Distribution and Life History Parameters of Elasmobranch Species in British Columbia Waters

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by

G.A. McFarlane, R.P. McPhie, and J.R. King

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ABSTRACT

McFarlane, G.A., McPhie, R.P., and King, J.R. 2010. Distribution and life history parameters of elasmobranch species in British Columbia waters. Can. Tech. Rep. Fish. Aquat. Sci. 2908: ix + 143 p.

In British Columbia (BC) waters there are 30 elasmobranch species (27 known, 3 probable): sixteen species of shark, eleven species of skate, and three species of ray. This report provides the first comprehensive synthesis of distribution and life history parameters for these 30 species, and will be used to generate more in-depth investigations of individual species, especially those that are commonly encountered in BC waters but for which little or no life history information is available. This information is crucial for the development of future population modelling or stock assessment research.

RESUME

McFarlane, G.A., McPhie, R.P., and King, J.R. 2010. Distribution and life history parameters of elasmobranch species in British Columbia waters. Can. Tech. Rep. Fish. Aquat. Sci. 2908: ix + 143 p.

On trouve dans les eaux de la Colombie-Britannique 30 espèces d'élasmobranches (27 dont la présence est connue, et 3 dont la présence est soupçonnée) : 16 espèces de requins, 11 espèces de raies, et 3 espèces de pastenagues/torpilles. Le présent rapport constitue le premier aperçu approfondi des paramètres de la répartition et du cycle vital de ces 30 espèces, et servira à étayer des études plus poussées sur des espèces précises, en particulier sur les espèces que l'on rencontre souvent dans les eaux de la Colombie-Britannique, mais pour lesquelles on ne dispose que de peu de données sur le cycle vital. De tels renseignements seront essentiels pour modéliser les populations et pour évaluer les stocks dans le futur.

INTRODUCTION

Worldwide, there are over 700 species of elasmobranch (or shark-like) fishes. Over the last few decades, with the decline of many traditional finfish stocks, there has been a growing interest in directed elasmobranch fisheries targeting species from wide-ranging pelagic sharks to demersal, deep-water skates. Overall, global commercial catches of elasmobranchs have risen steadily from 200,000 tonnes in the 1940s to over 800,000 tonnes in recent years, reflecting rapidly emerging markets for their meat and valuable fins (Benson et al. 2001). Along with directed fishing mortality, many species are also subject to unrestricted and unsustainable levels of bycatch mortality by fisheries targeting more highly-productive bony (teleost) fishes (Musick 1999, Stevens et al. 2000, Dulvy et al. 2008). In most cases, the call for assessment and management of the world's elasmobranch populations comes after years of exploitation, with many stocks now considered fully-exploited, declining or maintained at low levels (Musick et al. 2000, Cavanagh and Dulvy 2004). Fisheries scientists are faced with the immediate challenges of: 1) obtaining basic life history information necessary for the accurate assessment of elasmobranch stocks, and; 2) of adapting traditional stock assessment methods for application on species with relatively low productivities and high intrinsic vulnerabilities to over-exploitation (Dulvy et al. 2008).

In British Columbia (BC) waters there are 30 elasmobranch species (27 known, 3 probable): sixteen species of shark (from 11 families), eleven species of skate (from 2 families), and three species of ray (from 2 families). The most common species of elasmobranch currently encountered in BC waters are spiny dogfish (*Squalus acanthias*), big skate (*Raja binoculata*), and longnose skate (*Raja rhina*). Also commonly encountered are brown cat shark (*Apristurus brunneus*), sandpaper skate (*Bathyraja interrupta*), and roughtail skate (*Bathyraja trachura*). Basking sharks (*Cetorhinus maximus*), once common in inlets and bays along the Pacific coast of Canada during summer months (May – October), are now only rarely seen, with only twelve confirmed sightings since 1996 (DFO 2010). This species was recently listed as Endangered under Canada's *Species at Risk Act* (SARA), and is one of three species of elasmobranch listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), with bluntnose sixgill (*Hexanchus griseus*) and tope (or soupfin) shark (*Galeorhinus galeus*) both listed as Special Concern. Pacific populations of the blue shark (*Prionace glauca*), brown cat shark, and great white shark (*Carcharodon carcharias*) were also assessed by COSEWIC, but only classified as Data Deficient. While blue sharks and brown cat sharks are common in BC waters, great white sharks are very rare (Martin and Wallace 2005), as are shortfin makos (*Isurus oxyrinchus*) and hammerheads (*Shyrna zygaena*). There is only a single occurrence of a shortfin mako in BC waters (Gillespie and Saunders 1994), and what few records of hammerheads exist are all historical catches from the 1950s (Carl 1954). There are no official records of Pacific angel shark (*Squatina californica*) off the west coast of Canada, but they are found in California (Ebert 2003) and in Alaska (Mecklenburg et al. 2002) so it is likely that they are also present in BC waters.

Uncommon species of skate and ray include the whitebrow skate (*Bathyraja minispinosa*) and the pelagic stingray (*Dasyatis violacea*), each with only one catch record off the west coast of Canada. There are no official records of the diamond stingray (*Dasyatis brevis*) off the west coast of Canada but Hart (1988) and Gillespie (1993) maintain there is a possibility of their presence off the coast of BC. Similarly, California skate (*Raja inornata*) have not been encountered in BC waters, but according to Eschmeyer et al. (1983), their range extends into Canadian waters north of the Strait of Juan de Fuca.

Of the 30 species of elasmobranch in (or thought to be in) BC waters, targeted fisheries exist for only three species: spiny dogfish, big skate and longnose skate. Catches of sharks (in metric tonnes) on the Pacific coast are highest for spiny dogfish, with the directed fisheries landing an annual average of 4585 tonnes and discarding an average of 1467 tonnes between 2001 and 2005. Brown cat shark and Pacific sleeper shark are also caught but incidentally as bycatch, with average annual landings and discards (2001-2005), less than 1 tonne and 9 tonnes respectively.

For skates, directed fisheries exist for big skate and longnose skate since 2001, with average annual landings (2001-2005) of 1122 and 219 tonnes for big and longnose skate respectively. Average discards for the same period were 217 tonnes for big skate and 127 tonnes for longnose skate. Sandpaper skate, roughtail skate, deepsea skate and Alaska skate are also taken as bycatch, with sandpaper skate being the highest landed (and discarded) skate species after big and longnose skate (DFO 2007).

Overall, elasmobranch catches off the coast of BC mirror the increases occurring worldwide. In the 1970s and 80s, catches of elasmobranchs in BC (excluding spiny dogfish) averaged 550 tonnes, increasing to a maximum of 1850 tonnes in 1997. The average annual catch between 1998 and 2000 was 1400 tonnes (Benson et al. 2001), increasing to approximately 1895 tonnes between 2001 and 2005, with big skate accounting for the majority of the catch (DFO 2007). For spiny dogfish, which continues to be the shark species of greatest commercial importance on the Pacific coast, average annual landings increased from a record low of 273 tonnes (BC and Washington waters combined) in 1971-72 to between approximately 4000 and 5000 tonnes (landings only, BC waters) from 2001-2005 (Wallace et al. 2009). In 2008, the total catch (landings and discards) from both the longline and trawl fisheries was just over 3300 tonnes (Gallucci et al. *In press*).

Despite the growing interest in elasmobranch fisheries in BC, little remains known about most species inhabiting BC waters. In 2001, a report was written by Fisheries and Oceans Canada (DFO) scientists as a first step in acknowledging the need for a scientifically defensible approach to the development of new fisheries, and to the management of fisheries in which elasmobranchs are commonly taken as bycatch (Benson et al. 2001). In this report, the authors outlined, among others, the following research priorities:

1) the development of ageing methods for these species, and obtaining accurate life history parameters for BC elasmobranch species

2) determination of the number and geographical limits of BC elasmobranch populations

In order to address these research needs, the following life history parameter tables and catch distribution figures were compiled for the 30 species of elasmobranch found in (or thought to be in) BC waters. Catch-per-unit-effort (CPUE) maps were created for the more abundant species to give an indication of relative abundance by location. This document is an important step towards fulfilling the challenges outlined above. Results will be used to generate more in-depth investigations of individual species, especially those that are commonly encountered in BC waters but for which little or no life history information is available. For example, the brown cat shark (*Apisturus brunneus*) is an abundant species for which age, growth and maturity data is lacking throughout its geographic range. Accurate estimates of age are required for describing growth rates, longevity, and maturity, all of which are important for stock assessment (McFarlane and Beamish 1987). Likewise, age-based parameters are needed for demographic analyses, the results of which can be used to assess vulnerability and prioritize species for immediate management (McFarlane and Beamish 1987).

Another potential use for the life history parameter information compiled here is a meta-analysis of the data. Frisk et al. (2001) generated empirical relationships between several elasmobranch life history parameters such as age-at-maturity, length-at-maturity, *K* (von Bertalanffy growth parameter), *M* (natural mortality), and r' (potential rate of population increase). These empirical relationships could be used to calculate predicted parameters for BC species for which life history data is lacking. Demographic techniques similar to those employed by Smith et al. (1998) and Dulvy et al. (2008) could then be used in a preliminary study to reveal species most at risk from exploitation due to low productivity potentials.

Here it should be noted that life history characteristics between ocean basins, hemispheres, and in some cases, among latitudes, may not be comparable. For example, large variations in age, growth, and mortality characteristics exist between spiny dogfish in the northeast Pacific and the northwest Atlantic (Campana et al. 2006). Recently, Ebert et al. (2010) have provided evidence that these two spiny dogfish populations are indeed separate species. Nevertheless, for many species of elasmobranch in BC waters, a literature review revealed that the only available estimates of life history parameters were from other regions. These estimates are presented as a starting point for assessment, and hopefully for comparison with future values obtained from BC specimens.

METHODS

LIFE HISTORY PARAMETER TABLES

A comprehensive literature search of primary and secondary publications was conducted to assemble available elasmobranch life history parameters. Information is presented on the taxonomic classification; geographic range; age, growth, and maturity characteristics;

ageing methods; growth parameters; reproductive characteristics; and mortality and demographic parameters for each species. Much of the current knowledge summarized here is from an online life history matrix assembled by the Pacific Shark Research Centre at Moss Landing Marine Laboratories (http://psrc.mlml.calstate.edu/recommended-reading-list/life-history-data-matrix/), which contains up-at-date information on the characteristics of 102 shark, skate and ray species in Pacific waters. In the current summary, for some wide-ranging species life history information is also presented for regions outside of Pacific waters for comparison purposes. References are listed in **Appendix 1: Shark References**, **Appendix 2: Skate References,** and **Appendix 3: Ray References.**

RECENT TAXONOMIC CHANGES AND COMMENTS ON DISTRIBUTION

Sandpaper skate (*Bathyraja interrupta*) has been identified as black skate in the past. Databases have been corrected to reflect this error. Roughtail skate (*Bathyraja trachura*) is considered the synonym for black skate.

Mecklenburg et al. (2002) surmise that any starry skate (*Raja stellulata*) records from Alaska are in fact Alaska skate (*Bathyraja parmifera*). In British Columbia waters, it is uncertain whether records of *B. parmifera* in fisheries databases are correctly identified as such, or whether they are in fact *R. stellulata*. A number of records identified in the database(s) as *B. parmifera* exist from shallower waters and/or southerly areas, suggesting they are perhaps *R. stellulata*, which has an overall shallower depth distribution than *B. parmifera*. *R. stellulata* is a nearshore skate found usually at depths of less than 100 m, but can be found as deep as 732 m (Ebert 2003). *B. parmifera* is found at depths of 20 to 1,425, but is more common at depths of 90 to 250 m (Mecklenburg et al. 2002). It is known that *R. stellulata* is found in southern, shallow waters of BC. Winter and summer distribution maps of *B. parmifera* were created; however, it should be cautioned that a portion of these records might be misidentified *R. stellulata*. Research is ongoing to correctly identify these two species in commercial and research catches.

There has been a taxonomic debate over flathead and Alaska skate. According to Mecklenburg et al. (2002), *Bathyraja rosispinis* (flathead skate) and *B. parmifera* (Alaska skate) are synonymous. We have chosen to use Alaska skate in this report.

There are no official records of California skate (*Raja iornata*) off the west coast of Canada but according to Eschmeyer et al. (1983) their range includes the Strait of Juan de Fuca.

There are no official records of the diamond stingray (*Dasyatis brevis*) off the west coast of Canada but Hart (1988) and Gillespie (1993) maintain that there is a possibility of their presence off the coast of British Columbia.

There are no official records of Pacific angel shark (*Squatina californica*) off the west coast of Canada, but they are found in California (Ebert 2003) and in Alaska (Mecklenburg et al. 2002) so it is likely that they are also present in BC waters.

DISTRIBUTION MAPS

Positional data used to generate the elasmobranch distribution maps were obtained primarily from the following fisheries databases (Fisheries and Oceans Canada, Data Unit, Groundfish Stock Assessment, Marine Ecosystems and Aquaculture Division, Pacific Biological Station, Nanaimo, BC):

- **GFCatch**: contains both commercial trawl and commercial hook-and-line data in a common database from 1954-1996
- **PacHarvTrawl**: commercial trawl data from 1996- 2006
- **PacHarvHL**: commercial hook-and-line data from 1996- 2006
- **PacHar3**: contains commercial fish slip data to 1996
- **GFBio**: a database containing research cruise information collected by fisheries and oceans scientists to 2007

Other sources of data included:

- Data on **shark** survey catches (1991) obtained from an onboard standard operating procedure and quality control manual for the commercial longline fishery on sharks, albacore and pomfret. IEC Collaborative Marine Research and Development Limited, January 1992 (G. McFarlane, unpub. data)
- Incidental **salmon, tope and blue shark** catch data obtained from high seas salmon databases and Pacific sardine catch data (G. McFarlane, unpub. data)
- **Sixgill shark (*Hexanchus griseus*)** survey data obtained from a 1994 survey onboard the F/V Freedom Charger and F/V Glenn E (G. McFarlane, unpub. data)
- **Great white shark (*Carcharodon carcharias*)** distributional data obtained from: Martin, A.R. and Wallace, S. 2005. COSEWIC Status Report on white shark *Carcharodon carcharias* prepared for the Committee on the Status of Endangered Wildlife in Canada. 26 p.
- **Shortfin mako (*Isurus oxyrinchus*)** distributional data obtained from: Gillespie, G.E. and Saunders, M.W. 1994. First verified record of the shortfin mako shark, *Isurus oxyrhinchus*, and second records or range extensions for three additional species, from British Columbia Waters. Canadian Field Naturalist 108(3): 347-350.
- **Basking shark (*Cetorhinus maximus*)** distributional data obtained from: Wallace, S., and Gisborne, B. 2006. Basking Sharks: The Slaughter of BC's Gentle Giants. New Star Books, Vancouver, Canada. 92 p.
- **Smooth hammerhead shark (*Sphyrna zygaena*)** distributional data obtained from: Carl, G.C. 1954. The Hammerhead Shark in British Columbia. Victoria Naturalist 11 (4).
- Directed **blue shark (*Prionace glauca*)** cruise data (2007) obtained from blue shark tagging database (J. King, unpub. data)
- **California skate (*Raja iornata*)** distributional data obtained from: Eschmeyer, W.N., Herald, E.S. and Hammann, H. 1983. A Field Guide to Pacific Coast Fishes of North America. Houghton Mifflin Co., Boston, MA. 336 p.

Within the databases there were many records identified as "sharks" and "skates" with no further species' descriptions. These records were excluded from the report. The date range (i.e. years) of the positional catch data used to generate maps for each individual species is indicated in the figure captions. For species in which seasonal catch data was available, separate (i.e. winter and summer) catch distribution maps were created. For those species where no seasonal catches were recorded, overall catch distribution maps were made. All catch distribution maps were created using ArcGIS 8.0.

CPUE MAPS

For the following, more abundant elasmobranch species in BC waters, catch-per-unit effort (CPUE) maps were generated using data extracted from PacHarvTrawl (1996-2006) to give an indication of relative abundance by location.

- brown cat shark (*Apristurus brunneus*)
- spiny dogfish (*Sqaulus acanthias*)
- sandpaper skate (*Bathyraja interrupta*)
- roughtail skate (*Bathyraja trachura*)
- longnose skate (*Raja rhina*)
- big skate (*Raja binoculata*)

CPUE was only calculated for trawl-landed fish because of the uncertainty around effort data from the hook-and-line fishery prior to 2006. Canadian trawl vessels targeting in BC waters have been 100% observed since 1996, while the hook-and-line fishery was only partially covered through logbook records and at-sea observers until the integration of commercial groundfish fisheries in 2006. Only retained fish were used in the calculation of CPUE values, and only observer records were used.

Maps were created in R-Project 2.10.0 using PBS Mapping 2 (Schnute et al. 2004). Mean CPUE (representing the weight in kilograms of fish caught per hour) was calculated for each grid cell (0.2° by 0.2°).

RESULTS AND DISCUSSION

Contrary to the public misconception that BC waters are devoid of sharks and other shark-like fishes, elasmobranchs off the Pacific coast of Canada are in fact quite diverse and in some cases, abundant. There are 15 families of sharks, skates and rays in BC waters, with the Arhynchobatidae (softnose skates) being the most species-rich (6 species) (**Table 13**) followed by the Rajidae (skates) (4 species) (**Table 13**) and the Lamnidae (mackerel sharks) (3 species) (**Table 1**). Four families (Dasyatidae, Hexanchidae, Alopiidae and Squalidae) have two representative species each. Species range from the small brown cat shark (*Apristurus brunneus*), the California skate (*Raja inornata*), and the starry skate (*Raja stellulata*), all measuring just under a metre maximum total length (TL), to the second largest fish in the world, the basking shark, which can reach sizes of approximately 12 to 15 m TL (**Tables 2, 8 and 14**). Based on the catch distribution (**Figures 1-28**) and CPUE maps (**Figures 29-34**), the families that are most abundant in BC waters are the Squalidae and the Rajidae, with the spiny dogfish (*Squalus acanthias*), the longnose skate (*Raja rhina*), and the big skate (*Baja binoculata*) and making up the largest catches in recent years (**Figures 16, 24 and 26**).

However, despite the notable abundances of some species and recent increased efforts to collect information and determine basic biological characteristics of elasmobranchs in BC waters (Saunders and McFarlane 1993, McFarlane et al. 2002, McFarlane and King 2006, McFarlane and King 2009, King and McFarlane 2010), our compilation of known life history characteristics indicates substantial gaps in our understanding of many of the species (**Tables 1-18**). Of particular concern is the lack of information on basic age, growth and reproductive characteristics specific to populations of elasmobranchs off Canada's Pacific coast. Although elasmobranchs tend to be wide-ranging, exhibiting both seasonal movements (King and McFarlane 2010) and in some instances long-distance migrations (McFarlane and King 2003, Skomal et al. 2009), studies have shown marked differences in life history characteristics of individual species globally (Yamaguchi et al. 2000, Francis et al. 2007). This suggests complex population structuring, and raises the potential that multiple designatable units (DUs) (Green 2005) exist both within BC waters, as well as between BC waters and waters encompassed within the range of many of the species (**Tables 1, 7 and 13**), for example warmer waters to the south (i.e. Puget Sound, and along the west coasts of Washington, Oregon and California) or colder waters to the north (Alaska). Life history characteristics reported here from other geographic regions should thus be considered a starting point, indicative of general trends and not necessarily definitive for to BC populations of elasmobranchs.

