sixgill shark	temperate and tropical seas	continental shelf; to 1875m
sevengill shark	temperate seas	coastal areas, often <1m
Pacific sleeper shark	temperate North Pacific	0-2000m depends on latitude
spiny dogfish	antetropical, boreal, warm temperate waters	continental shelf; to 900+m
thresher shark	circumglobal in warm waters	coastal to 366m
bigeye thresher shark	circumglobal in warm waters	surface to 500m
basking shark	coastal boreal to warm temperate seas	coastal-pelagic
great white shark	circumglobal and amphitemperate	coastal areas, shallow bays
shortfin mako	temperate and tropical seas	surface to 150+m
salmon shark	temperate North Pacific	coastal –oceanic to 152m
brown cat shark	eastern North Pacific	benthic on shelf 33-950m
blue shark	circumglobal in oceanic temperate and tropical seas	epi-pelagic to 152m
soupfin shark	circumglobal in temperate coastal seas	coastal-pelagic to 471m
green-eye shark	-	-

7.1 BC Shark Catches

Records of shark bycatch in British Columbia (BC) fisheries date back to 1984. During the 1980s, the reported total shark catch was highest in the longline fishery (Table 9). There was an overall decline in total shark catch from the longline fishery from 14.3 t in 1985, to 7.9 t in 1993, to 1 t in 2000. Similar to the skates, the apparent increase in shark catch in the trawl fishery can be attributed to improved reporting of catches by observers starting in 1996. Additionally, there were no recorded discards in the late 1990s in the trawl fishery. Shark catch in the trawl fishery increased steadily through the late 1990s to 14.6 t in 2000, the highest catch on record (Table 9). The average shark catch over 1996-2000 was 11.6 t. Several species were recorded at both the Genus and Family level, and as a result the catches were combined as follows: the cowsharks include sixgill (*Hexanchus griseus*) and sevengill (*Notorynchus cepedianus*) sharks, brown cat sharks (*Apristurus brunneus*) appear as cat sharks, salmon sharks (*Lamna ditropis*) appear as mackerel sharks, and blue sharks (*Prionace glauca*) appear as requiem sharks. Of the eleven shark species (not including dogfish) taken as bycatch in British Columbia fisheries since 1984 (see Table 7), the cow sharks, predominantly sixgill sharks, account for the largest proportion (Table 10).

During 1984-2000, sharks were caught in all areas (Figure 11). The largest total catches over 1984-2000 occurred on the west coast of Vancouver Island in area 3D (24.2 t total), however, when the catches are examined by area and species, a peak in area 4B is evident, and is composed mainly of cow shark (23 t).

Table 9 Total reported British Columbia shark catch (tonnes) by gear type and utilization. "Other" includes seine, trap, troll, and unknown.

	TRAWL				LONGLINE				OTHER	**TOTAL**
Year	discards	retained	unknown	total	discards	retained	unknown	total		
1984	-	-	-	-	-	-	1.31	1.31	-	**1.31**
1985	-	-	0.01	0.01	-	-	14.29	14.29	0.06	**14.35**
1986	-	-	1.64	1.64	-	-	2.65	2.65	0.26	**4.56**
1987	-	-	-	-	-	-	6.24	6.24	0.19	**6.43**
1988	-	-	-	-	-	-	3.53	3.53	0.29	**3.82**
1989	-	-	-	-	-	0.20	0.21	0.42	0.11	**0.53**
1990	-	-	-	-	-	-	0.59	0.59	0.14	**0.72**
1991	-	-	-	-	-	-	0.76	0.76	-	**0.76**
1992	-	-	-	-	-	-	0.13	0.13	0.05	**0.18**
1993	-	-	-	-	-	2.99	4.94	7.92	0.17	**8.09**
1994	-	-	-	-	-	0.09	3.33	3.42	0.03	**3.45**
1995	-	-	-	-	-	-	0.35	0.35	0.02	**0.37**
1996	-	13.95	-	13.95	-	-	1.20	1.20	0.03	**15.17**
1997	-	7.28	-	7.28	-	-	-	0.00	0.04	**7.32**
1998	-	11.21	-	11.21	-	-	0.10	0.10	0.37	**11.68**
1999	-	10.71	-	10.71	2.06	-	1.23	3.29	0.05	**14.05**
2000	-	14.59	-	14.59	0.64	0.26	0.10	1.01	0.01	**15.61**

Table 10 Total reported British Columbia catch (tonnes) by year for the nine most common shark species.