Age information forms the foundation for calculations of growth and mortality rates, age at maturity, and longevity, ranking it among the most valuable of biological variables when attempting to assess species' susceptibility to exploitation (Campana 2001). Conventional structures used to determine age in teleost fishes, such as otoliths, fin rays, and scales, are lacking in elasmobranchs and therefore cannot be used for ageing. Instead, in Pacific species as well as elsewhere in the world, vertebral centra are the most commonly used structures, followed by fin spines and caudal thorns (Cailliet and Goldman 2004; **Tables 3, 9 and 15**).

Unfortunately, studies have shown that in some species, especially deep-water or relatively primitive species, the vertebral centra are too poorly calcified to be accurately used for ageing (Cailliet et al. 1983, McFarlane et al. 2002). This might present difficulties when attempting to age BC elasmobranchs, given the deep-water habitats of many of the species (**Tables 1, 7, and 13**). Skates in particular are frequently caught at great depths, with the deepest occurrence ranging from approximately 671 m (California skate, *Raja inornata*) to 2,904 m (deep sea skate, *Bathyraja abyssicola*) (**Table 7**). Among the sharks, the sixgill shark (*Hexanchus griseus*) and the basking shark (*Cetorhinus maximus*) have the deepest recorded occurrences at 2,000 m each (**Table 1**). Novel methods for ageing may be needed, such as the use of other skeletal structures with calcium phosphate deposits (i.e. neural arches; McFarlane et al. 2002) or the use of alternate techniques (i.e. histological techniques; Natanson et al. 2007) to enhance the visualization of growth increments to estimate age.

The deep-water nature of the two representative genuses of skate (*Bathyraja* and *Raja*) (**Table 7**) combined with a traditional disinterest in skates as a commercial resource relative to teleosts and even other elasmobranchs (Bonfil 1994, Benson et al. 2001) have likely resulted in the overall lack of age and growth studies on Pacific skate species to date (**Tables 8 and 9**). Of the 11 skate species residing in Canadian Pacific waters, age information is available for only six. In each case where verification or validation of the periodicity of ring deposition was attempted (6 of the 8 studies carried out to date), the method used was either marginal increment analysis (MIA) or edge analysis (EA) (**Table 9**). Although commonly used and prevalent in the literature, these techniques are difficult to carry out objectively and accurately for all life stages (Beckman and Wilson 1995, Campana 2001). In slow-growing species (including skates), the task of objectively interpreting vertebral edge characteristics is made especially difficult owing to the progressive narrowing of band pairs at the vertebral margins with age.

More accurate validation can be achieved through the use of direct measures of absolute age, such as the release of known age and marked fish, or bomb radiocarbon analysis. Of the 17 species of BC elasmobranch which have been aged using vertebral (or spine) band counts, annual band pair deposition has been validated using a direct method (bomb radiocarbon analysis) in only 1 species: the spiny dogfish (*Squalus acanthias*) (**Tables 3, 9 and 15**). One of the best methods available for validating growth increment periodicity is a mark-recapture of oxytetracycline (OTC) tagged individuals (Beamish and McFarlane 1983, Campana 2001), a method used successfully in only four of the shark species known to inhabit BC waters: the spiny dogfish (*Squalus acanthias*); the great white shark (*Carcharodon carcharias)*; the shortfin mako (*Isurus oxyrinchus)*; and the blue shark (*Prionace glauca*) (**Table 9**). Studies on the spiny dogfish were carried out in BC waters, confirming annual band pair deposition in fish at liberty for up to 20 years post-OTC marking (Beamish and McFarlane 1985, McFarlane and King 2009), whereas studies on the other three species were attempted outside of BC waters, with varied levels of success. In batoids, OTC validation was attempted unsuccessfully in the Pacific electric ray (**Table 3**), while no attempts have been made to validate the periodicity of growth increment formation in Pacific skate species using chemical-tagging (**Table 15**).

Given the multitude of calculations based upon age estimates, and the increased use of age in marine species stock assessment, the importance of accurate validation cannot be understated. Age misinterpretations can lead to potentially serious errors in the management and understanding of fish populations, as outlined by Beamish and McFarlane (1983). As such, as techniques for validation improve, we may see more validation studies being carried out. Bomb radiocarbon analysis – while used effectively on numerous species of long-lived teleosts (Piner et al. 2005, Piner et al. 2006) – is just beginning to gain promise as a accurate means of validating absolute age in elasmobranch species (Ardizzone et al. 2006, Campana et al. 2006, McPhie and Campana 2009). Provided archived specimens with growth increments formed during the period of rapid bomb radiocarbon increase in the northeast Pacific (1955-1975) (Piner and Wischniowski

2004) can be found, this method may prove useful in the future to validate age and growth characteristics in BC elasmobranchs.

Studies reporting age and growth characteristics for elasmobranchs showed an overwhelming use of the von Bertalanffy growth function (VBGF) to estimate growth parameters (**Tables 3, 9, and 15**), despite reports in the literature that small sample size, particularly of small or large individuals, can cause poor parameter estimation using this model (Cailliet and Tanaka 1990, Francis and Francis 1992). A traditional VBGF was used to describe growth in 35 cases; a modified VBGF was used in 6 cases; a Gompertz growth function was used in 7 cases; and another alternate growth model (i.e. logistic, etc.) was employed in 9 cases. When describing growth in skates, authors were more likely to fit their data to multiple models, with models other than the VBGF resulting in more suitable estimates in some instances. It has been suggested that the Gompertz growth function may be more suitable for elasmobranchs that hatch from eggs, and that alternatives to the VBGF (such as Faben's 1965 equation using L_0) should be applied where appropriate for comparison to other models (Cailliet and Goldman 2004).

Estimates of age are often used to determine parameters such as length- and age- at 50% maturity, which in turn are used along with estimates of longevity, fecundity and age-specific-mortality to assess the vulnerability of species through life tables or other demographic analyses. Currently, no estimates of age- at 50% maturity exist for 17 of the 30 species of elasmobranchs known to inhabit BC waters (59%) (**Tables 2, 8, and 14**) and no estimates of longevity exist for 9 of the 30 species of elasmobranchs known to inhabit BC waters (31%) (**Tables 2, 8 and 14**). For most species of sharks and rays there exist estimates of the number of offspring per litter and gestation time (with the exception of the Pacific sleeper shark *Somniosus pacificus* and the green-eye shark *Etmopterus villosus*), whereas for almost all species of skate, there are no accurate estimates of *annual fecundity* or the number of female offspring produced per female per year (**Tables 4, 10, 16**). Estimating fecundity is especially hard in elasmobranchs that are serial indeterminant spawners, where vitellogenic oocytes in various stages of development are present in the ovaries for protracted periods of time, as are egg cases *in utero*, making it difficult to determine spawning season. Many species of skates within the family Rajidae exhibit this type of reproductive strategy (Holden 1975, Ebert 2005). In addition, sperm storage has been observed in some species of elasmobranchs – including skates - (Pratt and Tanaka 1994), indicating a potential disjoint between the timing of mating and the timing of parturition and further complicating calculations of annual fecundity.

From the available demographic information gathered here, it is apparent that there is considerable intrinsic variation in demographic rates among species (and populations) of sharks, skates and rays known to inhabit BC waters (**Tables 5, 11, 17**). This has consequences for their relative responses to exploitation, with species exhibiting lower *r* values being theoretically more vulnerable to decline (Smith et al. 1998, Cortes 2002) and even extirpation (Brander 1981, Dulvy and Reynolds 2002, Griffiths et al. 2010). Based on the literature review carried out here, the larger species (i.e. the large sharks) are likely more susceptible to human- and/or environmental-induced decline than the smaller ones, with *r*-values as low as 0.013-0.04 in the basking shark (*Cetorhinus maximus*) and 0.026-

0.037 in the sevengill shark (*Notorynchus maculates*) (**Table 5**). The one exception appears to be the spiny dogfish (*Squalus acanthias*), which reaches a maximum TL of only 130 cm but has an *r*-value as low as 0.017. The highest estimated *r*-value in the literature for spiny dogfish was 0.07 (**Table 5**). The longnose skate (*Raja rhina*) has the lowest *r*-value (approx. 0.18) of the skates for which estimates of *r* exist, despite reaching a smaller maximum TL than both the Aleutian skate (*Bathyraja aleutica*) and the big skate (*Raja binoculata*), suggesting that the relationship between body size and vulnerability may be less pronounced in this group. In order to confirm these findings, more detailed analyses of the relationships between life history variables are needed using parameters specific to BC populations of elasmobranchs.

In addition to their use in demographic analyses, population-specific parameters can be very useful in stock assessments for long-lived species. The general consensus among fisheries scientists today is that traditional stock assessment models for teleost fishes are less applicable for use in the assessment and management of elasmobranchs because of their *equilibrium strategist* life history characteristics (i.e. extreme longevity, slow growth, late maturity, long gestation period and low fecundity) (King and McFarlane 2003). Surplus production models, for example, assume that the rate of natural increase of a population (1) responds immediately to changes in population density, and (2) is independent of the age composition of the stock, at any given population density (Holden 1977). These assumptions are not usually met in elasmobranch populations in which long lag times exist between reproduction and recruitment and where reproductive capacity is age- (or size-) dependent (Wood et al. 1979, Benson et al. 2001).

As such, age-structured models that incorporate up-to-date biological information such as age, growth, mortality and fecundity, have been used to assess elasmobranch populations in recent years, with varied levels of success (Anderson 1990, Punt and Walker 1998, Simpfendorfer 1999). The accuracy of each model is dependent not only on the quality of the input data but also on the models' ability to account for compensation mechanisms acting at low population densities and ontogenic shifts in habitat and ecological roles. Given the paucity of age composition data for many populations alternate models have been developed for elasmobranchs, such as the risk-based ecological techniques (Cortes et al. 2010) and reproductive value models (Aires-de-Silva and Gallucci 2007, Gallucci et al. 2006). Much more information is needed on the life history parameters of BC elasmobranchs – and on their varied population responses to exploitation - to accurately carry out such complex analyses.

Distribution and CPUE maps are only the very first steps in determining the overall range and abundance of elasmobranch species in BC waters. While CPUE is often used as an index of relative abundance over time, it can be biased by increases in fishing efficiency (or catchability) (Gillis and Peterman 1998, Cox et al. 2002), and by changes in the behaviour of the fishes i.e. hyperaggregation and habitat selection (Rose and Kulka 1999, Freon et al. 1993), resulting in a situation termed *hyperstability*. In the case of elasmobranchs, using commercial catch data as an index of relative abundance across taxonomic groups may be further biased by the fact that few fisheries target elasmobranchs directly. More data are available for targeted species – such as spiny dogfish – than for non-target species. Likewise, trawl fisheries are more likely to bycatch elasmobranchs of larger or similar size to and sharing similar habitats with, the target species. More fisheries-independent data is needed to establish both the distribution and abundance of elasmobranchs in BC waters across space and time. Genetic studies will help determine population structure of species both within BC waters and between BC waters and adjacent waters to the north and south; and further tagging studies will help resolve movement patterns and elucidate migratory behaviour.

In summary, a review of the literature to date allows us to identify gaps in our knowledge of BC elasmobranchs and to prioritize species for study based on: 1) the amount of basic life history data available to date; 2) the frequency of occurrence of the species in BC waters (i.e. whether distribution and abundance maps combined with the literature indicate that it is a rare, infrequent or common species in BC waters); 3) our current knowledge on the status of the species, either in BC or worldwide; and 4) the inherent vulnerability of the species (based on known *r*-values), affecting its ability to rebound in response to additional sources of mortality. Because population status information was lacking for almost all the species in BC waters, global status designations from the International Union for the Conservation of Nature (IUCN) were used (IUCN 2008, IUCN 2010). The lowest reported r-values from the literature were used to classify species into the following relative inherent vulnerability groupings:

r	**relative vulnerability**
0.013 to 0.08	high
0.08 to 0.19	medium
0.20+	low

Based on the four above-listed criteria, the species prioritized for future study are:

1) The sixgill shark (*Hexanchus griseus*)
2) The basking shark (*Cetorhinus maximus*)
3) The brown cat shark (*Apistrurus brunneus*)
4) The tope shark (*Galeorhinus galeus*)
5) The Pacific sleeper shark (*Somniosus pacificus*)
6) The roughtail skate (*Bathyraja trachura*)

All five shark species are (or have been historically) observed with some frequency in BC waters, and have been listed by the IUCN as vulnerable, near threatened or data deficient. Little is known about the basic life history characteristics of all five species, including their inherent vulnerabilities to decline given estimated *r*-values. Although the deep sea skate (*Bathyraja abyssicola*) and the California skate (*Raja inornata*) were also classified as “medium priority” in our evaluation along with the roughtail skate, these two species are only rarely observed in BC waters, suggesting that their centres of distribution may be located elsewhere along the Pacific coast.

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Table 1: Taxonomic classification (including common name), geographic distribution, depth range, and frequency of occurrence of sharks found in British Columbia waters.

Taxonomy				Range			
Family	**Latin Name**	**Common Name**	**Other Names**	**Global**	**Eastern North Pacific**	**Depth Range**	**Occurrence in BC waters**
Hexanchidae (cow sharks)	*Hexanchus griseus*	**sixgill shark**	shovel-nosed shark, cow shark, mud shark, bluntnose sixgill, gray shark	circumglobal from cold temperate regions to tropics, possibly polar (Ebert 2003)	Aleutian Islands, Alaska to southern tip of Baja California (Eschmeyer et al. 1983); evidence for localized movement in Puget Sound (Andrews et al. 2007)	1-2000 m (Last and Stevens 1994)	common (shallow water occurrence in the Strait of Georgia - Flora Islets b/w June 2001 and July 2002) (Dunbrack and Zielinski 2003)
Hexanchidae (cow sharks)	*Notorynchus maculatus*	**sevengill shark**	cow shark, mudshark, spotted cowshark, broadnose sevengill	circumglobal in most temperate waters (Compagno 1984)	Southeast Alaska to the Gulf of California (Eschmeyer et al. 1983, Ebert 1986)	range from surface to 500 m (Compagno 1984); common from 37-46 m but occuring in deeper water in southern part of range (Hart 1988)	rare
Lamnidae (mackerel sharks)	*Carcharodon carcharias*	**great white shark**	white shark, white pointer, man-eater shark	wide-ranging in most temperate and tropical seas from 60°N to 60°S (Compagno 2001, Martin and Wallace 2005); confirmed transoceanic migrations (Bonfil et al. 2005)	Bering Sea and Gulf of Alaska to Gulf of California (Compagno, 2001)	pelagic to 1280 m (Hart 1988)	rare (records in BC almost exclusively of strandings on leeward shores of Queen Charlotte Islands) (Martin and Wallace 2005)

Table 1 (continued).

Taxonomy				Range			
Family	**Latin Name**	**Common Name**	**Other Names**	**Global**	**Eastern North Pacific**	**Depth Range**	**Occurrence in BC waters**
Lamnidae (mackerel sharks)	*Isurus oxyrinchus*	**shortfin mako**	Pacific bonito shark	circumglobal in temperate and tropical seas (Compagno 2001)	mainly from Columbia River, Washington to Chile (Kato and Caravallo 1967), Miller and Lea 1972); only rarely encountered in BC waters (Hart 1973, Wallace et al. 2006a)	pelagic (Hart 1988)	rare (only 1 record from Canadian waters) (Wallace et al. 2006a)
Lamnidae (mackerel sharks)	*Lamna ditropis*	**salmon shark**	porbeagle, mackerel shark	eastern North Pacific and western North Pacific from Japan (Hokkaido, Tokahu, and Chyoshi) to the Bering Sea (Hart 1988, Compagno 2001); evidence of long range migrations throughout the entire eastern North Pacific Ocean during a seasonal migration cycle (Weng et al. 2008)	Alaska to northern Baja California (Compagno 2001); occurs in the Gulf of Alaska throughout the year (Hart 1988)	pelagic and coastwide (Hart 1988); to at least 150 m (Compagno 1984, 2001)	common (in British Columbia, generally distributed in the Strait of Georgia and offshore) (Hart 1988)
Cetorhinidae	*Cetorhinus maximus*	**basking shark**	elephant shark, bone shark, sailfish, sunfish, pelerin, hoe-mother, capidoli, oilfish, oil shark	circumglobal with a wide but disjunct distribution (Compagno 2001)	Aleutian Islands and Gulf of Alaska to Gulf of California (Compagno 2001)	sighted at the surface over the slopes from 200 to 2000 m, and with a few sighted in the oceanic basins at 2000 to 4000 m (Compagno 1984)	rare (animals < 3m now rarely encountered in BC waters); historically common (Wallace et al. 2007a)

Table 1 (continued).

Taxonomy				Range			
Family	**Latin Name**	**Common Name**	**Other Names**	**Global**	**Eastern North Pacific**	**Depth Range**	**Occurrence in BC waters**
Alopiidae (thresher sharks)	*Alopias vulpinus*	**common thresher**	long-tail shark	circumglobal in tropical and cold-temperate seas (Compagno 2001)	Alaska to Mexico (Compagno 2001, Mecklenburg et al. 2002)	pelagic species (Hart 1988)	rare (in British Columbia from Saanich Inlet and Sooke to Johnstone Strait and Goose Bay) (Hart 1988)
Alopiidae (thresher sharks)	*Alopias superciliosus*	**bigeye thresher**	N/A	virtually circumglobal in tropical and temperate seas (Compagno 2001)	southern California and Mexico (Fitch and Craig 1964); rarely encountered north in BC waters (Benson et al. 2001)	oceanic, pelagic and near bottom at 1 to greater than 500 m (Mundy 2005)	infrequent (small numbers reported from observed domestic and joint-venture trawl fisheries in 1992, 1993 and 1996 through 2000) (Benson et al. 2001)
Scyliorhinidae	*Apristurus brunneus*	**brown cat shark**	N/A	eastern Pacific (Hart 1988)	eastern Gulf of Alaska off Icy Point to northern Baja California (Mecklenburg et al. 2002); most British Columbia records from Strait of Georgia (Hart 1988)	137 to 360 m; as deep as 950 m (Hart 1988)	common
Triakidae	*Galeorhinus galeus*	**tope shark**	soupfin shark, school shark	South Pacific, eastern North Atlantic, South Atlantic and southwestern Indian Oceans from 68°N to 55°S; eastern north Pacific (Ebert 2003)	British Columbia to the Pacific coast of central Baja California (no records in Alaska) (Ebert 2003)	mainly demersal on continental and insular shelves, but also on the upper slopes, at depths from near shore to 550 m (Last and Stevens 1994)	common (in BC, records mainly from continental shelf waters along Van Island, QCS and into HS) (Wallace et al. 2007b)

Table 1 (continued).

Taxonomy				Range			
Family	**Latin Name**	**Common Name**	**Other Names**	**Global**	**Eastern North Pacific**	**Depth Range**	**Occurrence in BC waters**
Sphyrnidae (hammerhead sharks)	*Sphyrna zygaena*	**smooth hammerhead shark**	N/A	western Atlantic, north Atlantic, Mediterranean, western Indian Ocean, western Pacific, Australia, and eastern north Pacific (Compagno 1984)	northern California to Gulf of California (Compagno 1984)	coastal, pelagic, and semi-oceanic, but often bottom associated at 1-139 m (Mundy 2005)	rare
Carcharhinidae	*Prionace glauca*	**blue shark**	great blue shark, blue dog	circumglobal distribution in temperate and subtropical waters (Compagno 1984)	British Columbia to Equator (Strasburg 1958, Kato and Caravallo 1976, Pearcy 1991)	pelagic, depth range 1-350 m (Ebert 2003)	common
Somniosidae	*Somniosus pacificus*	**Pacific sleeper shark**	sleeper shark	western Bering Sea to Japan; eastern north Pacific (Compagno 1984)	eastern Bering Sea to Baja California (Compagno 1984)	to at least 448 m, occasionally coming to the surface (Hart 1988)	common
Squalidae	*Etmopterus villosus*	**green-eye shark**	Hawaiian lantern shark	eastern central Pacific, Hawaiian Islands, and eastern north Pacific (Compagno 1984)	eastern Pacific (Compagno 1984)	on or near bottom at 406 to 911 m (Ebert 2003)	rare (small numbers caught in joint-venture trawl surveys in 1991 and 1994) (Benson et al. 2001)
Squalidae	*Squalus acanthias*	**spiny dogfish**	dog shark, grayfish, picked dogfish, rock salmon	circumglobal, antetropical (Compagno 1984)	Bering Sea to central Baja California and Gulf of California (Ketchen 1986)	0 - 1460 m (Ebert 2003)	common

Table 1 (continued).

Taxonomy				Range			
Family	Latin Name	Common Name	Other Names	Global	Eastern North Pacific	Depth Range	Occurrence in BC waters
Squatinidae	*Squatina californica*	**Pacific angel shark**	N/A	eastern North Pacific (Roedel and Ripley 1950, Ebert 2003); Equador to southern Chile (Compagno 1984)	southern Alaska to Gulf of California (Roedel and Ripley 1950, Ebert 2003)	3 - 183 m (Roedel and Ripley 1950); primarily at depths 3 - 46 m (Eschmeyer et al. 1983, Compagno 1984)	rare

Table 2: Age, growth and maturity characteristics of sharks found in British Columbia waters. ♂ = male; ♀ = female; VBGF = von Bertalanffy growth function; K = VBGF growth coefficient; L_∞ = mean asymptotic total length; PCL = precaudal length; obs = observed; calc = calculated; vert = vertebral method; bomb = bomb radiocarbon method.

	Age and Growth							
Common Name	**Max length (TL) (cm)**	**Longevity (T_{max}) (yrs)**	**Method for longevity determ.**	**Length at 1st maturity (cm)**	**Age at 1st maturity (yrs)**	**Length-at-50% maturity (TL_{50}) (cm)**	**Age-at-50% maturity (T_{50}) (yrs)**
sixgill shark	348 (Springer and Waller 1969) 482-500+ (Compagno 1984, Ebert 2002) 550 (Clark and Kristof 1990)	80 (Ebert 2002, Wallace et al. 2007c)	efforts to age sixgills using vertebrae proved unsuccessful (Ebert 1986a)	450-482 (Springer and Waller 1969) 421 (Ebert 1986a) ♂: 309 (Crow et al. 1996) ♂: 310 ♀: 420 (Ebert 2002)	♂: 11-14 ♀: 18-35 (Florida Museum of Natural History 2006, Wallace et al. 2007c)	no estimate(s)	no estimate(s)
sevengill shark	300-400 (Hart 1973) ♂: 242 ♀: 296 (Ebert 1986)	no estimate(s)	sevengills do not have well calcified vertebrae; difficult to age directly (Ebert 1989) indirect estimate; 95% of L_∞ from VBGF (Van Dykhuizen and Mollet 2002)	♂: 150-180 ♀: 192-208 (Hart 1973) ♂: 153 ♀: 218-244 (Ebert 1989) ♂: 153-160 ♀: 218-254 (Van Dykhuizen and Mollet 2002)	♂: 4.3-5 (predicted) ♀: 11-21 (predicted) (Van Dylhuizen and Mollet 1992)	no estimate(s)	no estimate(s)

Table 2 (continued).

Common Name	Age and Growth						
	Max length (TL) (cm)	**Longevity (T_{max}) (yrs)**	**Method for longevity determ.**	**Length at 1st maturity (cm)**	**Age at 1st maturity (yrs)**	**Length-at-50% maturity (TL_{50}) (cm)**	**Age-at-50% maturity (T_{50}) (yrs)**
great white shark	♀: 445 (Bass et al. 1975) ♂: 477.5 (Klimley 1985) ♀: 563.9 (Cailliet et al. 1985) ♀: 348 PCL (Cliff et al. 1989) ♂: 500-580, possibly >700 (Mollet et al. 1996)† ♂: 373 PCL ♀: 297 PCL (Wintner and Cliff 1999) sex unspecified: 5.2 (in BC) (Coad 1995, Martin and Wallace 2005)	27 (Cailliet et al. 1985) 50-60 (Welden et al. 1987) 23+ (Ebert 2003) 23-60 (Cailliet et al. 1985, Mollet and Cailliet 2002, Martin and Wallace 2005)	annual growth rings (Cailliet et al. 1985) radiometric age determination using 210Pb (Welden et al. 1987) annual growth rings (Wintner and Cliff 1999)	366-427 (Cailliet et al. 1985) 500-550 (Weldon et al. 1987) ♂: 350-410 (Pratt 1996, Compagno 2001, Martin and Wallace 2005) ♀: 450-500 (Francis 1996, Compagno 2001, Martin and Wallace 2005)	9-10 (Cailliet et al. 1985) 16-20 (Weldon et al. 1987) ♂: 8-10 ♀: 12-13 (Wintner and Cliff 1999) ♂: 8-10 (Pratt 1996, Compagno 2001, Martin and Wallace 2005) ♀: 12-18 (Francis 1996, Compagno 2001, Martin and Wallace 2005)	♂: 317-460 (Pratt 1996)	no estimate(s)

Table 2 (continued).

Common Name	Max length (TL) (cm)	Longevity (T_{max}) (yrs)	Method for longevity determ.	Length at 1st maturity (cm)	Age at 1st maturity (yrs)	Length-at-50% maturity (TL_{50}) (cm)	Age-at-50% maturity (T_{50}) (yrs)
	Age and Growth						
shortfin mako	396 (Bigelow and Schroeder 1948) 351 (Applegate 1977) 337 (Uchida et al. 1987) 400 (Compagno 2001) ♀: 347 (Bishop et al. 2006) ♀: 330 (Cerna and Licandeo 2009)	45 (theoretical) (Cailliet et al. 1983) 28 (theoretical) (Smith et al. 1998) 21-22 (Campana et al. 2002) 24 (Campana et al. 2004a) ♂: 9 ♀:18 (Ribot-Carballal et al. 2005) ♂: 29 (obs), 21 (calc) ♀: 32 (obs), 38 (calc) (Natanson et al. 2006) ♀: 31 (Ardizonne et al. 2006) ♂: 29 ♀: 28 (Bishop et al. 2006) ♂: 14 ♀: 20 (Semba et al. 2009) both sexes: 25+ (Cerna and Licandeo 2009)	VBGF (Cailliet et al. 1983) VBGF (Smith et al. 1998) bomb radiocarbon (inference) (Campana et al. 2002) vertebral cross-sections (Campana et al. 2004a) vertebral band counts and calculated using L_∞ (Natanson et al. 2006) bomb radiocarbon (Ardizonne et al. 2006) vertebral band counts (Ribot-Carballal et al. 2005, Bishop et al. 2006, Semba et al. 2009, Cerna and Licandeo 2009)	180-183 (Bigelow and Schroeder 1948, Cailliet et al. 1983) ♂: 180-185 ♀: 275-285 (Francis and Duffy 2005) ♂: 180 ♀: 210-290 (est) (Maia et al. 2007)	7-8 (Cailiet et al. 1983) ♂: 7 ♀: 15 (Ribot-Carballal et al. 2005) ♂: 6 ♀: 16 (Semba et al. 2009)	♂: 200-220 (Pratt and Casey 1983) ♀: 298 (western NA), 273 (southern hemisphere) (Mollet et al. 2000) ♂: 185 ♀: 275 (Natanson et al. 2006)	♂: 8 ♀: 18 (Natanson et al. 2006) ♂: 7-9 (6.9 probit), 8-9 (indirect) ♀: 19-21 (19.1 probit), 20-21 (indirect) (Bishop et al. 2006)

Table 2 (continued).

	Age and Growth						
Common Name	**Max length (TL) (cm)**	**Longevity (T_{max}) (yrs)**	**Method for longevity determ.**	**Length at 1st maturity (cm)**	**Age at 1st maturity (yrs)**	**Length-at-50% maturity (TL_{50}) (cm)**	**Age-at-50% maturity (T_{50}) (yrs)**
salmon shark	305 (Roedel and Ripley 1950) 310 (Stevenson et al. 2007)	♂: 25 ♀: 17 (Tanaka 1980) ♂: 17 ♀: 20 (Goldman and Musick 2006) ♂: 27+ ♀: 20+ (Compagno 2001)	growth rings (Tanaka 1980) vertebral centra: sagittal sections (Goldman and Musick 2006)	♂: 91-155.4 PCL (mean 124 PCL) ♀: 164-176.5 PCL (mean 164.7 PCL) (Goldman and Musick 2006)	♂: 3-5 ♀: 6-9 (Goldman and Musick 2006)	♂: 124 PCL ♀: 164.7 PCL (Goldman and Musick 2006)	♂: 3-5 ♀: 6-9 (Goldman and Musick 2006)
basking shark	1500 (Phillips 1948) 980-1400 (Kato et al. 1967) 1220-1520 (Compagno 2001) 970 (Pauly 2002)	8 (Parker and Stott 1965) 50 (est.) (Pauly 2002, UK CITES proposal 2002, Wallace et al. 2007a) 33 (Natanson et al. 2008) 44 (Campana et al. 2008)	vertebral ring counts, assuming rings formed twice per year (Parker and Stott 1965) re-analysis of Parker and Stott's (1965) data (Pauly 2002) vertebral ring counts; concluded age estimates not accurate (Natanson et al. 2008) growth bands; bomb radiocarbon suggests vert sections overestimate age by 7-8 yrs. (Campana et al. 2008)	♂: 460-610 ♀: presumed to mature at larger size (Bigelow and Schroeder 1948)	♂: 12-16 ♀: 16-20 (UK CITES proposal 2002, Wallace et al. 2007a, Campana et al. 2008)	no estimates(s)	no estimate(s)

Table 2 (continued).

	Age and Growth						
Common Name	**Max length (TL) (cm)**	**Longevity (T_{max}) (yrs)**	**Method for longevity determ.**	**Length at 1st maturity (cm)**	**Age at 1st maturity (yrs)**	**Length-at-50% maturity (TL_{50}) (cm)**	**Age-at-50% maturity (T_{50}) (yrs)**
common thresher	609.6 (Bigelow and Schroeder 1948) 760.0 (Hart 1973) 573.3+ (Cailliet and Bedford 1983)	15+ (Cailliet and Bedford 1983) possibly 45-50 (Cailliet et al. 1983)	vertebral band counts (whole vertebrae) (Cailliet and Bedford 1983) estimation from VBGF (Cailliet et al. 1983)	♂: 333 ♀:260-426.7 (Cailliet and Bedford 1983)	3-7 (Cailliet and Bedford 1983) 3-8 (Cailliet et al. 1983)	no estimates(s)	no estimates(s)
bigeye thresher	♀: 460.7 (Nakamura 1935) ♂: 410 (Moreno and Moron 1992) ♂: 378 (Gruber and Compagno 1981) ♂: 357.7 ♀: 422.8 (Chen et al. 1997)	♂: 19 ♀: 20 (Liu et al. 1998)	vertebral band counts and extrapolation from VBGF (Liu et al. 1998)	♀: 332-366 (Nakamura 1935), 356 (Gruber and Compagno 1981) ♂: 276 ♀: 341 (NE Atlantic and Med) (Moreno and Moron 1992) ♂: 253 (140 PCL) ♀: 341.1 (180 PCL) (Chen et al. 1997) ♂: 138-171 PCL ♀: 154-185 PCL (Liu et al. 1998)	♂: 7-13 ♀: 8.4-14.7 (Liu et al. 1998)	♂: 270.1-287.6 (150-155 PCL) ♀: 332-341.1 (175-180 PCL) (Chen et al. 1997)	♂: 9-10 ♀: 12.3-13.4 (Liu et al. 1998)

Table 2 (continued).

	Age and Growth							
Common Name	**Max length (TL) (cm)**	**Longevity (T_{max}) (yrs)**	**Method for longevity determ.**	**Length at 1st maturity (cm)**	**Age at 1st maturity (yrs)**	**Length-at-50% maturity (TL_{50}) (cm)**	**Age-at-50% maturity (T_{50}) (yrs)**
brown cat shark	69 (Eschmeyer et al. 1983) ♂: 58.0 ♀: 54.0 (Jones and Geen 1977) ♂: 70.4 (in BC) ♀: 65.1 (in BC) (Wallace et al. 2006)	no estimate(s)	no attempts have been made to age this species (Wallace et al. 2006b)	♀: 45.0 (w/ mature eggs) (Jones and Geen 1977) ♂: 45-50 ♀: 42.5-47.5 (Cross 1988) ♂: 48.8 ♀: 48.5 (latitudinal gradient, with maturity occuring at larger sizes in more northern latitudes) (Flammang 2005) ♂: 55 (in BC) ♀: 54 (in BC) (Flammang 2006 pers. comm., Wallace et al. 2006b)	no estimate(s)	♂: 51.4 ♀: 50.1 (Flammang 2005)	no estimate(s)
tope shark	♂: 175 ♀: 195 (NE Pacific) (Compagno 1984)	45 (Moulton et al. 1989) 40 (Ferreira and Vooren 1991) 20 (Moulton et al. 1992) 15 (vert), 23 (bomb) (NZ) (Kalish and Johnston 2001)	tagging study w/ individ at liberty 35 yrs. (Moulton et al. 1989) vertebral annulus counts (Ferreira and Vooren 1991, Moulton et al. 1992)	♂: 135 ♀: 150 (NE Pacific) (Ripley 1946)	♂: 12-17 ♀: 13-15 (NZ) (Francis and Mulligan 1998) ♀: 12 (Smith et al. 1998)	♂: 87% were mature at 155 ♀: 65% were mature at 160 (Ripley 1946)	♀: 14 (Francis and Mulligan 1998)

Table 2 (continued).

	Age and Growth						
Common Name	**Max length (TL) (cm)**	**Longevity (T_{max}) (yrs)**	**Method for longevity determ.**	**Length at 1st maturity (cm)**	**Age at 1st maturity (yrs)**	**Length-at-50% maturity (TL_{50}) (cm)**	**Age-at-50% maturity (T_{50}) (yrs)**
hammerhead shark (smooth)	370-400 (Compagno 1984) 500 (Muus and Nielsen 1999)	no estimates(s)	N/A	♂: 275-335 ♀: 275-335 (Compagno et al. 1995)	no estimates(s)	no estimates(s)	no estimates(s)
blue shark	396.2 (Bigelow and Schroeder 1948, Hart 1973, Pratt 1979) comb: 266 (estimated from VBGF) (Cailliet and Bedford 1983) 380 (largest authenticated) (Hart 1988)	20 (Cailliet et al. 1983) ♂: 16 ♀: 15 comb: 16.5-26.1 (calc) (N Atl.) (Skomal and Natanson 2003) ♂: 16 ♀: 12 (Blanco-Parra et al. 2008)	vertebral band counts (Cailliet et al. 1983, Blanco-Parra et al. 2008) sagittal sections of vertebral centra and calculations using equation from Taylor (1958) and Fabens (1965) (Skomal and Natanson 2003)	♂: 183 ♀: 145-185 (N.Atl.) (Pratt 1979) ♂: 120-140 PCL (N Pacific) (Nakano et al. 1985) ♂: 130-160 PCL (N Pacific) (Nakano 1994) ♂: 193-210 FL (N Atl.) (Campana et al. 2004b)	< 8 (Pratt 1979)	220 (Pratt 1979) ♂: 150-155 PCL ♀: 159 PCL (Nakano et al.1985) ♂: 203 ♀: 186-212 (N Pacific) (Nakano 1994)	6-7 (Cailiet and Bedford 1983) ♂: 4-5 ♀: 5 (Skomal and Natanson 2003) ♂: 4-5 ♀: 5-6 (N Pacific) (Nakano 1994)
Pacific sleeper shark	430+ (possibly as large as 700) (Ebert et al. 1987)	no estimates(s)	N/A	♂: 397 (Phillips 1953) ♀: 370 (Ebert et al. 1987)	no estimates(s)	no estimates(s)	no estimates(s)
green-eye shark	♂/unsexed: 46.0 (Compagno 1984)	no estimates(s)	N/A	no estimates(s)	no estimates(s)	no estimates(s)	no estimates(s)

Table 2 (continued).

	Age and Growth						
Common Name	**Max length (TL) (cm)**	**Longevity (T_{max}) (yrs)**	**Method for longevity determ.**	**Length at 1st maturity (cm)**	**Age at 1st maturity (yrs)**	**Length-at-50% maturity (TL_{50}) (cm)**	**Age-at-50% maturity (T_{50}) (yrs)**
spiny dogfish	130-160 (Hart 1988) 130+ (Saunders and McFarlane 1993)	40 (Hart 1973) 60+ (Ketchen 1975) 35-40 (Atl.) (Nammack et al. 1985) 80-100 (McFarlane and Beamish 1987) 45 (Atl.) (Campana et al. 2006)	annuli count of 2nd dorsal spine (Ketchen 1975, Jones and Geen 1977a, Saunders and McFarlane 1993) bomb radiocarbon dating (Campana et al. 2006)	♂: 72 ♀: 93.5 (Ketchen 1975) ♂: 72 ♀: 76 (Jones and Geen 1977a) ♀: 80 (Saunders and McFarlane 1993)	♂: 14 ♀: 23 (Ketchen 1975) ♂: 15 ♀: 18 (Jones and Geen 1977a) ♀: 24 (Saunders and McFarlane 1993)	♀: 93.5 (Ketchen 1972) ♂: 72 ♀: 93.5 (Hart 1973) ♂: 78.5 ♀: 93.5 (Jones and Geen 1977a) ♂: 72.3 ♀: 94.2 (Saunders et al. 1984) ♀: 93.9 (NE Pacific) (Saunders and McFarlane 1993) ♂: 63.6 ♀: 82 (NW Atl.) (Campana et al. 2007)	♂: 19 ♀: 29 (Jones and Geen 1977a) ♀: 35.5 (NE Pacific) (Saunders and McFarlane 1993) ♂: 10 ♀: 16 (NW Atl.) (Campana et al. 2007)
Pacific angel shark	152 (Roedel and Ripley 1950, Compagno 1984) ♂: 118 ♀: 152 (Natanson 1984)	35 (Natanson 1984)	equation 7(ln2)/*K* (Fabens 1965)	♂: 90-100 ♀: 90-100 (Natanson and Cailliet 1986)	8-13 (Natanson and Cailliet 1986) 10 (estimate) (Cailliet et al. 1992)	♀: 107 (Natanson and Cailliet 1986)	no estimate(s)

† stress difficulty in determining maximum size of great white shark, esp. maximum weight

Table 3: Ageing methodology, growth model(s) and growth parameters for sharks found in British Columbia waters. ♂ = male; ♀ = female; comb = combined; OTC = oxytetracycline; VBGF = von Bertalanffy growth function; K = VBGF growth coefficient; L_∞ = mean asymptotic length; t_0 = hypothetical age at zero (0) length or disc width; L_0 = mean length at birth; Gomp = Gompertz growth function; PCL = precaudal length; L-F = length-frequency; G&H = Gulland and Holt (1959) method.