year	BASKING SHARK	CAT SHARKS	COWSHARKS	MACKEREL SHARKS	PACIFIC SLEEPER	REQUIEM SHARKS	SOUPFIN SHARK	THRESHER SHARK	UNID. SHARKS
1984	-	-	1.31	-	-	-	-	-	-
1985	-	-	14.35	-	-	-	-	-	-
1986	-	-	4.56	-	-	-	-	-	-
1987	-	-	6.43	-	-	-	-	-	-
1988	-	-	3.82	-	-	-	-	-	-
1989	-	-	0.53	-	-	-	-	-	-
1990	-	-	0.72	-	-	-	-	-	-
1991	-	-	0.76	-	-	-	-	-	-
1992	-	-	0.18	-	-	-	-	-	-
1993	-	-	8.09	-	-	-	-	-	-
1994	-	-	3.45	-	-	-	-	-	-
1995	-	-	0.37	-	-	-	-	-	-
1996	1.17	0.30	1.31	0.50	2.15	0.41	-	-	9.34
1997	-	0.53	0.51	0.43	0.55	0.55	0.03	-	4.73
1998	-	0.57	2.44	0.48	3.16	0.88	0.07	-	4.09
1999	0.25	1.64	4.47	0.15	5.27	0.63	0.02	-	1.61
2000	2.04	1.29	1.24	0.73	8.24	1.42	0.15	0.03	0.48

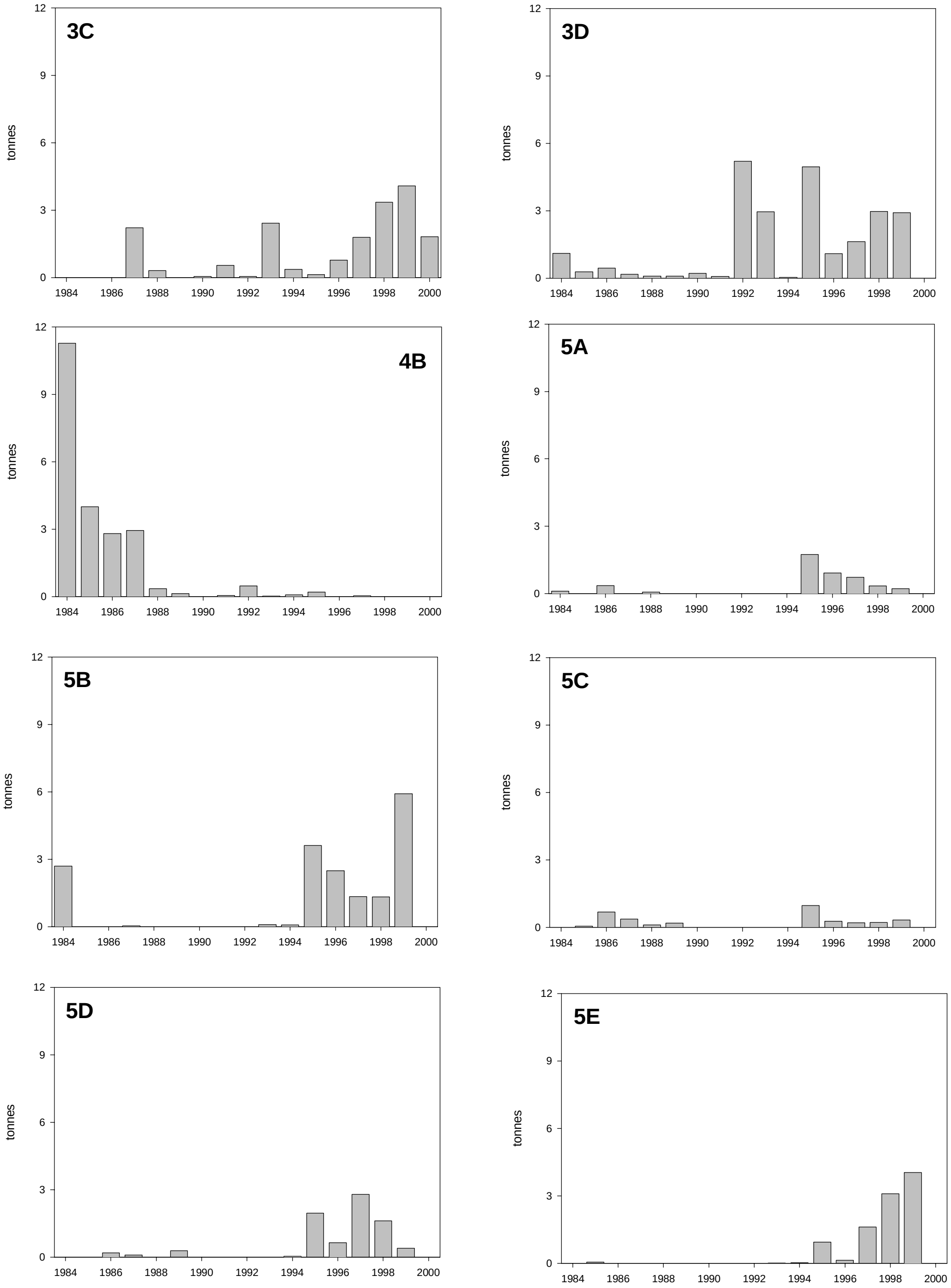

Figure 14 British Columbia total reported shark catch by area and year.