					Growth Parameters		
Common Name	**Ageing Method**	**Validation**	**Verification**	**Growth model**	***K***	**L_∞**	**t_0**
sixgill shark	efforts to age sixgills using vertebrae proved unsuccessful (Ebert 1986a)	N/A	N/A	N/A	N/A	N/A	N/A
sevengill shark	captive growth (Van Dylhuizen and Mollet 1992) preliminary study on use of neural arches as ageing structures (McFarlane et al. 2002)	none	none	Faben's 2-parameter VBGF w/ fixed L_0 (Van Dykhuizen and Mollet 1992)	♂: 0.22 (S.E. 0.11) ♀: 0.295 (S.E. 0.052) comb: 0.258 (S.E. 0.043) (Van Dykhuizen and Mollet 1992)	♂: 229 (S.E. 41) ♀: 189 (S.E. 12) comb: 202.1 (S.E. 12.5) (Van Dykhuizen and Mollet 1992)	N/A
great white shark	vertebral centra: x-radiography, silver nitrate staining (Cailliet et al. 1985) vertebral centra w/ x-radiography band enhancement and back-calculation (Wintner and Cliff 1999)	OTC injection (942 days at liberty) (Wintner and Cliff 1999) validation attempt using bomb radiocarbon; confounded by number of factors (Kerr et al. 2006)	centrum analysis (unsuccessful) (Wintner and Cliff 1999)	VBGF (Cailliet et al. 1985) 3-parameter VBGF, Gompertz growth function (Winter and Cliff 1999)	comb: 0.058 (Cailliet et al. 1985) comb: 0.065 (Wintner and Cliff 1999)	comb: 763.7 (Cailliet et al. 1985) comb: 544 PCL (or 686 TL) (Wintner and Cliff 1999)	comb: -3.53 (Cailliet et al. 1985) comb: -4.4 (Wintner and Cliff 1999)

Table 3 (continued).

Common Name	Ageing Method	Validation	Verification	Growth model	Growth Parameters *K*	 *L∞*	 *t_0*
shortfin mako	vertebral centra: x-radiography (Cailliet et al. 1983) vertebral centra, sectioned (Campana et al. 2004) whole vertebrae stained w/ silver nitrate (Ribot-Carballal et al. 2005) sagittal sections of vertebra centra (Natanson et al. 2006, Bishop et al. 2006) half-cut vertebral centra w/ shadowing method (Semba et al. 2009) vertebral band counts (sectioned centra) (Cerna and Licandeo 2009)	OTC injection (Natanson et al. 2006)	modal frequency analysis (Cailliet et al. 1983) edge analysis (Ribot-Carballal et al. 2005) centrum edge analysis (Semba et al. 2009) centrum edge analysis (Cerna and Licandeo 2009)	VBGF and Gompertz, tag-recapture methods** (Natanson et al. 2006) VBGF and Gompertz, Schnute generalized growth model*** (Bishop et al. 2006) modified VBGF with birth length fixed (Semba et al. 2009) VBGF (Cailliet et al. 1983, Campana et al. 2004, Ribot-Carballal et al. 2005, Cerna and Licandeo 2009)	comb: 0.072 (Cailliet et al. 1983) comb: 0.05 (Ribot-Carballal et al. 2005) ♂: 0.125 (CI 0.016) ♀: 0.043 (CI 0.011), 0.087 (CI 0.013) (Gomp) (Natanson et al. 2006) ♂: 0.052 (SE 0.011) ♀: 0.013 (SE 0.009) (Bishop et al. 2006) ♂: 0.16 (S.E. 0.0175) ♀: 0.090 (S.E. 0.0091) (Semba et al. 2009) ♂: 0.087 ♀: 0.076 (Cerna and Licandeo 2009)	comb: 321.0 (Cailliet et al. 1983) comb: 411 (Ribot-Carballal et al. 2005) ♂: FL 253.3 (CI 8.3) ♀: FL 432.2 (CI 54.8), 365.6 (Gomp) (Natanson et al. 2006) ♂: 302.3 (SE 22.2) ♀: 820.1 (SE 391.0) (Bishop et al. 2006) ♂: 231.0 (S.E. 15.5) ♀: 308.3 (S.E. 21.7) (Semba et al. 2009) ♂: 296.60 ♀: 325.29 (Cerna and Licandeo 2009)	comb: -3.75 (Cailliet et al. 1983) comb: -4.7 (Ribot-Carballal et al. 2005) ♂: FL L_0 71.6 (CI 5.9) ♀: FL L_0 81.2 (CI 7.4), 88.4 (CI 6.6) (Gomp) (Natanson et al. 2006) ♂: -9.0 (SE 1.5) ♀: -11.3 (SE 2.1) (Bishop et al. 2006) ♂: L_0 59.7 (fixed) ♀: L_0 59.7 (fixed) (Semba et al. 2009) ♂: -3.58 ♀: -3.18 (Cerna and Licandeo 2009)

Table 3 (continued).

					Growth Parameters		
Common Name	**Ageing Method**	**Validation**	**Verification**	**Growth model**	***K***	***L∞***	t_0
salmon shark	vertebral centra sagittal sectioning (NW Pacific) (Tanaka 1980) vertebral centra sagittal sectioning (w/ back calculations) (NE Pacific) (Goldman and Musick 2006)	none	relative marginal increment analysis (RMI) (Goldman and Musick 2006)	VBGFI (Tanaka 1980) VBGF and VBGF w/ back calculations* (Goldman and Musick 2006)	♂: 0.17 ♀: 0.14 (Tanaka 1980) ♂: 0.23 (S.E. 0.03) ♀ 0.17 (S.E. 0.01) comb: 0.18 (S.E. 0.01) (Goldman and Musick 2006)	♂: 180.0 ♀: 203.8 (Tanaka 1980) ♂: 182.8 (S.E. 3.7) ♀ 207.4 (S.E. 2.5) comb: 204.5 (S.E. 2.4) (Goldman and Musick 2006)	♂: -3.6 ♀: -3.9 (Tanaka 1980) ♂: -1.9 (S.E. 0.3) ♀: -2.3 (S.E. 0.2) comb: -2.2 (S.E. 0.2) (Goldman and Musick 2006)
basking shark	vertebral sections (Natanson et al. 2008, Campana et al. unpublished)	bomb radiocarbon dating suggests vert sections overestimate age by 7-8 yrs (Campana et al. 2008)	none	vertebral sections (Natanson et al. 2008, Campana et al. 2008)	comb: 0.062 (Pauly 2002, Natanson et al. 2008, Campana et al. 2008)	comb: 1000 (Pauly 2002, Natanson et al. 2008, Campana et al. 2008)	comb: -2.62 (Natanson et al. 2008, Campana et al. 2008)
common thresher	vertebral centra: whole, x-radiography, silver nitrate (Cailliet and Bedford 1983, Cailliet et al. 1983)	none	modal frequency analysis (Cailliet and Bedford 1983, Cailliet et al. 1983)	von Bertalanffy growth model (Cailliet and Bedford 1983, Cailliet et al. 1983)	♂: 0.215 ♀: 0.158 comb: 0.108 (Cailliet and Bedford 1983)	♂: 492.7 ♀: 636 comb: 650.9 (Cailliet and Bedford 1983)	♂: -1.416 ♀: -1.021 comb: -2.362 (Cailliet and Bedford 1983)

Table 3 (continued).

					Growth Parameters		
Common Name	**Ageing Method**	**Validation**	**Verification**	**Growth model**	***K***	***L∞***	***t_0***
bigeye thresher	vertebral centra: whole, x-radiography (Liu et al. 1998)	none	marginal increment analysis (Liu et al. 1998)	VBGF and length-frequency analysis (Liu et al. 1998)	♂: 0.088 (vert), 0.087 (L-F) ♀: 0.092 (vert), 0.092 (L-F) (Liu et al. 1998)	♂: 400.188, 218.8 PCL (vert), 224.4 PCL (L-F) ♀: 421.826, 224.6 PCL (vert), 230.5 PCL (L-F) (Liu et al. 1998)	♂: -4.24 (vert), -4.61 (L-F) ♀: -4.21 (vert), -3.69 (L-F) (Liu et al. 1998)
brown cat shark	no attempts have been made to age this species (Wallace et al. 2006b)	N/A	N/A	N/A	N/A	N/A	N/A
tope shark	sectioned centra, annulu counts from radiographs (Ferreira and Vooren 1991) whole vertebral centra, alizarin red staining (Moulton et al. 1992) bomb radiocarbon analysis (Kalish and Johnston 2001)	bomb radiocabon analysis (indicated gross age underestimation) (Kalish and Johnston 2001) none (age determ constrained globally by difficulty reading centra) (Wallace et al. 2007b)	centrum edge analysis (Ferreira and Vooren 1991)	VBGF fit to back-calculated length-at-age (Ferreira and Vooren 1991) VBGF (Moulton et al. 1992)	♂: 0.092 ♀: 0.075 (Ferreira and Vooren 1991) comb: 0.124 (Moulton et al. 1992)	♂: 152 ♀: 163 (Ferreira and Vooren 1991) comb: 182.9 (Moulton et al. 1992)	♂: -2.69 ♀: -3.00 (Ferreira and Vooren 1991) comb: -1.29 (Moulton et al. 1992)
smooth hammerhead shark	no efforts have been made to age this species (globally)	N/A	N/A	N/A	N/A	N/A	N/A

Table 3 (continued).

Common Name	Ageing Method	Validation	Verification	Growth model	Growth Parameters K	L_∞	t_0
blue shark	silver nitrate, x-radiography, whole vertebral ring counts (Cailliet and Bedford 1983) vertebral ring counts and tag-recaptured sharks (Skomal and Natanson 1993) vertebral ring counts (whole w/ staining and sectioned) (Tanaka et al. 1990) Gaussian length frequency modes, vetebral ring counts (Nakano 1994) vertebral annulus counts, whole centra (Henderson et al. 2001) vertebral centra, whole and sectioned annulus counts (MacNeil and Campana 2002) vert sagittal sections w/ silver nitrate (Blanco-Parra et al. 2008)	OTC-injected sharks (2 individuals recaptured) (Skomal and Natanson 1993)	modal frequency analysis (Cailliet and Bedford 1983)	VBGF (Cailliet and Bedford 1983, Tanaka et al. 1990, Nakano 1994, Henderson et al. 2001, MacNeil and Campana 2002, Blanco-Parra et al. 2008) VBGF and tag-recapture methods (GROTAG and Gulland and Holt 1959) (Skomal and Natanson 1993)	♂: 0.18 ♀: 0.25 comb: 0.223 (Cailliet and Bedford 1983) ♂: 0.18 ♀: 0.13 comb: 0.17 (Skomal and Natanson 2003) ♂: 0.1 ♀: 0.16 (Tanaka et al. 1990) ♂: 0.129 ♀: 0.144 (Nakano 1994) comb: 0.12 (Henderson et al. 2001) comb: 0.68 (whole), 0.58 (sect) (MacNeil and Campana 2002) ♂: 0.10 ♀: 0.15 (Blanco-Parra et al. 2008)	♂: 295.3 (246.7 FL) ♀: 241.9 (202.6 FL) comb: 222.1 FL (Cailliet and Bedford 1983) ♂: 282 FL ♀: 310 FL comb: 286.8 FL (Skomal and Natanson 1993) ♂: 369 (308.1 FL) ♀: 304 (254.1 FL) (Tanaka et al. 1990) ♂: 319.5 FL ♀: 268.9 FL (Nakano 1994) comb: 377 (314.4 FL) (Henderson et al. 2001) comb: 300 (whole), 302 (sect) (MacNeil and Campana 2002) ♂: 299.85 ♀: 237.5 (Blanco-Parra et al. 2008)	♂: -1.11 ♀: -0.80 comb: -0.802 (Cailliet and Bedford 1983) ♂: -1.35 ♀: -1.77 comb: -1.43 (Skomal and Natanson 1993) ♂: -1.38 ♀: -1.01 (Tanaka et al. 1990) ♂: -0.756 ♀: -0.849 (Nakano 1994) comb: -1.33 (Henderson et al. 2001) comb: -0.25 (whole), -0.24 (sect) (MacNeil and Campana 2002) ♂: -2.44 ♀: -2.15 (Blanco-Parra et al. 2008)

Table 3 (continued).

Common Name	Ageing Method	Validation	Verification	Growth model	Growth Parameters *K*	*L*∞	t_0
Pacific sleeper shark	no efforts have been made to age this species (globally)	N/A	N/A	N/A	N/A	N/A	N/A
green-eye shark	no efforts have been made to age this species (globally)	N/A	N/A	N/A	N/A	N/A	N/A
spiny dogfish	dorsal fin spine: surface reading (Ketchen 1975) vertebral centra: x-ray spectrometry (Jones and Geen 1977a) dorsal fin spine annulus counts (Saunders and McFarlane 1993, Campana et al. 2007, McFarlane and King 2009)	bomb radiocarbon dating (Atl. And Pacific) (Campana et al. 2006) OTC tagging (McFarlane and King 2009)	none	VBGF (Ketchen 1975, Jones and Geen 1977a, Saunders and McFarlane 1993) 2-parameter VBGF w/ fixed length-at-birth (Campana et al. 2007) VBGF w/ range values reflecting precision in no-wear point measurements (McFarlane and King 2009)	♂: 0.07 ♀: 0.048 (Ketchen 1975) ♂: 0.07 ♀: 0.036 (Jones and Geen 1977a) ♀: 0.0437 (Saunders and McFarlane 1993) ♂: 0.099 ♀: 0.042 (NE Atlantic) (Campana et al. 2007) comb: 0.08 to 0.05 to 0.04 (McFarlane and King 2009)	♂: 99.8 ♀: 125.3 (Ketchen 1975) ♂: 97.3 ♀: 128.5 (Jones and Geen 1977a) ♀: 114.94 (Saunders and McFarlane 1993) ♂: 78.0 ♀: 119.5 (NE Atlantic) (Campana et al. 2007) comb: 85 to 93 to 99 (McFarlane and King 2009)	♂: -4.7 ♀: -4.88 (Ketchen 1975) ♂: -4.5 ♀: -6.9 (Jones and Geen 1977a) ♀: -3.557 (Saunders and McFarlane 1993)

Table 3 (continued).

					Growth Parameters		
Common Name	**Ageing Method**	**Validation**	**Verification**	**Growth model**	***K***	***L∞***	***t_0***
Pacific angel shark	vertebral centra not useful due to irregular band deposition (Natanson and Cailliet 1990) tag-recapture and laboratory growth estimates and equations (Cailliet et al. 1992)	tag recapture, OTC injection, captive growth (Natanson and Cailliet 1990)	interreader comparison (Natanson and Cailliet 1990)	VBGF (Natanson and Cailliet 1990) Gulland and Holt (1959) VBGF Faben's (1965) VBGF (Cailliet et al. 1992)	♂: 0.152 (0.016) G&H ♀: 0.162 (0.021) G&H comb: 0.146 (0.011) G&H ♂: 0.143 (0.022) Fabens ♀: 0.072 (0.031) Fabens comb: 0.101 (0.017) G&H (Cailliet et al. 1992)	♂: 125.9 (2.6) G&H ♀: 126.0 (4.9) G&H comb: 127.0 (2.5) G&H ♂: 121.7 (2.4) Fabens ♀: 129.4 (16.1) Fabens comb: 125.2 (3.8) Fabens (Cailliet et al. 1992)	used L_0 = 24 cm from Natanson and Cailliet (1986)

*VBGF results using back-calculations are not presented here. For all calculated growth parameters, see Goldman and Musick 2006.

**results of the 3-parameter von Bertalanffy growth model are shown for males and females (produced the most biolgically reasonal results in males). For females, results of the 3-parameter Gompertz are shown (model which produced the most biologically reasonable results). See Natanson et al. 2006 for all growth model parameter estimates.

***Schute generalized growth model described the growth patterns best

Table 4: Reproductive characteristics of sharks found in British Columbia waters. ♂ = male; ♀ = female; *K* = von Bertalanffy growth parameter.

	Reproduction						
Common Name	**Reproductive mode**	**Sexual dimorphism**	**Fecundity**	**Gestation time (months)**	**Reproductive cycle**	**Sex ratio at birth**	**Length at birth (cm)**
sixgill shark	aplacental viviparity (Ebert 2002)	♀ larger than ♂ (Ebert 2002)	22-108 (Ebert 1986a) 47-70 (one observation of 108 pups) (Ebert 2002, Ebert 2003, Wallace et al. 2007c)	12-24 (Ebert 1990) no reliable estimates (only one mature female recorded from northeast Pacific) (Wallace et al. 2007c)	biannual (Ebert 1990)	1:1 (Ebert 1986a)	68-74 (Ebert 1986a) 61-73 (Ebert 2002, Ebert 2003)
sevengill shark	aplacental viviparity	♀ larger than ♂ (Ebert 1989, Ebert 1996)	up to 82 (Hart 1973) 82-95 (Ebert 1989)	12 (Ebert 1986b)	24 months (Ebert 1996)	unknown	45-53 (Hart 1973) 35-45 (Ebert 1989, Van Dykhuizen and Mollet 1992)
great white shark	aplacental viviparity with oophagy	♀ larger than ♂ (Francis 1996)	3-14 (Francis 1996, Uchida et al. 1996) 2-10, possibly 17, avg. 7 (fecundity increases with maternal size) (Cliff et al. 2000, Compagno 2001) max. lifetime repro. output est. 45 pups (Compagno 2001)	gestation unknown, may last 14 months (Mollet and Cailliet 2002)	may be 3+ yrs., with females replenishing energy stores in between births (Compagno 1991)	unknown	122-129 (Cailliet et al. 1985) 120-150 (Francis 1996) 100 (back-calculated) 135 (predicted) (Wintner and Cliff 1999) 109-165 (Compagno 2001)

Table 4 (continued).

	Reproduction						
Common Name	**Reproductive mode**	**Sexual dimorphism**	**Fecundity**	**Gestation time (months)**	**Reproductive cycle**	**Sex ratio at birth**	**Length at birth (cm)**
shortfin mako	aplacental viviparity with oophagy	not documented	16 (Uchida et al. 1987) 1-6, rarely 10 (Compagno et al. 1995) 4-25, increasing w/ maternal size (Mollet et al. 2000, Compagno 2001)	4-16, avg. 12 (Stevens 1983) 9-14 (Cliff et al. 1990) 15-18 (Mollet et al. 2000, Compagno 2001)	after parturition, females rest for 18 months; triannual (3 yrs.) (Mollet et al. 2000, Compagno 2001)	unknown	70.5 (Garrick 1967) 65-75 (Pratt and Casey 1983) 55.5-62.5 (Duffy and Francis 2001) 62-70 (Mollet et al. 2000) 60-70 (Compagno 2001) 74 (Joung and Hsu 2005) 61 (Bishop et al. 2006) 57-75 PCL (Semba et al. 2009)
salmon shark	aplacental viviparity with oophagy	not documented	up to 5 (Tanaka 1980) 2-5 (Compagno 2001) 3-5 (Goldman 2002)	9 (Cailliet et al. 1983, Goldman 2002)	biannual (Goldman 2002)	2.2:1 (Tanaka 1980)	60-70 (Tanaka 1980) 60-65 (Nagasawa 1998) 40-85 (Compagno 2001) 65-80 (Ebert 2003)
basking shark	aplacental viviparity possibly with oophagy	not documented	6 (based on one animal) (Compagno 2001)	3.5 yrs. (Parker and Stott 1965) 2.6 yrs. (assumed length-at-birth 1.5m and *K*-value of 0.062/yr) (Pauly 2002) *longest gestation of any animal (Wallace et al. 2007a)	time between litters of 2-4 yrs. (Compagno 2001)	1:1 (Compagno 2001, Campana et al. 2008)	165 (Bigelow and Schroeder 1948) 150-200 (Hart 1973) 260 (Izawa and Shibata 1993) 150-170 (Compagno 2001)

Table 4 (continued).

	Reproduction						
Common Name	**Reproductive mode**	**Sexual dimorphism**	**Fecundity**	**Gestation time (months)**	**Reproductive cycle**	**Sex ratio at birth**	**Length at birth (cm)**
common thresher	aplacental viviparity with oophagy	not documented	<6 (Hixon 1979) 4 (Cailliet and Bedford 1983) 2-4 (Hanan 1984)	9 (Cailliet and Bedford 1983)	annual (Cailliet and Bedford 1983)	unknown	116.8-150.0 (Bigelow and Schroeder 1948, Hixon 1979) 158 (Cailliet and Bedford 1983, Hanan 1984)
bigeye thresher	aplacental viviparity with oophagy	♀ larger than ♂ (Liu et al. 1998)	1-4, usually 2 per litter (Chen et al. 1997)	could not be determined b/c pregnant females present year-round (Chen et al. 1997) 12 (Liu et al. 1998)	no fixed mating or birthing season (Chen et al. 1997)	1:1 (Chen et al. 1997)	>100 (Moreno and Moron 1992) 135-140 (73.7 PCL) (Chen et al. 1997) 69.6 PCL (Liu et al. 1998)
brown cat shark	oviparity	unknown	eggs contain 2 developing embryos (Ebert 2003)	incubation period approx. 1 yr. (Jones and Geen 1977)	continuous (Cross 1988, Flammang 2005); in BC eggs preferentially deposited in Feb and Aug (Jones and Geen 1977)	unknown	7 (Jones and Geen 1977) 7-9 (Ebert 2003)
tope shark	aplacental viviparity	unknown	6-52 (w/ fecundity increasing with maternal size) (Ripley 1946)	12 (global) (Ripley 1946, Last and Stevens 1994)	annual w/ pups released b/w Mar and Jul (eastern North Pacific) (Ripley 1946) 2 yrs. (Australia) (Olsen 1954) up to 3 yrs. (Brazil) (Perez and Vooren 1991)	unknown	35-37 (Ripley 1946)

Table 4 (continued).

	Reproduction						
Common Name	**Reproductive mode**	**Sexual dimorphism**	**Fecundity**	**Gestation time (months)**	**Reproductive cycle**	**Sex ratio at birth**	**Length at birth (cm)**
smooth hammerhead shark	aplacental viviparity	unknown	29-37 (Compagno 1984)	10-11 (Ebert 2003)	unknown	unknown	50-60 (Compagno et al. 1995)
blue shark	placental viviparity	some polymorphism of dentition described (Litvinov 1982)	41 (NW Atl.) (Bigelow and Schroeder 1948) 1-54 (N Pacific) (Nakano et al. 1985) 1-62 (av. 25.6) (length pups same in all pregnant ♀) (N Pacific) (Nakano 1994) 36.6 (Euro waters), 25-50 (global) (Wallace et al. 2006c) *fecundity (#) positively correlated w/ ♀ length (Nakano and Seki 2002)	9-12 (Pratt 1979, Cailliet and Bedford 1983)	2 yr. parturition cycle (New England) (Pratt 1979)	1:1 (Nakano et al. 1985, Nakano 1994, Nakano and Seki 2002)	34-48 (Strasburg 1958) 36 PCL (Nakano 1994) 35-60 (Nakano and Seki 2002) 40-50 (global) (Wallace et al. 2006c)
Pacific sleeper shark	aplacental viviparity	unknown	fecundity (i.e. mean ovarian eggs) 300 (Gotshall and Jow 1965) 372 (Ebert et al. 1987)	unknown	unknown	unknown	65 (Ebert 2003)
green-eye shark	ovoviviparous (Breder and Rosen 1966)	unknown	unknown	unknown	unknown	unknown	unknown

Table 4 (continued).

	Reproduction						
Common Name	**Reproductive mode**	**Sexual dimorphism**	**Fecundity**	**Gestation time (months)**	**Reproductive cycle**	**Sex ratio at birth**	**Length at birth (cm)**
spiny dogfish	aplacental viviparity	♀ mature later and grow larger than ♂ (Jones and Geen 1977b, Ketchen 1975, Campana et al. 2007)	3-14 (Roedel and Ripey 1950) 2-20 (8 avg.) (Alverson and Stansby 1963) 2-17 (6-7 avg.) (Ketchen 1972) avg. 7.3 (Jones and Geen 1977b) 2-15 (av. 6) (Soldat 1979) 1-14 (mode 5) (fecundity increasing with female length) (NW Atl.) (Campana et al. 2007)	20 (Alverson and Stansby 1963) 22-24 (Holden 1977) 24 (Ketchen 1972) 23 (Jones and Geen 1977b) 18-24 (Pacific and Atlantic) (Compagno 1984, Ketchen 1986) *longest gestation of any animal	♂: annual (Jones and Geen 1977b) ♀: biannual (Jones and Geen 1977b, Campana et al. 2007)	1:1 assumed (Jones and Geen 1977b)	24-30 (NE Pacific) (Ketchen 1972) 22-25 (NW Atl.) (Campana et al. 2007)
Pacific angel shark	aplacental viviparity	♂ and ♀ begin maturing at approx. the same size (Natanson and Cailliet 1986)	1-11 (6 avg) (Natanson and Cailliet 1986) 1-13 (6 avg) (Ebert 2003)	10 (Natanson and Cailliet 1986)	annual (Natanson and Cailliet 1986)	1:1 (Natanson and Cailliet 1986)	21-26 (Compagno 1984) 25-26 (Natanson and Cailliet 1986)

Table 5: Demographic parameters of sharks found in British Columbia waters. ; r = intrinsic rate of increase; e^r = finite population growth rate; R_0 = net reproductive rate; G(T) = generation time; LHT = life history table; r_{2M} or r_{msy} = intrinsic rate of population increase at MSY; M = natural mortality.

	Demographic Parameters						
Common Name	***r***	**e^r**	**R_0**	**G(T)**	**Geographic Region**	**Method**	**Source**
sixgill shark	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A
sevengill shark	r_{2M} = 0.026-0.037				Pacific	demographic technique incorporating concepts of density-dependence (useing female age-at-mat, max. repro. age, and average fecundity)	Smith et al. 1998

Table 5 (continued).

	Demographic Parameters						
Common Name	***r***	e^r	R_0	**G(T)**	**Geographic Region**	**Method**	**Source**
great white shark	r_{2M} = 0.040-0.056				Pacific	demographic technique incorporating concepts of density-dependence (useing female age-at-mat, max. repro. age, and average fecundity)	Smith et al. 1998
		1.098 (1.075 to 1.139 95% CI)		12.3 (11 to 13.8 95% CI)	northeastern Pacific	age-structured life history tables, Leslie matrices, and Monte Carlo simulation	Cortes 2002
	0.07869	1.0819	6.163	23.11	California	life history table and Leslie matrix (LHT to 60)	Mollet and Cailliet 2002
	0.07869	1.0819	6.163	23.11	California	life history table and Leslie matrix (L 60x60)	Mollet and Cailliet 2002
	0.07869	1.0819	6.3385	23.47	California	stage-based matrix model with fixed stage distribution (15x15[B])	Mollet and Cailliet 2002
	0.07869	1.0819	4.1884	18.2	California	stage-based matrix model with fixed stage distribution (3x3)	Mollet and Cailliet 2002
	0.07869	1.0819	3.9462	17.44	California	stage-based matrix model with fixed stage distribution (2x2)	Mollet and Cailliet 2002
	0.1493	1.161	6.6431	12.68	California	stage-based matrix model with geometric distribution (3x3)	Mollet and Cailliet 2002

Table 5 (continued).

	Demographic Parameters						
Common Name	***r***	**e^r**	**R_0**	**G(T)**	**Geographic Region**	**Method**	**Source**
great white shark (cont.)	0.17	1.1853	6.9027	11.36	California	stage-based matrix model with geometric distribution (2x2)	Mollet and Cailliet 2002
	0.051	1.0523		0.051	global	age-structured life table using discrete form of Euler equation, and using the maximum estimate of age-specific survivroship	Dulvy et al. 2008
shortfin mako	r_{2M} = 0.051-0.071				Pacific	demographic technique incorporating concepts of density-dependence (useing female age-at-mat, max. repro. age, and average fecundity)	Smith et al. 1998
		1.141 (1.098 to 1.181 95% CI)		10.1 (9.2 to 11.1 95% CI)	northwestern Atlantic	age structured life history tables, Leslie matrices, and Monte Carlo simulation	Cortes 2002
	-0.352 (fishing) - 0.014 (no fishing)		0.032 (fishing) - 1.236 (no fishing)		Atlantic	life table analyses with Monte Carlo simulation	Takeuchi et al. 2005
	0.047	1.0481		24	NW Atlantic Ocean	age-structured life table using discrete form of Euler equation, and using the maximum estimate of age-specific survivroship	Dulvy et al. 2008
	0.034	1.0346		23	SW Pacific Ocean	age-structured life table using discrete form of Euler equation, and using the maximum estimate of age-specific survivroship	Dulvy et al. 2008
salmon shark	0.0117 (95% C.I. -0.0151 to -0.0412)	1.012 (95% C.I. 0.985 to 1.042)	1.2 (95% C.I. 0.8 to 1.6)	13.1 (95% C.I. 11.4 to 15)	eastern North Pacific	age-structured life tables	Goldman 2002

Table 5 (continued).

	Demographic Parameters						
Common Name	***r***	**e^r**	**R_0**	**G(T)**	**Geographic Region**	**Method**	**Source**
salmon shark (cont.)	-0.0234 (95% C.I. 0.0385 to -0.0065)	0.977 (95% C.I. 0.962 to 0.994)	0.7 (95% C.I. 0.6 to 0.9)	14.9 (95% C.I. 13 to 16.7)	western North Pacific	age-structured life tables	Goldman 2002
	0.081	1.0844		13	NE Pacific Ocean	age-structured life table using discrete form of Euler equation, and using the maximum estimate of age-specific survivroship	Dulvy et al. 2008
basking shark	0.013-0.023 (r_{msy}) *annual productivity lowest of any shark known (Wallace et al. 2006)			22 (UK CITES Proposal 2002) 33 (based on ♀ age-at-maturity of 18 yrs.) (Wallace et al. 2006)	global	based on methodology of Smith et al. (1998) using age-at-maturity, maximum age, and average fecundity	UK CITES proposal 2002, Wallace et al. 2007a
	0.04	1.0408	0.208		Atlantic Canada waters	life table analysis	Campana et al. 2008
	median value 0.032	1.0325			Atlantic Canada waters	life table analysis w/ Monte Carlo simulation model	Campana et al. 2008
common thresher	r_{2M} = 0.069-0.099				Pacific population	demographic technique incorporating concepts of density-dependence (useing female age-at-mat, max. repro. age, and average fecundity)	Smith et al. 1998
		1.125 (1.078 to 1.178 95% CI)		8.9 (7.1 to 10.6 95% CI)	northwestern Pacific Ocean	age-structured life history tables, Leslie matrices, and Monte Carlo simulation	Cortes 2002

Table 5 (continued).

	Demographic Parameters						
Common Name	***r***	**e^r**	**R_0**	**G(T)**	**Geographic Region**	**Method**	**Source**
common thresher (cont.)	0.254	1.2892		8	NE Pacific Ocean	age-structured life table using discrete form of Euler equation, and using the maximum estimate of age-specific survivroship	Dulvy et al. 2008
bigeye thresher		0.996 (0.978 to 1.014 95% CI)		16.7 (15.2 to 18.1 95% CI)	northwestern Pacific Ocean	age-structured life history tables, Leslie matrices, and Monte Carlo simulation	Cortes 2002
	0.002	1.0020		17	NW Pacific Ocean	age-structured life table using discrete form of Euler equation, and using the maximum estimate of age-specific survivroship	Dulvy et al. 2008
brown cat shark	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A
tope shark	r_{2M} = 0.033-0.045				Pacific population	demographic technique incorporating concepts of density-dependence (useing female age-at-mat, max. repro. age, and average fecundity)	Smith et al. 1998
		1.077 (95% C.I. 1. 037 to 1.128)		17.7 (95% C.I. 13.3 to 21)	southwestern Pacific	age-structured life history tables, Leslie matrices, and Monte Carlo simulation	Cortes 2002
smooth hammerhead shark	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)

Table 5 (continued).

Common Name	Demographic Parameters				Geographic Region	Method	Source
	r	e^r	R_0	G(T)			
blue shark	r_{2M} = 0.061-0.086				Pacific population	demographic technique incorporating concepts of density-dependence (useing female age-at-mat, max. repro. age, and average fecundity)	Smith et al. 1998
		1.401 (95% C.I. 1.284 to 1.534)		7 (95% C.I. 6 to 8.4)	northwestern and northern Atlantic	age-structured life history tables, Leslie matrices, and Monte Carlo simulation	Cortes 2002
	0.36 (43%)			8.1 yrs.	N Atlantic population	life table analysis	Campana et al. 2004b
	0.203 (fishing) - 0.343 (no fishing)		3.917 (fishing) - 9.894 (no fishing)		Atlantic	life table analyses with Monte Carlo simulation	Takeuchi et al. 2005
	0.287	1.3324		10	N Atlantic Ocean	age-structured life table using discrete form of Euler equation, and using the maximum estimate of age-specific survivroship	Dulvy et al. 2008
Pacific sleeper shark	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)
green-eye shark	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)
spiny dogfish	0.023	1.023	3.05	49.63	Strait of Georgia, British Columbia, Canada	(calculated by Eguchi and Cailliet)	Jones and Geen 1977a

Table 5 (continued).

Common Name	Demographic Parameters: *r*	e^r	R_0	G(T)	Geographic Region	Method	Source
spiny dogfish (cont.)	3.4 (%) or r_{2M} =0.034-0.047				Atlantic population	demographic technique incorporating concepts of density-dependence (useing female age-at-mat, max. repro. age, and average fecundity)	Smith et al. 1998
	1.7-2.3 (%) or r_{2M} = 0.017-0.023				Pacific population (British Columbia)	demographic technique incorporating concepts of density-dependence (useing female age-at-mat, max. repro. age, and average fecundity)	Smith et al. 1998
	0.113	0.893 (0.876 to 0.912 95% CI)		55.6 yrs. (50.0 to 62.2 95% CI)	northeastern Pacific	age structured life history table with Monte Carlo simulation	Cortes 2002
				25-40	Atlantic and Pacific populations	used best available estimates	Germany CITES proposal 2003
				42	Pacific population	used best available estimates	Courtney et al. 2004
				23 (Atl.) and 51 (Pacific)	Atlantic and Pacific populations	used age-at-maturity of 16 (Atl.) and 35.5 (Pacific) and natural mortality (*M*) estimates of 0.15 (Atl.) and 0.065 (Pacific) in equation gen. time. = (age-at-mat)+1/*M*	Wallace et al. 2006d

Table 5 (continued).

	Demographic Parameters						
Common Name	***r***	**e^r**	**R_0**	**G(T)**	**Geographic Region**	**Method**	**Source**
Pacific angel shark	0.056		2.25	14.5	California	tag-recapture and lab growth results (Natanson and Cailliet 1990) used to estimate age and growth parameters for demographic analysis; incoporation of age-specific mortality and natality rates into a static life table	Cailliet et al. 1992
	3.8-5.3 (%) or r_{2M} =0.038-0.053				California	demographic technique incorporating concepts of density-dependence (useing female age-at-mat, max. repro. age, and average fecundity)	Smith et al. 1998

Table 6: Mortality parameters and details of each associated study for sharks in British Columbia waters. *M* = natural mortality; *F* = fishing mortality; *Z* = total mortality; t_{max} = longevity; t_{50} = age-at-50%-maturity; VBGF = von Bertalanffy growth function; L_∞ = mean maximum length; *K* = von Bertalanffy growth parameter; M_{age0} = mortality at age zero; F_{crit} = fishing mortality above which population driven to extinction.

	Mortality Parameters						
Common Name	***M***	***F***	***Z***	**Geographic area**	**Equation used**	**Age range used (yrs)**	**Source**
sixgill shark	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A	N/A
sevengill shark	0.14			Pacific	Hoenig's equation	32	Smith et al. 1998
great white shark	0.125			Pacific	Hoenig's equation	36	Smith et al. 1998
	0.07675			California	-1n(0.01)/longevity	60	Mollet and Cailliet 2002
shortfin mako	0.16			Pacific	Hoenig's equation	28 (calculated from VBGF)	Smith et al. 1998
	0.1266 (average)	*F = Z-M* = 0.319	0.535	Atlantic (w/ some input data from north Pacific)	used methods from Pauly (1980), Hoenig (1983), Jensen (1996), Campana (2001), Chen and Watanabe (1989), and Peterson and Wroblewski (1984); also used catch curve analysis	33	Takeuchi et al. 2005
	♂: 0.14 ♀: 0.15			New Zealand	Hoenig (1983) fish using t_{max}	♂: 29 ♀: 28	Bishop et al. 2006
	♂: 0.16 ♀: 0.16			New Zealand	Hoenig (1983) fish and mammals using t_{max}	♂: 29 ♀: 28	Bishop et al. 2006
	♂: 0.24 ♀: 0.09			New Zealand	Jensen (1996) using t_{50}	♂: 7 t_{50} ♀: 19 t_{50}	Bishop et al. 2006

Table 6 (continued).

Common Name	Mortality Parameters: *M*	*F*	*Z*	Geographic area	Equation used	Age range used (yrs)	Source
shortfin mako (cont.)	♂: 0.15 ♀: 0.15			New Zealand	Peterson and Wroblewski (1984) using age	♂: 5 ♀: 5	Bishop et al. 2006
	♂: 0.10 ♀: 0.09			New Zealand	Peterson and Wroblewski (1984) using age	♂: 29 ♀: 28	Bishop et al. 2006
salmon shark	0.091-0.255			eastern North Pacific	used methods from Hoenig (1983), Pauly (1980), Chen and Watanabe (1989), Peterson and Wroblewski (1984) and Jensen (1996)	see Goldman 2002 for input data	Goldman 2002
	0.097-0.209			western North Pacific	used methods from Hoenig (1983), Pauly (1980), Chen and Watanabe (1989), Peterson and Wroblewski (1984) and Jensen (1996)	see Goldman 2002 for input data	Goldman 2002
basking shark	0.068	F (adults) = 0.162-0.068 = 0.094	Z = 0.33 (juveniles) Z = 0.16 (adults)	North Atlantic	M calculated using L_∞ and K and a mean annual temp. of 10°C; Z calculated using length converted catch curves (LCCC)	L_∞ = 10m	Pauly 2002

Table 6 (continued).