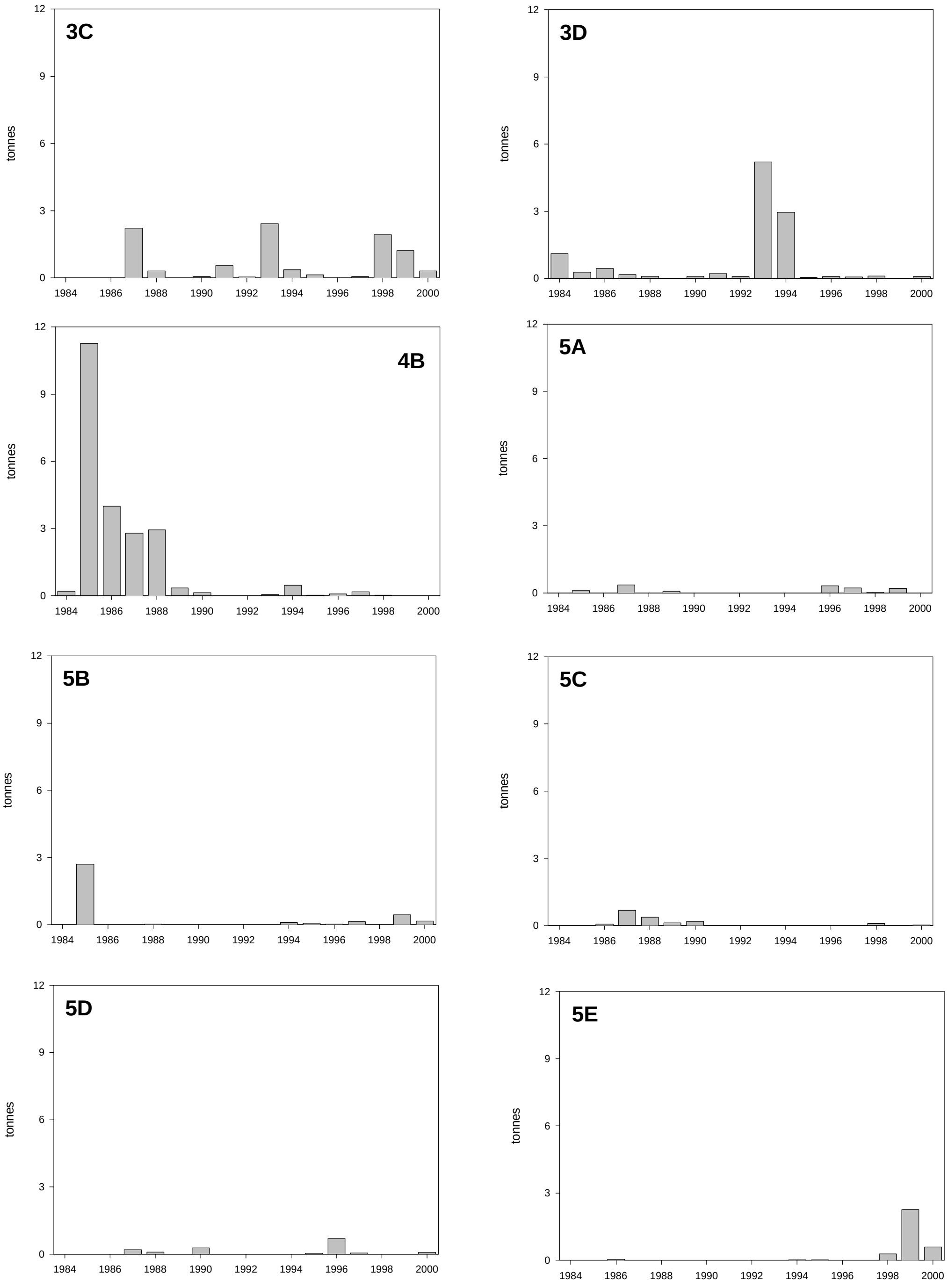

Figure 15 British Columbia reported cow shark catch by area and year.

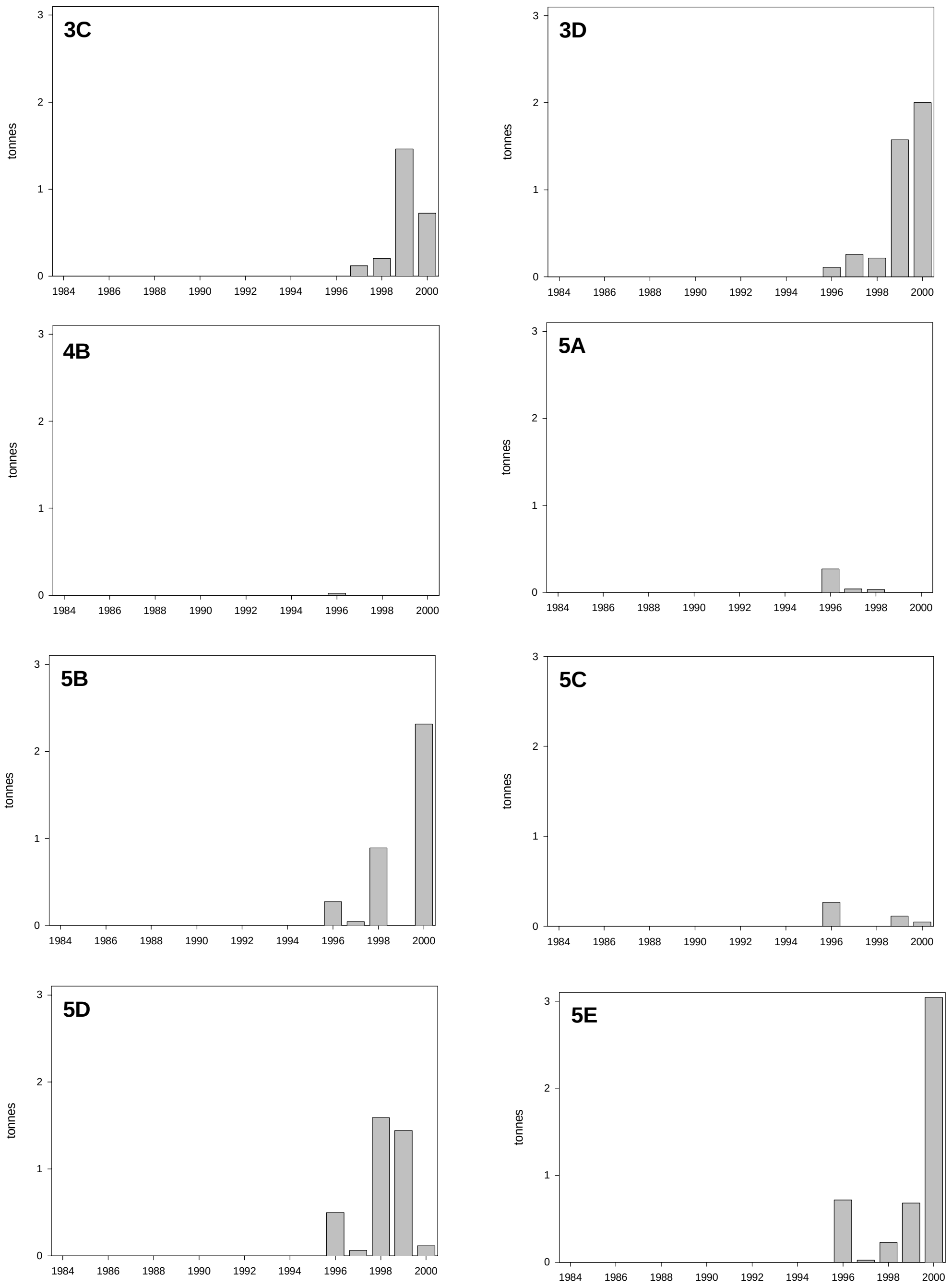

Figure 16 British Columbia reported Pacific sleeper shark catch by area and year.

Cow shark catches were at their highest levels during 1984 to 1988 (Figure 12). The highest catch of 11.3 t was reported from area 4B in 1985. Pacific sleeper shark (*Somniosus pacificus*) catches peaked at 3t in area 5E in 2000 (Figure 13). Misidentification of Pacific sleeper sharks as sixgill sharks by observers was corrected in 1999 and 2000, and resulted in an apparent increase in Pacific sleeper catch in those years. In general, the reported catches of all other sharks have also been increasing since 1996 (Table 10). Cat sharks are caught in areas 3C, 3D, and 5B. Annual requiem shark catches have been intermittent but maintained at low levels (less than 0.5 t) in areas 3C, 3D, 5A, 5B, 5C, 5D, and 5E since 1988. No requiem shark catches have been reported from area 4B. Mackerel shark catches were low in area 5B over 1996 to 1999 (average of 0.11 t), and they increased in 2000 to 0.68 t. Basking sharks were caught only in area 3D in 1999 (0.25 t) and area 5B in 1996 (1.2 t) and 2000 (2.1 t).