Common Name	Mortality Parameters: *M*	*F*	*Z*	Geographic area	Equation used	Age range used (yrs)	Source
basking shark (cont.)	M = 0.068 M_{age0} = 0.136 (=2*M) (assumption)	F_{crit} = 0.043		Atlantic Canada waters	life table analysis	age-at-maturity = 18 yrs. (as per UK CITES proposal 2002) longevity = 50 yrs. (as per Pauly 2002)	Campana et al. 2008
common thresher	0.234			Pacific	Hoenig's equation	19	Smith et al. 1998
bigeye thresher	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A	N/A
brown cat shark	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A	N/A
tope shark	0.113			Pacific	Hoenig's equation	40	Smith et al. 1998
smooth hammerhead shark	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A	N/A
blue shark	0.223			Pacific	Hoenig's equation	20	Smith et al. 1998

Table 6 (continued).

	Mortality Parameters						
Common Name	***M***	***F***	***Z***	**Geographic area**	**Equation used**	**Age range used (yrs)**	**Source**
blue shark (cont.)	0.07-0.48 (mean 0.23)	0.29-0.66	0.52-0.89	Canadian NW Atlantic population	calculated based on life history parameters (i.e. meta-analysis of observed relationships b/w growth rate, mortality rate and/or longevity); used length-converted catch curves to calculate *Z*	*for equations requiring longevity, used Skomal and Natanson (2003) longevity of 16 yrs. (obs) and 21 yrs. (inferred)	Campana et al. 2004
	0.244 (average)	*F* = *Z*-*M* = 0.319	0.563	Atlantic (w/ catch-at-age from Japanese longline observer data)	used methods from Pauly (1980), Hoenig (1983), Jensen (1996), Campana (2001), Chen and Watanabe (1989) and Peterson and Wroblewski (1984); also used catch curve analysis	17	Takeuchi et al. 2005
Pacific sleeper shark	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A	N/A
green-eye shark	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A	N/A

Table 6 (continued).

	Mortality Parameters						
Common Name	***M***	***F***	***Z***	**Geographic area**	**Equation used**	**Age range used (yrs)**	**Source**
spiny dogfish	0.094 (instant. rate of natural mortality at natural equilibrium)			northeastern Pacific (British Columbia and Puget Sound)	age-structured model	*assumed natural mortality equal for all age groups	Wood et al. 1979
	0.091			NW Atlantic population	Hoenig's equation	50	Smith et al. 1998
	0.065			Pacific population (British Columbia)	Hoenig's equation	70	Smith et al. 1998
	0.10 (immature)-0.15 (mature)			Atlantic population		age-structured model	Campana et al. 2007
Pacific angel shark	0.2	simulations (0-0.22)		California	Hoenig's equation	35	Cailliet et al. 1992
	0.129			California	Hoenig's equation	35	Smith et al. 1998

Table 7: Taxonomic classification (including common name), geographic distribution, depth range, and frequency of occurrence of skates found in British Columbia waters.

Taxonomy				Range			
Family	Latin Name	Common Name	Other Names	Global	Eastern North Pacific	Depth Range	Occurrence in BC waters
Arhynchobatidae	*Bathyraja abyssicola*	**deep sea skate**	N/A	western Bering Sea to northern Japan; eastern north Pacific (Ishihara and Ishiyama 1985)	Cortes Bank, southern California to eastern Bering Sea (Ishihara and Ishiyama 1985)	on bottom in deep water; depths of 362 to 2,904 m (Mecklenburg et al. 2002)	rare
Arhynchobatidae	*Bathyraja interrupta*	**sandpaper skate**	black skate, Bering skate	eastern north Pacific	Gulf of Alaska to northern Baja California (Ebert 2003)	on bottom; depths of 55 to 1372 m, usually shallower than 500 m in Alaska (Mecklenburg et al. 2002)	common
Arhynchobatidae	*Bathyraja trachura*	**roughtail skate**	black skate	eastern north Pacific	Bering Sea to northern Baja California (Ishihara and Ishiyama 1985)	on bottom; deep water at depths of 400 to 1994 m (Mecklenburg et al. 2002) 213-2550 m (most common below 600 m) (Ishihara and Ishiyama 1985)	infrequent
Arhynchobatidae	*Bathyraja aleutica*	**Aleutian skate**	N/A	northern Japan and eastern North Pacific (Ebert 2003)	Cape Mendocino, northern California to the Bering Sea (Ebert 2003)	on bottom; depths of 15 to 1,602 m usually on outer shelf and upper slope at 100 to 800 m (Mecklenburg et al. 2002)	infrequent
Arhynchobatidae	*Bathyraja parmifera*	**Alaska skate**	N/A	western Bering Sea and Commander Islands to Sea of Okhotsk, northern Sea of Japan and Pacific Hokkaido; eastern North Pacific (Mecklenburg et al. 2002)	eastern Bering Sea and Aleutian Islands to eastern Gulf of Alaska (Mecklenburg et al. 2002)	on bottom; depths of 20 to 1,425, usually at 90 to 250 m off Aleutian Islands, deeper in western Pacific (Mecklenburg et al. 2002) typically found between 50-200 m (Stevenson 2004)	rare (was previously identified as starry skate in BC waters) (Benson et al. 2001)

Table 7 (continued).

Taxonomy				Range			
Family	**Latin Name**	**Common Name**	**Other Names**	**Global**	**Eastern North Pacific**	**Depth Range**	**Occurrence in BC waters**
Arhynchobatidae	*Bathyraja minispinosa*	**whitebrow skate**	N/A	western Bering sea to Commander Islands to Hokkaido and Sea of Okhotsk; eastern North Pacific (Mecklenburg et al. 2002)	Bering Sea and Aleutian Islands (Mecklenburg et al. 2002, Ishiyama and Ishihara 1977)	on bottom; depths of 150 to 1,420 m, usually 200 to 800 m (Mecklenburg et al. 2002)	rare
Rajidae (skates)	*Raja badia*	**broad skate**	N/A	Japanese archipelago (Tohoku slope and Okhotsk slope) (Nakaya and Shirai 1992) and eastern Pacific (Ebert 2003)	Navarin Canyon, Bering Sea to Panama (Ebert 2003)	very deep water to 1,600 m off British Columbia and Oregon (Eschmeyer et al. 1983)	rare
Rajidae (skates)	*Raja rhina*	**longnose skate**	N/A	distribution limited to eastern north Pacific Ocean between 61°N and 28°N Latitudes (Love et al. 2005)	southeastern Bering Sea to Cedros Islands, Baja California, also Gulf of California (Mecklenburg et al. 2002, Love et al. 2005)	on bottom; depths of 20 to at least 622 m, usually 55 to 350 m (Mecklenburg et al. 2002) 9- 1069 m (Love et al. 2005)	common
Rajidae (skates)	*Raja inornata*	**California skate**	N/A	eastern North Pacific	Straight of Juan de Fuca to Turtle Bay, Baja California, Mexico, also found in the Gulf of California (Miller and Lea 1972, McEachran and Notobartolo-di-Sciara 1995)	18 to 671 m, common inshore and in shallow bays (Eshmeyer et al. 1983)	rare
Rajidae (skates)	*Raja binoculata*	**big skate**	N/A	eastern North Pacific	eastern Bering Sea and southeast Alaska to southern Baja California, Mexico; uncommon south of Point Conception, California (Eshmeyer et al. 1983, Castro-Aguirre et al. 1993, Mecklenburg et al. 2002)	on sandy and muddy bottom at depths of 3 to 800 m (Mecklenburg et al. 2002); usually less than 200 m on the continental shelf (Miller and Lea 1972, Benson et al. 2001)	common

Table 7 (continued).

Taxonomy				Range			
Family	**Latin Name**	**Common Name**	**Other Names**	**Global**	**Eastern North Pacific**	**Depth Range**	**Occurrence in BC waters**
Rajidae (skates)	*Raja stellulata*	**starry skate**	rock skate, prickly skate	eastern North Pacific	Eureka, California to Coronado Bank, Baja California, Mexico (Miller and Lea 1972); Bering Sea to northern Baja California, Mexico (McEachran and Dunn 1998, Ebert 2003)	18 to 732 m (Miller and Lea 1972, Eschmeyer et al. 1983)	rare (idenficiation issues with Alaska skate in northerly waters) (Benson et al. 2001, Mecklenburg et al. 2002)

Table 8: Age, growth and maturity characteristics of skates found in British Columbia waters. ♂ = male; ♀ = female.

	Age and Growth						
Common Name	**Max length (TL) (cm)**	**Longevity (T_{max}) (yrs)**	**Method for longevity determ.**	**Length at 1st maturity (cm)**	**Age at 1st maturity (yrs)**	**Length-at-50% maturity (TL_{50}) (cm)**	**Age-at-50% maturity (T_{50}) (yrs)**
deep sea skate	157 (Sheiko and Tranbenkova 1998)	no estimate(s)	no estimate(s)	♂: 110.0 (Zorzi and Anderson 1988)	no estimate(s)	no estimate(s)	no estimate(s)
sandpaper skate	86 (Mecklenberg et al. 2002) ♂: 82.5 ♀: 82 (Ebert 2005) ♂: 82.4 ♀: 87.1 (Ebert et al. 2007)	♂: 18 ♀: 17 (Perez 2005) ♂: 12 ♀: 13 (Ebert et al. 2007)	no estimate(s)	♂: 48 ♀: 46-50 (Ebert 2003) ♂: 44.0 ♀: 45.0 (Perez 2005) ♂: 67 ♀: 70 (Ebert 2005) ♂: 63.2 ♀: 66.6 (Ebert et al. 2007)	♂: 3 ♀: 4 (Perez 2005)	♂: 69.4 ♀: 70.0 (Ebert 2005) ♂: 49.2 ♀: 46.7 (Perez 2005) ♂: 67.6 ♀: 70.2 (Ebert et al. 2007)	♂: 7.5 ♀: 7.1 (Perez 2005) ♂: 7 ♀: 7.5 (Ebert et al. 2007)
roughtail skate	89 (Mecklenburg et al. 2002) ♂: 83.0 ♀: 89.0 (Ebert 2003) ♂: 82.5 ♀: 88.5 (Ebert 2005) 91 (Davis et al. 2007)	♂: 20 ♀: 17 (Davis et al. 2007)	annual band pair counts in vertebral thin sections (Davis et al. 2007)	♂: 75 ♀: 74 (Ebert 2003) ♂: 75.0 ♀: 75.0 (Ebert 2005)	no estimate(s)	♂: 75.5 ♀: 73.5 (Ebert 2005)	no estimate(s)

Table 8 (continued).

Common Name	Age and Growth: Max length (TL) (cm)	Longevity (T_{max}) (yrs)	Method for longevity determ.	Length at 1st maturity (cm)	Age at 1st maturity (yrs)	Length-at-50% maturity (TL_{50}) (cm)	Age-at-50% maturity (T_{50}) (yrs)
Aleutian skate	150 (Ishiyama 1958) 150 (Teshima and Tomonaga 1986) ♂: 133 ♀: 154 (Ebert 2005) ♂: 149.9 ♀: 153.4 (Ebert et al. 2007)	♂: 16 ♀: 17 (Ebert et al. 2007)	annual band pair counts in vertebral thin sections (also looked at caudal thorns) (Ebert et al. 2007)	♂: 113 ♀: 125 (Ebert 2003) ♂: 119 ♀: 133 (Ebert 2005) ♂: 117.7 ♀: 111.6 (Ebert et al. 2007)	♂: 7 ♀: 9 (Ebert et al. 2007)	♂: 121 ♀: 133 (Ebert 2005) ♂: 122.8 ♀: 124.4 (Ebert et al. 2007)	♂: 10.2 ♀: 10.4 (Ebert et al. 2007)
Alaska skate	107 (Orlov 1998) 107 (Mecklenberg et al. 2002) ♂: 111 ♀: 109.5 (Ebert 2005)	♂: 15 ♀: 17 (Matta and Gunderson 2007)	annual band pair counts in vertebral thin sections (Matta and Gunderson 2007)	♂: 87.0 ♀: 95.4 (Ebert 2005) ♂: 85 ♀: 87 (Matta and Gunderson 2007)	no estimate(s)	♂: 87.9 ♀: 92.0 (Ebert 2005) ♂: 91.75 ♀: 93.28 (Matta and Gunderson 2007)	♂: 9 ♀: 10 (Matta and Gunderson 2007)
whitebrow skate	79 (Ishiyama and Ishihara 1977) 83 (Mecklenburg et al. 2002) ♂: 80.1 ♀: 79.5 (Ebert 2005)	no estimate(s)	no estimate(s)	♂: 70 ♀: 68 (Ebert 2005)	no estimate(s)	♂: 69.5 ♀: 66.1 (Ebert 2005)	no estimate(s)
broad skate	♂: 95 ♀: 99 (Ebert 2003)	no estimate(s)	no estimate(s)	♂: 86-93 (Ebert 2003)	no estimate(s)	no estimate(s)	no estimate(s)

Table 8 (continued).

	Age and Growth						
Common Name	**Max length (TL) (cm)**	**Longevity (T_{max}) (yrs)**	**Method for longevity determ.**	**Length at 1st maturity (cm)**	**Age at 1st maturity (yrs)**	**Length-at-50% maturity (TL_{50}) (cm)**	**Age-at-50% maturity (T_{50}) (yrs)**
longnose skate	♂: 132.2 ♀: 106.8 (Zeiner and Wolf 1993) ♂: 122.0 ♀: 124.6 (McFarlane and King 2006) ♂: 129.0 ♀: 140.0 (Gburski et al. 2007) ♂: 135.8 ♀: 145.0 (Ebert et al. 2008)	♂: 13 ♀: 12 (Zeiner and Wolf 1993) ♂: 23 ♀: 26 (McFarlane and King 2006) ♂: 25 ♀: 24 (Gburski et al. 2007)	annual band pair count (Zeiner and Wolf 1993) annual band pair count with estimation of first two band band pairs (McFarlane and King 2006) annual band pair count (Gburski et al. 2007)	♂: 61.5-74 ♀: 70 (Zeiner and Wolf 1993) ♂: 50 ♀: 70 (McFarlane and King 2006) ♂: 101.0 ♀: 102.2 (Ebert et al. 2008) ♀: 75-125 (Gertseva 2009)	♂: 10-11 ♀: 10-12 (Zeiner and Wolf 1993) ♀: 11-18 (average) (Gertseva 2009)	♂: 65 ♀: 93 (McFarlane and King 2006) ♂: 102.9 ♀: 113.1 (Ebert et al. 2008)	♂: 7 ♀: 10 (McFarlane and King 2006)
California skate	76 (Eschmeyer et al. 1983)	no estimate(s)	no estimate(s)	♂: 47 ♀: 52 (Ebert 2003)	no estimate(s)	no estimate(s)	no estimate(s)

Table 8 (continued).

	Age and Growth						
Common Name	**Max length (TL) (cm)**	**Longevity (T_{max}) (yrs)**	**Method for longevity determ.**	**Length at 1st maturity (cm)**	**Age at 1st maturity (yrs)**	**Length-at-50% maturity (TL_{50}) (cm)**	**Age-at-50% maturity (T_{50}) (yrs)**
big skate	240 (Miller and Lea 1972, Ebert 2003) ♂: 132.1 ♀: 160.7 (Zeiner and Wolf 1993) ♂: 184 ♀: 214 (Mecklenburg et al. 2002) ♂: 183.6 ♀: 203.9 (McFarlane and King 2006) ♂: 141 ♀: 178 (Gburski et al. 2007)	♂: 11 ♀: 12 (Zeiner and Wolf 1993) ♂: 25 ♀: 26 (McFarlane and King 2006) ♂: 15 ♀: 14 (Gburski et al. 2007)	annual band pair count (Zeiner and Wolf 1993) annual band pair count with estimation of first two band band pairs (McFarlane and King 2006) annual band pair count (Gburski et al. 2007)	♂: 100-110 (Zeiner 1991) ♀: >130 (Zeiner and Wolf 1993) ♂: 50 ♀: 60 (McFarlane and King 2006) ♂: 124.0 ♀: 125.8 (Ebert et al. 2008)	♂: 7-8 (Zeiner 1991) ♀: 10-12 (Zeiner and Wolf 1993)	♂: 72 ♀: 90 (McFarlane and King 2006) ♂: 119.2 ♀: 148.6 (Ebert et al. 2008)	♂: 6 ♀: 8 (McFarlane and King 2006)
starry skate	76 (Eschmeyer et al. 1983)	no estimate(s)	no estimate(s)	♂: 67 ♀: 68 (Ebert 2003)	no estimate(s)	no estimate(s)	no estimate(s)

Table 9: Ageing methodology, growth model(s) and growth parameters for skates found in British Columbia waters. ♂ = male; ♀ = female; comb = combined; VBGF = von Bertalanffy growth function; 2-VBGF = 2 parameter VBGF; K = VBGF growth parameter; L_∞ = mean maximum length; t_0 = VBGF parameter (x-axis intercept); L_0 = mean length at birth; G = instantaneous rate of growth at time t; g = rate of decrease of G; L_a = asymptotic total length; r = logistic growth coefficient; MIR = marginal increment ratio; MIA = marginal increment analysis.

				Growth Parameters							
				von Bertalanffy				Gompertz		Logistic	
Common Name	**Ageing Method**	**Verification and/or Validation**	**Growth model**	***K***	***L_∞***	***t_0***	***L_0***	***G***	***g***	***L_a***	***r***
deep sea skate	no attempts to age this species (globally)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
sandpaper skate	vertebral thin sections (and caudal thorns) (Perez 2005, Ebert et al. 2007)	marginal increment and edge analysis (Perez 2005, Ebert et al. 2007)	4 models used** (Perez 2005) 6 growth models used (polynomial model provided best statistical fit)*** (Ebert et al. 2007)	♂: 0.185 ♀: 0.237 comb: 0.207 (Perez 2005) ♂: 0.09 ♀: 0.07 comb: 0.08 (Ebert et al. 2007)	♂: 580.2 ♀: 537.3 comb: 557.8 (Perez 2005) ♂: 116.73 ♀: 138.95 comb: 126.4 (Ebert et al. 2007)	♂: -2.530 ♀: -1.629 comb: -2.147 (Perez 2005) ♂: -1.99 ♀: -2.65 comb: -2.32 (Ebert et al. 2007)	N/A	N/A	N/A	N/A	N/A

Table 9 (continued).