7.2 Biology

7.2.1 Biological Data

In order to gain information on the distribution, age and growth of sixgill sharks in British Columbia waters, a cooperative tagging program between industry and government was conducted off the west coast of Vancouver Island from May through September 1994. Using hook and line gear, a total of 265 sharks were captured. The sex and total length (cm) was recorded for all specimens. Sizes ranged from 76cm to 417cm (Figure 15), not exceeding the maximum reported length of 482cm (Table 11, Compagno 1984). Additionally, none of the female sixgills were in the range of sizes considered to be mature (450-482cm). No information is available on the size at maturity of males. The largest amount of shark is taken in area 3D and is in large part composed of cow shark (sixgills). No females examined from the west coast of Vancouver Island (areas 3C and 3D) were mature, which is an indication that the largest amount of shark catch in the Canadian fishery is immature sixgills.

When compared by area, the length frequencies are similar, but the largest males and females were taken in area 3C. Sixgill sharks measure between 65 and 70cm at birth (Compagno 1984). Two of the captured sharks were less than 80cm in length (76 and 78cm), and both were female, while 21 sharks were less than 100cm in length, 10 of which were male. The two smallest sharks were captured off Tofino (area 3C) in early June. Although the range of sizes captured was wide, the frequency distributions are heavily weighted toward the smaller sizes for both male and female sixgills. 56 stomachs were examined from sixgills ranging from 85 to 417cm in length. Of these, 48 were empty, 7 contained salmon and 1 contained squid.

The DFO groundfish biological database contains mostly biological data from target species, but some records exist for bycatch. Shark data exists for August 2000. Two blue sharks (*Prionace glauca*) were caught by longline gear in area 5E in August 2000. Both were females, measuring 218 and 164cm total length. According to Compagno (1984) the largest was close to maturity (Table 11). Two Pacific sleeper sharks were captured by a trawler in area 5E in August 2000. Again, both were female and measured 136.5 and 147.5cm total length.

7.2.2 Life History Parameters

A considerable amount of biological information on sharks was summarized by Compagno (1984). The available information on the common British Columbia shark species reproduction, maturity, size, and diet is summarized in Table 11. It should be noted that two values of maximum length have been reported for sevengill, thresher and soupfin sharks. The lower values were obtained off California for sevengill and thresher sharks and off Australia for soupfin shark.

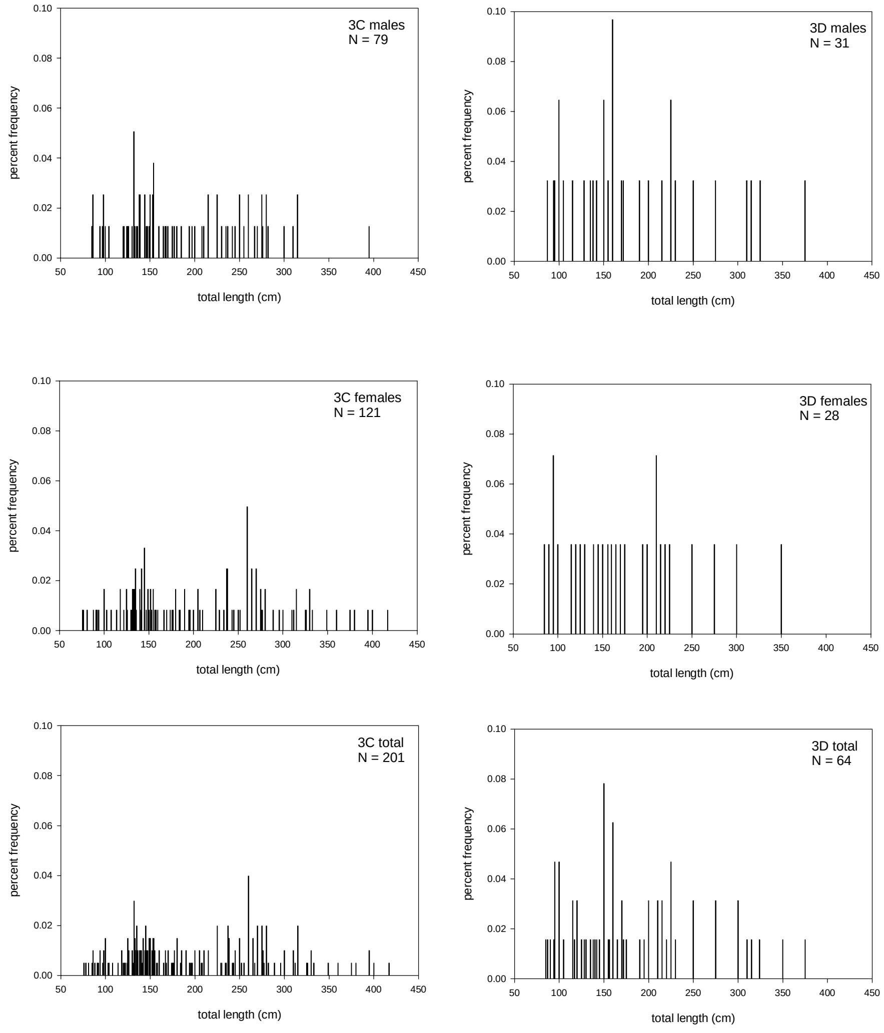

Figure 17 Length frequency of sixgill sharks sampled in areas 3C and 3D off the west coast of Vancouver Island May-September 1994.

Table 11 Biology of the nine most common British Columbia shark species.
Based on Compagno (1984) except where noted.

SPECIES		BIOLOGY
sixgill shark	reproduction	Ovoviviparous
	Litter size	22-108
	size at birth	65-70cm
	maturity	females: 450-482cm
	max length	482cm TL
	Diet	fish, shark, marine mammal
sevengill shark	reproduction	Ovoviviparous
	Litter size	up to 82
	size at birth	45-53cm
	maturity	females: 192-208cm males:150-180cm (11-21yr Ebert 1989)
	max length	300-400cm TL (291 Ebert 1989)
	Diet	fish, rays, sharks, marine mammals
Pacific sleeper shark	reproduction	Ovoviviparous
	Litter size	-
	size at birth	-
	maturity	-
	max length	430cm TL; possibly 700cm
	Diet	invertebrates, fish, marine mammals
thresher shark	reproduction	Ovoviviparous
	Litter size	2-4
	size at birth	114-150cm
	maturity	females: 376-549cm TL males:319-420cm TL (246cm 5yr Cailliet and Bedford 1983)
	max length	549cm TL poss. 609cm
	Diet	small pelagic fishes, invertebrates
basking shark	reproduction	ovoviviparous (?), possible 3.5yr gestation
	Litter size	-
	size at birth	170cm
	maturity	females: 8.1-9.8m males: 4-5m
	max length	9.8m
salmon shark	reproduction	Ovoviviparous
	Litter size	up to 4
	size at birth	-
	maturity	females: n/a males: 180-240cm
	max length	305cm TL; (250-260cm Anderson and Goldman 2001)
	Diet	Salmon
brown cat shark	reproduction	oviparous, eggs incubate 1yr
	Litter size	single egg per oviduct
	size at birth	7cm
	maturity	-
	max length	68cm
	Diet	shrimps, euphausiids, squids
blue shark	reproduction	viviparous, 9-12 month gestation
	Litter size	4-135
	size at birth	35-44cm
	maturity	females:5-6yr; 221-323cm males: 4-5yr, 181-281cm
	max length	383cm
	Diet	bony fishes and squid
soupfin shark	reproduction	Ovoviviparous
	Litter size	6-52
	size at birth	30-40cm
	maturity	females: 11yr, 130-185cm males : 8yr. 120-170cm
	max length	195cm (165 Grant et al., 1979)
	Diet	bony fishes and squid

Frisk et al (2001) generated a predictive model for requiem shark age at maturity: $T_{mat} = 5.92*\ln(L_{max})-23.25$. This model was used to predict blue shark age at maturity. The resulting value (~6yr) (Table 12) is double that reported by Compagno (1984) (~12yr) (Table 11), which may be an indication that the predicted values should be used cautiously. A predictive model was used to obtain r' for Canadian shark species (Table 12). The model was taken from Frisk et al. (2001), and is the same model used for skates (Table 5). Frisk et al noted that the blue shark was an outlier in their analyses, therefore r' was not estimated for this species. The intrinsic rate of population increase (r) at MSY (when the population is growing at its maximum rate), r_{2m} (Smith et al. 1998) is also reported. According to Jennings et al. (1998) r is analogous to r'. Both are indicators of the potential productivity of a species.

Table 12 Estimates of biological parameters for the nine most common British Columbia sharks. Values in parentheses reported by Frisk et al. (2001). L_{max} values from Compagno (1984). r_{2m} values from Smith et al. (1998), who used the lower L_{max} values for thresher, soupfin, and sevengill shark reported in Table 11.

SPECIES	Lmax (cm)	Tmat	r'	r_{2m}
brown cat shark	68	-	0.38	-
soupfin shark	195	(12.00)	0.24 (0.22)	0.03
salmon shark	305	-	0.19	-
sevengill shark	350	(16.00)	0.17 (0.24)	0.03
blue shark	383	11.96	-	0.06
sixgill shark	482	-	0.13	-
thresher shark	549	(5.00)	0.11 (0.14)	0.07
Pacific sleeper shark	430/700	-	0.14/0.08	-
basking shark	980	-	0.03	-

In general, the trends in British Columbia shark species follow the predictions: the higher potential rates of population increase are seen for the smaller shark species. However, the r_{2m} values do not follow the same trend. A similar finding was reported by Stevens et al. (2000), who showed that there is no correlation between body size and Smith et al.'s (1998) rebound potential (r_{2m}). In their analysis, Smith et al. (1998) found that sharks with the highest rebound capabilities tended to be the smaller, relatively short-lived species. Thresher and blue sharks were in the mid range, while sevengill sharks were among those with the lowest recovery capabilities. This is not reflected in the r' values in Table 12.