				Growth Parameters							
				von Bertalanffy				**Gompertz**		**Logistic**	
Common Name	**Ageing Method**	**Verification and/or Validation**	**Growth model**	***K***	L_∞	t_0	L_0	***G***	***g***	L_a	***r***
roughtail skate	vertebral thin sections; attempted caudal thorns (Davis et al. 2007)	edge analysis MIR (Davis et al. 2007)	VBGF 2-parameter VBGF* Gompertz growth function (Davis et al. 2007)	VBGF comb: 0.06 2-VBGF comb: 0.09 (Davis et al. 2007)	VBGF comb: 112.11 2-VBGF comb: 101.25 (Davis et al. 2007)	VBGF comb: -3.45 (Davis et al. 2007)	2-VBGF comb: 19.0 Gompertz comb: 23.59 (Davis et al. 2007)	N/A	N/A	N/A	N/A
Aleutian skate	vertebral thin sections (and caudal thorns) (Ebert et al. 2007)	MIA and edge analysis (Ebert et al. 2007)	6 growth models used (logistic growth model provided best statistical fit)***	♂: 0.11 ♀: 0.10 comb: 0.11 (Ebert et al. 2007)	♂: 170.47 ♀: 174.43 comb: 172.6 (Ebert et al. 2007)	♂: -1.69 ♀: -1.86 comb: -1.78 (Ebert et al. 2007)	N/A	N/A	N/A	N/A	N/A

Table 9 (continued).

				Growth Parameters							
				von Bertalanffy				Gompertz		Logistic	
Common Name	Ageing Method	Verification and/or Validation	Growth model	K	L_∞	t_0	L_0	G	g	L_a	r
Alaska skate	vertebral thin sections; attempted caudal thorns (Matta and Gunderson 2007)	edge analysis MIA (Matta and Gunderson 2007)	VBGF modified Gompertz growth function* (Matta and Gunderson 2007)	♂: 0.12 ♀: 0.087 comb: 0.10 (Matta and Gunderson 2007)	♂: 126.29 ♀: 144.62 comb: 135.39 (Matta and Gunderson 2007)	♂: -1.39 ♀: -1.75 comb: -1.60 (Matta and Gunderson 2007)	♂: 21.90 ♀: 22.54 comb: 22.50 (Matta and Gunderson 2007)	♂: 1.63 ♀: 1.68 comb: 1.64 (Matta and Gunderson 2007)	♂: 0.23 ♀: 0.19 comb: 0.21 (Matta and Gunderson 2007)	N/A	N/A
whitebrow skate	no attempts to age this species (globally)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
broad skate	no attempts to age this species (globally)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 9 (continued).

				Growth Parameters							
				von Bertalanffy				Gompertz		Logistic	
Common Name	**Ageing Method**	**Verification and/or Validation**	**Growth model**	***K***	***L_∞***	***t_0***	***L_0***	***G***	***g***	***L_a***	***r***
longnose skate	vertebral centra; thin sectioning (Zeiner and Wolf 1993, McFarlane and King 2006, Gburski et al. 2007)	centrum edge analysis (Zeiner and Wolf 1993) none (McFarlane and King 2006) none (Gburski et al. 2007)	VBGF (Zeiner and Wolf 1993) VBGF and logistic growth function (McFarlane and King 2006) VBGF with back-calculated sizes-at-age in younger skates (Gburski et al. 2007)	♂: 0.25 (S.E. 0.10) ♀: 0.16 (S.E. 0.05) comb: 0.17 (S.E. 0.05) (Zeiner and Wolf 1993) ♂: 0.07 ♀: 0.06 comb: 0.07 (McFarlane and King 2006) ♂: 0.0561 ♀: 0.0368 comb: 0.0437 (Gburski et al. 2007)	♂: 96.7 (S.E. 10) ♀: 106.9 (S.E. 13.1) comb: 104.7 (S.E. 9.1) (Zeiner and Wolf 1993) ♂: 131.5 ♀: 137.2 comb: 133.8 (McFarlane and King 2006) ♂: 168.8 ♀: 234.1 comb: 203.8 (Gburski et al. 2007)	♂: 0.73 (S.E. 1.1) ♀: -0.3 (S.E. 0.08) comb: -0.16 (S.E. 0.62) (Zeiner and Wolf 1993) ♂: -2.17 ♀: -1.80 comb: -1.92 (McFarlane and King 2006) ♂: -1.67 ♀: -1.99 comb: -1.868 (Gburski et al. 2007)	♂: 25.9 ♀: 22.3 comb: 24.2 (McFarlane and King 2006)	N/A	N/A	♂: 107.5 ♀: 109.4 comb: 108.5 (McFarlane and King 2006)	♂: 0.20 ♀: 0.21 comb: 0.20 (McFarlane and King 2006)
California skate	no attempts to age this species (globally)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 9 (continued).

Common Name	Ageing Method	Verification and/or Validation	Growth model	Growth Parameters: von Bertalanffy K	L_∞	t_0	L_0	Gompertz G	g	Logistic L_a	r
big skate	vertebral centra; thin sectioning (Zeiner and Wolf 1993, McFarlane and King 2006, Gburski et al. 2007)	centrum edge analysis (Zeiner and Wolf 1993) none (McFarlane and King 2006) none (Gburski et al. 2007)	logistic growth function (Zeiner and Wolf 1993) VBGF and logistic growth function* (McFarlane and King 2006) VBGF with back-calculated sizes-at-age in younger skates (Gburski et al. 2007) GROTAG and Fabens method (King and McFarlane 2010)	♂: 0.05 ♀: 0.04 comb: 0.04 (McFarlane and King 2006) ♂: 0.152 ♀: 0.080 comb: 0.1145 (Gburski et al. 2007) GROTAG ♂: 0.27 ♀: 0.02 comb: 0.05 Fabens ♂: 0.23 ♀: 0.06 comb: 0.16 (King and McFarlane 2010)	♂: 233.0 ♀: 293.5 comb: 293.4 (McFarlane and King 2006) ♂: 153.3 ♀: 247.5 comb: 189.6 (Gburski et al. 2007) GROTAG ♂: 139.21 ♀: 719.81 comb: 294.7 Fabens ♂: 145.95 ♀: 151.09 comb: 168.6 (King and McFarlane 2010)	♂: -2.10 ♀: -1.60 comb: -2.01 (McFarlane and King 2006) ♂: -0.632 ♀: -1.075 comb: -8.35 (Gburski et al. 2007) GROTAG ♂: -0.51 ♀: -1.62 comb: -1.44 Fabens ♂: -0.57 ♀: -2.75 comb: -0.81 (King and McFarlane 2010)	♂: 13.3 (S.E. 2.8) ♀: 15.0 (S.E. 3.1) comb: 15.0 (S.E. 2.2) (Zeiner and Wolf 1993) ♂: 33.6 ♀: 29.8 comb: 32.7 (McFarlane and King 2006)	N/A	N/A	♂: 139.3 (S.E. 7.7) ♀: 167.9 (S.E. 13.7) comb: 151.0 (S.E. 7.6) (Zeiner and Wolf 1993) ♂: 163.0 ♀: 188.5 comb: 185.4 (McFarlane and King 2006)	♂: 0.43 (S.E. 0.05) ♀: 0.37 (S.E. 0.05) comb: 0.38 (S.E. 0.04) (Zeiner and Wolf 1993) ♂: 0.20 ♀: 0.20 comb: 0.19 (McFarlane and King 2006)

Table 9 (continued).

				Growth Parameters							
				von Bertalanffy				Gompertz		Logistic	
Common Name	**Ageing Method**	**Verification and/or Validation**	**Growth model**	***K***	L_{∞}	t_0	L_0	***G***	***g***	L_a	***r***
starry skate	no attempts to age this species (globally)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

*determined to be the best model describing growth

**only results for 3-parameter VBGF provided; see Perez 2005 for results of other 3 growth models

***only results for 3-parameter VBGF are provided; see Ebert et al. 2007 for results of other 5 growth models

Table 10: Reproductive characteristics of skates found in British Columbia waters. ♂ = male; ♀ = female; m_x = number of offspring produced annually by individuals at age x; V_x = reproductive value (elasticity analysis); avg. = average.

	Reproduction							
Common Name	**Reproductive mode**	**Sexual dimorphism**	**Fecundity**	**Gestation time (months)**	**Reproductive cycle**	**Estimated number repro yrs.**	**Sex ratio at birth**	**Length at birth (cm)**
deep sea skate	oviparity	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)
sandpaper skate	oviparity	largest individuals ♂; size-at-maturity approx. equal (Ebert 2005)	total number of mature oocytes 5-11; increased number w/ maternal size (Ebert 2005) no relationship b/w # or size of mature ova and female TL (Ebert et al. 2007) m_x = 30-75 V_x (peak at 10 yrs.) = 131 (Ebert et al. 2007)	1 yr (assumed) (Ebert et al. 2007)	continuous w/ resting period following parturition (Perez 2005)	no estimate(s)	1:1 (juveniles) (Ebert 2005) 1:1 (assumed) (Ebert et al. 2007)	12-16 (Ebert 2003)
roughtail skate	oviparity	♀ and ♂ same size; size-at-maturity approx. equal (Ebert 2005)	total number of mature oocytes 3-12; increase in number w/ maternal size (Ebert 2005)	no estimate(s)	no estimate(s)	no estimate(s)	1:1 (juveniles) (Ebert 2005)	9-16 (Ebert 2003)

Table 10 (continued).

Common Name	Reproduction: Reproductive mode	Sexual dimorphism	Fecundity	Gestation time (months)	Reproductive cycle	Estimated number repro yrs.	Sex ratio at birth	Length at birth (cm)
Aleutian skate	oviparity	♂ and ♀ same size (Ishiyama 1958) largest individuals ♀; ♀ mature at larger size (Ebert 2005)	total number of mature oocytes 0-20; increased number w/ maternal size; possible senescence (Ebert 2005) no sig. increase in # or size of ova w/ female size (Ebert et al. 2007) m_x = 50-85 V_x (peak at 13 yrs.) = 178 (Ebert et al. 2007)	1 yr (assumed) (Ebert et al. 2007)	no estimate(s)	no estimate(s)	1:1 (juveniles) (Ebert 2005) 1:1 (assumed) (Ebert et al. 2007)	12-15 DW (Teshima and Tomonaga 1986)
Alaska skate	oviparity	largest individuals ♂; size-at-maturity approx. equal (Ebert 2005)	total number of mature oocytes 6-16; no apparent increase w/ maternal size (Ebert 2005)	no estimate(s)	no estimate(s)	no estimate(s)	1:1 (juveniles) (Ebert 2005)	19.8-21 (Matta and Gunderson 2007)
whitebrow skate	oviparity	largest individuals ♂; size-at-maturity approx. equal (Ebert 2005)	total number of mature oocytes 4-12; no apparent increase in number w/ maternal size (Ebert 2005)	no estimate(s)	no estimate(s)	no estimate(s)	1:1 (juveniles) (Ebert 2005)	no estimate(s)
broad skate	oviparity	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	23 (Ebert 2003)

Table 10 (continued).

	Reproduction							
Common Name	**Reproductive mode**	**Sexual dimorphism**	**Fecundity**	**Gestation time (months)**	**Reproductive cycle**	**Estimated number repro yrs.**	**Sex ratio at birth**	**Length at birth (cm)**
longnose skate	oviparity	♀ larger than ♂; statistically significant differences in growth b/w sexes (Gburski et al. 2007)	est. <50 per year (Gertseva 2009, Frisk et al. 2001) m_x = 50-85 V_x (peak at 19 yrs.) = 237 (Ebert et al. 2007)	1 yr (assumed) (Ebert et al. 2007)	continuous; gravid females w/ egg cases found throughout sampling period; no seasonal cycle evident (Ebert et al. 2008)	4 (Zeiner and Wolf 1993)	1:1 (assumed) (Ebert et al. 2007)	12-17 (Ebert 2003)
California skate	oviparity	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	15-23 (Ebert 2003)
big skate	oviparity	♀ larger than ♂ (Zeiner and Wolf 1993) ♀ larger than ♂; statistically significant differences in growth b/w sexes (Gburski et al. 2007)	1-5 per case, average 3.25 (Hitz 1964) 2-7, av 3-4 per case (DeLacy and Chapman 1935) 1-8 per case (Ford 1971) m_x = 50-100 V_x (peak at 13 yrs.) = 206 (Ebert et al. 2007) 1260 neonates (using avg. 3.5 embryos per case) (Ebert and Davis 2007)	12 (DeLacy and Chapman 1935, Hitz 1964) 12+ (Ford 1971) 1 yr (assumed) (Ebert et al. 2007)	continuous; no gravid females w/ egg cases *in utero* encountered during study; no seasonal cycle evident (Ebert et al. 2008)	1 to 3 (Zeiner and Wolf 1993)	1:1 (Hitz 1964) 1:1 (assumed) (Ebert et al. 2007)	18-23 (Ebert 2003)
starry skate	oviparity	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	12-16 (Ebert 2003)

Table 11: Demographic parameters of skates found in British Columbia waters. λ = finite population growth rate; R_0 = net reproductive rate; t_{x2} = population doubling time; rT = rate of increase per generation.

	Demographic Parameters						
Common Name	**λ**	**R_0**	**t_{x2}**	**rT**	**Geographic Region**	**Method**	**Source**
deep sea skate	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A
sandpaper skate	1.36 (C.I. 1.357-1.362)	30.29 (C.I. 29.92-30.65)	2.35 (C.I. 2.34-2.37)	3.69 (C.I. 3.67-3.71)	Gulf of Alaska and Bering Sea	deterministic and probabilistic life tabel models with Monte Carlo simulations	Ebert et al. 2007
roughtail skate	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A
Aleutian skate	1.252 (C.I. 1.251-1.253)	23.26 (C.I. 23.06-23.45)	3.14 (C.I. 3.13-3.16)	3.33 (C.I. 3.32-3.34)	Gulf of Alaska and Bering Sea	deterministic and probabilistic life tabel models with Monte Carlo simulations	Ebert et al. 2007
Alaska skate	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A
whitebrow skate	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A
broad skate	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A
longnose skate	1.202 (C.I. 1.201-1.203)	36.47 (C.I. 36.12-36.83)	3.82 (C.I. 3.81-3.83)	3.72 (C.I. 3.70-3.73)	Gulf of Alaska and Bering Sea	deterministic and probabilistic life tabel models with Monte Carlo simulations	Ebert et al. 2007
California skate	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A
big skate	1.334 (C.I. 1.333-1.336)	48.69 (C.I. 48.26-49.12)	2.45 (C.I. 2.44-2.46)	4.31 (C.I. 4.30-4.33)	Gulf of Alaska and Bering Sea	deterministic and probabilistic life tabel models with Monte Carlo simulations	Ebert et al. 2007

Table 11 (continued).

	Demographic Parameters						
Common Name	**λ**	**R_0**	**t_{x2}**	**rT**	**Geographic Region**	**Method**	**Source**
starry skate	no estimate(s)	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A

λ = finite population growth rate

R_0 = net reproductive rate

t_{x2} = population doubling time

rT = rate of increase per generation

Table 12: Mortality parameters and details of each associated study for skates in British Columbia waters. ♂ = male; ♀ = female; M = natural mortality; F = fishing mortality; Z = total instantaneous mortality; ω = maximum age; α = median age at first reproduction; k = von Bertalanffy growth parameter.

	Mortality Parameters						
Common Name	***M***	***F***	***Z***	**Geographic area**	**Equation used**	**Age range used (yrs)**	**Source**
deep sea skate	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A	N/A
sandpaper skate	0.3			Gulf of Alaska and Bering Sea	Hoenig (1983) $\ln M = 1.46-1.01*(\ln\omega)$	ω = 13 (Ebert et al. 2007) (triangular density function, ω = 15-25) (Ebert et al. 2007)	Ebert et al. 2007
	0.32			Gulf of Alaska and Bering Sea	Hoenig (1983) $\ln M = 1.44-0.982*(\ln\omega)$	same as above	Ebert et al. 2007
	0.22			Gulf of Alaska and Bering Sea	Jensen (1996) $M = 1.65/\alpha$	α = 9-11 (mean 10)	Ebert et al. 2007
	0.1			Gulf of Alaska and Bering Sea	Jensen (1996) $M = 1.50*k$	N/A	Ebert et al. 2007
	0.1			Gulf of Alaska and Bering Sea	Jensen (1996) $M = 1.6*k$	N/A	Ebert et al. 2007
	0.33			Gulf of Alaska and Bering Sea	Campana et al. (2001) $M = -\ln 0.01/\omega$	same as above	Ebert et al. 2007
roughtail skate	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A	N/A

Table 12 (continued).

	Mortality Parameters						
Common Name	***M***	***F***	***Z***	**Geographic area**	**Equation used**	**Age range used (yrs)**	**Source**
Aleutian skate	0.23			Gulf of Alaska and Bering Sea	Hoenig (1983) ln$M$ = 1.46-1.01*(lnω)	ω = 17 (Ebert et al. 2007) (triangular density function, ω = 18-45) (Ebert et al. 2007)	Ebert et al. 2007
	0.25			Gulf of Alaska and Bering Sea	Hoenig (1983) ln$M$ = 1.44-0.982*(lnω)	same as above	Ebert et al. 2007
	0.16			Gulf of Alaska and Bering Sea	Jensen (1996) M = 1.65/α	α = 6-9 (mean 7.5)	Ebert et al. 2007
	0.16			Gulf of Alaska and Bering Sea	Jensen (1996) M = 1.50*k	N/A	Ebert et al. 2007
	0.17			Gulf of Alaska and Bering Sea	Jensen (1996) M = 1.6*k	N/A	Ebert et al. 2007
	0.26			Gulf of Alaska and Bering Sea	Campana et al. (2001) M = -ln0.01/ω	same as above	Ebert et al. 2007

Table 12 (continued).

	Mortality Parameters						
Common Name	***M***	***F***	***Z***	**Geographic area**	**Equation used**	**Age range used (yrs)**	**Source**
Alaska skate	♂: 0.28 ♀: 0.25			eastern Bering Sea	Hoenig's equation (1983)	♂: 15 ♀: 17	Matta and Gunderson 2007
	♂: 0.19 (C.I. = 0.15, 0.23) ♀: 0.14 (C.I. = 0.11, 0.17)			eastern Bering Sea	Jensen's equation (1996) using growth coefficient; modified by Pauly (1980)	N/A	Matta and Gunderson 2007
	♂: 0.18 ♀: 0.17			eastern Bering Sea	Jensen's equation (1996) using age-at-maturity	N/A	Matta and Gunderson 2007
whitebrow skate	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A	N/A
broad skate	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A	N/A
longnose skate	0.17			Gulf of Alaska (GOA)	Hoenig's equation (1983)	25	Gburski et al. 2007
	0.19			Gulf of Alaska and Bering Sea	Hoenig (1983) $\ln M = 1.46-1.01*(\ln \omega)$	ω = 24 (Gburski et al. 2007) (triangular density function, ω = 21-36) (Ebert et al. 2007)	Ebert et al. 2007

Table 12 (continued).