The brown cat shark and the soupfin shark have r' values in the same range as the skates, while values for the other shark species are much lower, indicating they are likely to be less resilient to exploitation. The sixgill shark, which comprises the majority of the total shark catch in British Columbia, lies in the mid-range of potential rates of increase. Although there appears to be considerable variety in the r' values for British Columbia elasmobranchs, all are on the low end of the scale when compared to teleosts. For example, the r' of relatively large, long-lived species such as halibut (*Hippoglossus*

hippoglossus) and cod (*Gadus morhua*) is 3.83 and 2.26 for each respectively (Frisk et al. 2001).

7.3 Sharks in Other Jurisdictions

The shark species discussed in this section are similar to the species that are caught as bycatch in BC fisheries. Unlike skates, the sharks that are captured in large quantities off the west coast of the United States are not the same species that feature prominently as bycatch in the BC fishery (Holts 1988). The California shark fishery targets predominantly pelagic species such as blue, salmon, thresher, and shortfin mako sharks (Holts 1988; Holts et al. 1998), while sixgill and Pacific sleeper sharks comprise the majority of the British Columbia bycatch.

7.3.1 Deep Water Fisheries

The shark species that are most important as bycatch to BC fisheries are the cowsharks (predominantly sixgill sharks) and the Pacific sleeper sharks. Both of these, along with the brown cat shark, are deep water (>400m) species (Compagno 1984). Compagno (1990) classifies these species as being of moderate importance to global fisheries, while most deepwater species are of minor importance. A moderate rating means that they are regularly caught in substantial amounts or they are rarely caught but are of high value.

According to Gordon (1999), deep water sharks are particularly vulnerable to exploitation because the survival rate of individuals that are brought from great depths and subsequently discarded at sea is either nil or low because they are severely damaged by rapid changes in temperature and pressure. Low survival is probably also the case for the ‘no catch discards’ – sharks that encounter fishing gear and subsequently escape. Adding to their vulnerability is that deep water sharks have particularly low productivity (gestation periods of up to 2 years and fewer young per pregnancy) and increased longevity compared to pelagic species (Walker 1998). Walker further notes that the limited depth ranges of many demersal species means that the total area they occupy is small. The progressive expansion of fishing into the habitat of species with restricted ranges is a threat to the populations.

Deep-water sharks are taken as bycatch in line gear, gillnets, traps, and pelagic and bottom trawls throughout the world (Compagno 1984; Gordon 1999). Deep water fisheries for teleosts have grown rapidly in recent years because of technological improvements to fishing vessels and in response to depleted stocks of shallow water and pelagic species. As a result, shark bycatch has also grown (Gordon 1999). Relatively little is known about deep water fish species, and even less is known about deep water shark species, which adds to conservation concerns (Compagno 1990).

The majority of the available information on deep-water sharks was collected as part of a recent European Union project on deep water fisheries in the eastern Atlantic and Mediterranean. The fisheries operate along and beyond the continental slope, at depths exceeding 200m (Pawson and Vince 1999). France ranks first in landed weight of elasmobranch species in Europe, and deep water trawling by French vessels has increased dramatically since 1990 (Pawson and Vince 1999). The deep water shark species for which the majority of records exist belong primarily to the Squalidae. They are landed in aggregate in French bottom trawl fisheries as "siki" (Gordon 1999). The available information suggests that the majority of deep water species landed from the northeast Atlantic are taken as bycatch in trawl fisheries operating in water deeper than 500m, and increasingly beyond 1000m (Pawson and Vince 1999). Spain and Portugal have recently begun a directed deep water longline fishery for sharks.

Stock assessments for deep-water shark species are a low priority, falling behind the coastal and pelagic species that are the focus of the limited research and management of sharks. Although concern has developed regarding harvesting deep water elasmobranchs in the northeast Atlantic, the focus is on skates and rays (Pawson and Vince 1999). Deep water shark species are harvested in most parts of the world, although very little information exists. For example, Bonfil (1994) identified the high potential of the New Zealand orange roughy fishery to threaten deep water shark populations. Although relatively high bycatch of deep water dogfish in this fishery has been confirmed (Gordon 1999), no catch data have been published.

Gordon (1999) summarized the key problems for management of deep water sharks: the landings are generally of minor importance compared to pelagic species and as a result, most catches are discarded and not reported. The FAO fisheries database confirms this: no catch was reported for cowsharks (Hexanchidae) prior to 1998, and the global reported catches in 1998 and 1999 were 2 and 3 tonnes respectively. When deep water shark catches are reported they are generally aggregated, and often only the fins and liver are retained, neither of which is particularly useful for identification. Because the deep water species are top predators in the ecosystem, all are attracted to baited hooks. The minor importance of most deep water species means that little is known about their life history, behavior, and distribution (Gordon 1999). Another problem is that the aging methods developed for deep water sharks have not been validated (see section 2.2.1).

7.4 Assessment and Management of Sharks in British Columbia

Shark bycatch in B.C. waters is small and stable (<16 tonnes). There appears no immediate concern that current levels of bycatch are negatively impacting the stocks. However, the biology of sharks suggests that some species may be vulnerable to bycatch exploitation.

The life history parameters of sixgill and Pacific sleeper sharks suggest that they are of low to moderate vulnerability to overexploitation compared to the other species examined. Sevengill sharks were grouped together with sixgill sharks as cowsharks for the purpose of this paper, but because of their size, they should be slightly more resilient than sixgills. The basking shark is the most vulnerable while smaller species such as the brown cat shark should be the most resilient to bycatch fishing pressure. Due to the range of life histories and habitats used by the various shark species, it is unlikely that a single management plan will be effective. Pelagic and demersal species will likely require different considerations.

Although there are no indications that current levels of bycatch fishing effort are negatively impacting B.C. shark stocks, there is a need to monitor the bycatch by species and area for catch, effort and length frequencies to ensure that the future production of the most vulnerable species is not negatively impacted.

8.0 RECOMMENDATIONS FOR BRITISH COLUMBIA ELASMOBRANCHS

8.1. Scientific Recommendations

1. Determine the number and geographical limits of the elasmobranch stocks in British Columbia waters. As a starting point, the population distribution of big and longnose skates should be described via survey and fisheries data. Additionally, genetic, tagging and biometric data should be collected and used for stock delineation.

2. Evaluate existing aging techniques, and if necessary develop new methods. Promising methods of aging elasmobranchs include using dorsal spines, vertebral centra, and neural arches (Martin and Cailliet 1988; McFarlane et al. *In press*). Accurate estimates of age can then be combined with other biological data and used to obtain the life history parameters specific to BC elasmobranch species. The empirical relationships that were used to derive preliminary estimates in sections 6.2.2 and 7.2.2 do not account for differences between species or across populations and ranges (Frisk et al. 2001).

3. Examine the role of elasmobranchs as apex predators in the coastal ecosystems of British Columbia, with an aim toward improved ecosystem-based management. A possible approach is to align this study with the new Hecate Strait Program, which would enable an evaluation of the effects of the skate fishery in this area.

4. Examine how the change to targeted fishing of big and longnose skates affected mortality. It may be that not all skates captured prior to 1996 died, as unwanted skate bycatch was often released.

8.2 Management Recommendations

1. Examine the applicability of existing elasmobranch management procedures for B.C. species. There is international concern regarding the increased catches of elasmobranch species, and the management of elasmobranchs has been identified as a global priority (Musick et al. 2000). Promising management actions include: time/area closures of the pupping/nursery grounds, limits on the expansion of effort into offshore and deep water, and size-based limits that will ensure recruitment to the populations.

2. All management must be species-specific. In terms of catch limits, managers must recognize that these limits are species-specific because size-based limits intended to protect individuals of the largest, most vulnerable species (e.g. big skate) might divert effort to smaller species such as black and longnose skates.

3. All catches in all fisheries must be reported by species. Additionally, in order to improve identification and landings statistics, catches should be landed whole.

The coastwide skate catch has averaged 1476 t since 1996- this figure is close to 4 times the historical (1954-1995) average of 382 t. However, the reported catches between 1954 and 1995 are probably low. For example, in area 5D skate catch averaged 870 t between 1996 and 2000. This represents a 9-fold increase over the 1954-1995 reported average of 96 t, but only a 150 t increase over the predicted historical average of 720 t. It appears that this level of exploitation has been sustainable. It is possible that a coastwide limit on skate catch would result in increased effort in area 5D - we therefore recommend that area-specific catch limits for area 5D be set at the 1996-2000 median catch level (700 t for big skate and 200 t for longnose skate). Because of a close association between dover sole and longnose skate catches, some conflict is anticipated when implementing the longnose skate limit.

There is no immediate concern regarding the bycatch of sharks in the B.C. fisheries, therefore no specific recommendations are made. However, the bycatch should be monitored by species and area in order to ensure that the future production of B.C. sharks is not compromised.

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