Common Name	Mortality Parameters			Geographic area	Equation used	Age range used (yrs)	Source
	M	*F*	*Z*				
longnose skate (cont.)	0.2			Gulf of Alaska and Bering Sea	Hoenig (1983) ln$M$ = 1.44-0.982*(lnω)	same as above	Ebert et al. 2007
	0.11			Gulf of Alaska and Bering Sea	Jensen (1996) M = 1.65/α	α = 13-16 (mean 10)	Ebert et al. 2007
	0.06			Gulf of Alaska and Bering Sea	Jensen (1996) M = 1.50*k	N/A	Ebert et al. 2007
	0.06			Gulf of Alaska and Bering Sea	Jensen (1996) M = 1.6*k	N/A	Ebert et al. 2007
	0.21			Gulf of Alaska and Bering Sea	Campana et al. (2001) M = -ln0.01/ω	same as above	Ebert et al. 2007
California skate	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A	N/A
big skate	0.28			Gulf of Alaska (GOA)	Hoenig's equation (1983)	15	Gburski et al. 2007
	0.16			Gulf of Alaska and Bering Sea	Hoenig (1983) ln$M$ = 1.46-1.01*(lnω)	ω = 26 (McFarlane and King 2006) (triangular density function, ω = 18-31) (Ebert et al. 2007)	Ebert et al. 2007
	0.17			Gulf of Alaska and Bering Sea	Hoenig (1983) ln$M$ = 1.44-0.982*(lnω)	same as above	Ebert et al. 2007
	0.17			Gulf of Alaska and Bering Sea	Jensen (1996) M = 1.65/α	α = 8-11 (mean 9)	Ebert et al. 2007

Table 12 (continued).

	Mortality Parameters						
Common Name	***M***	***F***	***Z***	**Geographic area**	**Equation used**	**Age range used (yrs)**	**Source**
big skate (cont.)	0.12			Gulf of Alaska and Bering Sea	Jensen (1996) M = 1.50*k	N/A	Ebert et al. 2007
	0.13			Gulf of Alaska and Bering Sea	Jensen (1996) M = 1.6*k	N/A	Ebert et al. 2007
	0.18			Gulf of Alaska and Bering Sea	Campana et al. (2001) M = -ln0.01/ω	same as above	Ebert et al. 2007
starry skate	no estimate(s)	no estimate(s)	no estimate(s)	N/A	N/A	N/A	N/A

M = natural mortality rate

F = fishing mortality

Z = total instantaneous mortality

Table 13: Taxonomic classification (including common name), geographic distribution, depth range, and frequency of occurrence of rays found in British Columbia waters.

Taxonomy				Range			
Family	**Latin Name**	**Common Name**	**Other Names**	**Global**	**Eastern North Pacific**	**Depth Range**	**Occurrence in BC waters**
Torpedinidae	*Torpedo californica*	**Pacific electric ray**	California electric ray, Pacific torpedo ray	eastern north Pacific (Hart 1988)	northern British Columbia to central Baja California (Mecklenburg et al. 2002)	most commonly encountered in shallower water < 275 m (Hart 1988)	infrequent (small numbers caught in domestic and J/V trawl surveys since 1991) (Benson et al. 2001)
Dasyatidae (stingrays)	*Dasyatis violacea*	**pelagic stingray**	N/A	cosmopolitan in tropical and temperate seas (Mollet 2002); specimens only rarely found in NE Atlantic (Ellis 2007)	southeast Alaska to equatorial Central America (Mecklenburg et al. 2002, Mollet 2002)	pelagic (Hart 1988)	rare
Dasyatidae (stingrays)	*Dasyatis dipterura*	**diamond stingray**	N/A	Hawaii (Nishida and Nakaya 1990) and eastern north Pacific ocean (Eschmeyer et al. 1983)	British Columbia, Canada to Chile, including the Galapagos Islands (Eschmeyer et al. 1983, Nishida and Nakaya 1990)	on beaches in shallow water (Hart 1988) common benthic inhabitant of inshore waters; have expanded into continental slope to at least 480m, euryhaline, pelagic and freshwater environments (Compagno 1990)	rare (recorded rarely north of southern California) (Eschmeyer et al. 1983)

Table 14: Age, growth and maturity characteristics of rays found in British Columbia waters. ♂ = male; ♀ = female; DW = disc width; *k* = von Bertalanffy growth parameter; ω = theoretical longevity based on maximum observed ages and three models: Ricker (1979), Fabens (1965), and Taylor (1958); α = median age at maturity.

	Age and Growth						
Common Name	**Max length (TL) (cm)**	**Longevity (T_{max}) (yrs)**	**Method for longevity determ.**	**Length at 1st maturity (cm)**	**Age at 1st maturity (yrs)**	**Length-at-50% maturity (TL_{50}) (cm)**	**Age-at-50% maturity (T_{50}) (yrs)**
Pacific electric ray	♂: 92 ♀: 137 (Ebert 2003)	16, but possibly up to 24 (Neer and Cailliet 2001)	predicted from von Bertalanffy growth function (Neer and Cailliet 2001)	♂: 61.0 ♀: 72.1 (Neer and Cailliet 2001)	no estimate(s)	♂: 64.5 ♀: 73.1 (Neer and Cailliet 2001)	♂: 6 (est.) ♀: 9 (est.) (Neer and Cailliet 2001)
pelagic stingray	80 DW (Bigelow and Schroeder 1965) 96 DW (Mollet 2002) ♂: 67-69 DW ♀:97 DW (Mollet et al. 2002) ♂: 42 DW ♀: 46 DW (Ellis 2007)*	comb: 10 (Mollet and Cailliet 2002) ♂: 7.2-8.3 (DW) ♀: 8.5-8.7 (DW) ♂: 7 (mass) ♀: 9-11 (mass) ♂: 8.4-13.9 (*k*) ♀: 11.8-24 (*k*) (Mollet et al. 2002) 12 (Neer 2008)	equation: 7ln/*k* (Mollet and Cailliet 2002) Gulland and Holt (1959) and Fabens (1965) methods, using DW and mass; equation 7ln2/*k* (Mollet et al. 2002)	♂: 35-40 DW ♀: 40-50 DW (Mollet et al. 2002)	♂: 2 ♀: 3 (Mollet et al. 2002)	no estimate(s)	no estimate(s)
diamond stingray	100 DW (McEachran and Notarbartolo-di-Sciara 1995) ♂: 60 DW ♀: 83 DW (Smith et al. 2007)	♂: 19 ♀: 28 (Smith et al. 2007) ♂: ω = 22.3-47.1 ♀: ω = 47.3-63.5 (Smith et al. 2007)	annual band pair deposition in vertebral centra (Smith et al. 2007)	♂: 50 DW (Mathews and Druck-Gonzalez 1975) ♂: 45.5 DW ♀: 65.5 DW (Mariano-Melendez 1997) ♂: 57 DW ♀: 47 DW (Smith et al. 2007)	no estimate(s)	♂: 45.5 DW ♀: 65.5 DW (Mariano-Melendez 1997) ♂: 46.5 DW ♀: 57.3 DW (Smith et al. 2007)	α = 10 years (Smith 2005, Smith et al. 2007)

*from the North Sea; 2 most northerly records in the Atlantic Ocean

Table 15: Ageing methodology, growth model(s) and growth parameters for rays found in British Columbia waters. ♂ = male; ♀ = female; VBGF = von Bertalanffy growth function; K = VBGF growth coefficient; L_∞ = mean asymptotic length; t_0 = hypothetical age at zero (0) length or disc width; L_0 = mean length at birth; OTC = oxytetracycline; G = Gompertz growth function; DW_∞ = mean asymptotic disc width; DW_0 = mean disc width at birth.

					Growth Parameters			
Common Name	**Ageing Method**	**Validation**	**Verification**	**Growth model**	***K***	L_∞	t_0	L_0
Pacific electric ray	whole vertebral centra with graphite microtopography band enhancement (Neer and Cailliet 2001)	unsuccessful OTC injection (Neer and Cailliet 2001)	edge analysis (Neer and Cailliet 2001)	VBGF (Neer and Cailliet 2001)	♂: 0.13 ♀: 0.07 (Neer and Cailliet 2001)	♂: 92.1 (95% C.I. 10.74) ♀: 137.3 (95% C.I. 28.82) (Neer and Cailliet 2001)	♂: -1.483 ♀: -1.934 (Neer and Cailliet 2001)	N/A
pelagic stingray	captive growth (Mollet et al. 2002)	none (Mollet et al. 2002)	none (Mollet et al. 2002)	VBGF, Gompertz growth function** (Mollet et al. 2002)	♂: VBGF 0.35 (S.E. 0.03), G 0.58 (S.E. 0.04) ♀: VBGF 0.20 (S.E. 0.02), G 0.41 (S.E. 0.02) (Mollet et al. 2002)	♂: VBGF DW_∞ 74 (S.E. 2), G 70 ♀: VBGF DW_∞ 116 (S.E. 5), G 101 (Mollet et al. 2002)	♂: VBGF 17 (S.E. 1), G 18 (S.E. 1) ♀: VBGF 17 (S.E. 1), G 18 (S.E. 1) (Mollet et al. 2002)	♂: DW_0 VBGF 17 (S.E. 1), G 18 (S.E. 1) ♀: DW_0 VBGF 17 (S.E. 1), G 18 (S.E. 1) (Mollet et al. 2007)
diamond stingray	annual band pair deposition in vertebral centra (Smith 2005, Smith et al. 2007)	none (Smith 2005, Smith et al. 2007)	modified centrum edge and marginal increment analysis (Smith 2005, Smith et al. 2007)	3-parameter VBGF fit to disc width data* (Smith et al. 2007)	♂: 0.10 ♀: 0.05 (Smith 2005, Smith et al. 2007)	♂: DW_∞ 62.2 ♀: DW_∞ 92.4 (Smith 2005, Smith et al. 2007)	♂: -6.80 ♀: -7.61 (Smith 2005, Smith et al. 2007)	♂: DW_0 31.3 ♀: DW_0 31.4 (Smith 2005, Smith et al. 2007)

*7 growth models were used; the 3-parameter VBGF generated the most appropriate fit based on standard error of model estimates, and Akaike's information criteria

**Gompertz model produced more reasonable values for size at birth, maximum size, and longevity

Table 16: Reproductive characteristics of rays found in British Columbia waters. ♂ = male; ♀ = female; DW = disc width; m_x = fecundity; est = estimated.

	Reproduction						
Common Name	**Reproductive mode**	**Sexual dimorphism**	**Fecundity (embryos)**	**Gestation time (months)**	**Reproductive cycle**	**Sex ratio at birth**	**Length at birth (cm)**
Pacific electric ray	aplacental viviparity	♀ grow larger (Neer and Cailliet 2001)	number of ova 0-55, with number increasing with ♀ size; 17 young/litter (Neer and Cailliet 2001)	no estimate(s)	♂: annual ♀: biannual (Neer and Cailliet 2001)	10:7 (Neer and Cailliet 2001)	21.4-23.1 (Neer and Cailliet 2001) 18-23 (Ebert 2003)
pelagic stingray	aplacental viviparity	♀ larger than ♂ (Wilson and Beckett 1970, Mollet et al. 2002)	5-6 (McEachran and Notarbartolo-di-Sciara 1995) 4-9, average 6 (Mollet and Cailliet 2002, Mollet et al. 2002)	2 (Ranzi 1934) 1 yr (McEachran and Notarbartolo-di-Sciara 1995) 2-3 (Mollet et al. 2002)	probably annual (Mollet et al. 2002) 0.5 yrs. (Mollet 2002, Neer 2008)	1:1 (Wilson and Beckett 1970)	15-23.5 DW (Mollet et al. 2002) 19 DW (Neer 2008)
diamond stingray	aplacental viviparity	♀ larger than ♂ (Mariano-Melendez 1997)	2-4 (Mariano-Melendez 1997) observed fecundity from 1 to 3 embryos (Smith et al. 2007) avg litter size 6 (Mollet et al. 2002, Mollet 2002, Neer 2008) m_x mean: 2.72 m_x range: 1-4 (Smith et al. 2008)	2-2.5 (Mariano-Melendez 1997)	annual , 9.5 to 10 month diapause (Mariano-Melendez 1997) seminal fluid readily expelled from mature ♂ in Aug but not detected in June, Oct or Dec; gravid ♀ present in Aug (Smith et al. 2007)	1:1 (Mariano-Melendez 1997)	17-19 DW (Mariano-Melendez 1997) mean DW 21.3 (est) (Smith et al. 2007)

Table 17: Demographic parameters of rays found in British Columbia waters. stg = stage; *r* = intrinsic rate of increase; e^r (λ) = finite population growth rate; R_0 = net reproductive rate; G(T) = generation time; t_{x2} = theoretical population doubling time; c_x/w_x = stable age distribution; *M* = natural mortality; *r*T = rate of increase per generation.

	Demographic Parameters								
Common Name	***r***	**e^r (λ)**	**R_0**	**G(T)**	**t_{x2}**	**c_x/w_x**	**Geographic Region**	**Method**	**Source**
Pacific electric ray	0.09	1.09	2.59	11.15			central and southern California	age-based life history table (w/ diff mortality estimates) *M* = 0.277	Neer and Cailliet 2001
	0.18	1.2	8.89	13.03			central and southern California	age-based life history table (w/ diff mortality estimates) *M* = 0.186	Neer and Cailliet 2001
	0.27	1.31	38.07	17.97			central and southern California	age-based life history table (w/ diff mortality estimates) *M* = 0.096	Neer and Cailliet 2001
pelagic stingray	0.1604	1.1739	1.9907	4.29		age 1: 46.4% age 10: 0.17%	Monterey Bay, California	life history table	Mollet and Cailliet 2002*
	0.1604	1.1739	1.9907	4.29		age 1: 46.4% age 10: 0.17%	Monterey Bay, California	10x10 Leslie matrix; post-breeding census, birth-pulse, fixed stage duration	Mollet and Cailliet 2002*
	0.1604	1.1739	1.8706	3.91			Monterey Bay, California	9x9 stage based matrix	Mollet and Cailliet 2002*
	0.1604	1.1739	2.0211	4.39		stg 1: 46.4 stg 2: 24.9% stg 3: 28.7%	Monterey Bay, California	3x3 stage based matrix	Mollet and Cailliet 2002*

Table 17 (continued).

	Demographic Parameters								
Common Name	***r***	**e^r (λ)**	**R_0**	**G(T)**	**t_{x2}**	**c_x/w_x**	**Geographic Region**	**Method**	**Source**
pelagic stingray (cont.)	0.1604	1.1739	1.8892	4		stg 1: 71.3 stg 2: 28.7%	Monterey Bay, California	2x2 stage based matrix	Mollet and Cailliet 2002*
	0.311	1.3648	NG	6			global	age-structured life table using discrete form of Euler equation, and using the maximum estimate of age-specific survivorship	Dulvy et al. 2008
diamond stingray	*r*T = 0.83	1.05-1.06 (5-6% increase)	2.3-2.4	two measures of generation time; 14.9-16.5 years	14.7-15.0		Bahia Magdalena lagoon complex, Baja California Sur, Mexico	density-dependent, age-structured life table models using empirical estimates of growth, longevity, fecundity and maturity	Smith et al. 2008**

*study based on captive growth data from Monterey Bay, California

**only probabilistic results are presented; for deterministic results and confidence intervals see Smith et al. 2008

Table 18: Mortality parameters and details of each associated study for rays in British Columbia waters. *M* = natural mortality; *F* = fishing mortality; *Z* = total mortality; *ω* = longevity; *α* = median age at maturity; *k* = VBGF growth coefficient.

	Mortality Parameters						
Common Name	***M***	***F***	***Z***	**Geographic area**	**Equation used**	**Age range used (yrs)**	**Source**
Pacific electric ray			0.277	central and southern California	Hoenig's equation	16	Neer and Cailliet 2001
			0.186	central and southern California	Hoenig's equation	24	Neer and Cailliet 2001
			0.096	central and southern California	Hoenig's equation	47	Neer and Cailliet 2001
pelagic stingray	0.4604			California	-ln (0.01)/longevity	1 to 10	Mollet and Cailliet 2002
diamond stingray	0.149		0.149	Baja California Sur, Mexico	Hoenig (1983) $\ln Z = 1.46 - 1.01(\ln \omega)$	28	Smith et al. 2008
	0.16		0.16	Baja California Sur, Mexico	Hoenig (1983) $\ln Z = 1.44 - 0.982(\ln \omega)$	28	Smith et al. 2008
	0.082			Baja California Sur, Mexico	Jensen (1996) $M = 1.65/\alpha$	N/A	Smith et al. 2008
	0.165			Baja California Sur, Mexico	Jensen (1996) $M = 1.50k$	N/A	Smith et al. 2008

Table 18 (continued).

	Mortality Parameters						
Common Name	***M***	***F***	***Z***	**Geographic area**	**Equation used**	**Age range used (yrs)**	**Source**
diamond stingray (cont.)	0.087			Baja California Sur, Mexico	Jensen (1996) $M = 1.6k$	N/A	Smith et al. 2008
	0.164			Baja California Sur, Mexico	Campana et al. (2001) $M = -\ln 0.01/\omega$	28	Smith et al. 2008
	0.151-0.347			Baja California Sur, Mexico	Peterson and Wrobleski (1984)	N/A	Smith et al. 2008
	0.064-0.087			Baja California Sur, Mexico	Chen and Watanabe (1989)	28	Smith et al. 2008

Table 19: Species prioritized for study in BC waters based upon the criteria of: 1) amount of basic life history information available; 2) the frequency of occurrence in BC waters; 3) the current knowledge of the species' status based on the IUCN Red List (2010); and 4) the inherent vulnerability of the species based on the lowest estimated *r*-value from the literature, where *r* = intrinsic rate of population increase.

	Amount of basic life history available	Frequency of occurrence (in BC waters)	Current knowledge of population status (IUCN)	Inherent vulnerability of species (lowest estimated *r*-value)	Overall Priority for Study
Sharks					**Sharks**
Sixgill shark	low	common	near threatened	unknown	**HIGH**
Sevengill shark	low	rare	data deficient	high	**HIGH**
Great white shark	medium	rare	vulnerable	high	**HIGH**
Shortfin mako	medium	rare	vulnerable	high	**HIGH**
Salmon shark	medium	common	least concern	high	**HIGH**
Basking shark	low	rare*	vulnerable	high	**HIGH**
Common thresher	low	rare	vulnerable	high	**HIGH**
Bigeye thresher	low	infrequent	vulnerable	high	**HIGH**
Brown cat shark	low	common	data deficient	unknown	**HIGH**
Soupfin shark	medium	common	vulnerable	high	**HIGH**
Smooth hammerhead shark	low	rare	vulnerable	unknown	**HIGH**
Blue shark	high	common	near threatened	medium	**MED**
Pacific sleeper shark	low	common	data deficient	unknown	**HIGH**
Green-eye shark	low	rare	data deficient	unknown	**MED**
Spiny dogfish	high	common	vulnerable	high	**HIGH**
Pacific angel shark	medium	rare	near threatened	high	**MED**
Skates					**Skates**
Deep sea skate	low	rare	data deficient	unknown	**MED**
Sandpaper skate	medium	common	least concern	low	**LOW**
Roughtail skate	medium	infrequent	least concern	unknown	**MED**
Aleutian skate	medium	infrequent	least concern	low	**LOW**
Alaska skate	medium	rare	least concern	unknown	**LOW**
Whitebrow skate	low	rare	least concern	unknown	**LOW**
Broad skate	low	rare	least concern	unknown	**LOW**
Longnose skate	high	common	least concern	medium	**LOW**
California skate	low	rare	data deficient	unknown	**MED**
Big skate	high	common	near threatened	low	**LOW**
Starry skate	low	rare	least concern	unknown	**LOW**
Rays					**Rays**
Pacific electric ray	high	infrequent	least concern	medium	**LOW**
Pelagic stingray	high	rare	least concern	medium	**LOW**
Diamond stingray	high	rare	data deficient	unknown	**LOW**

*used to be common in BC waters, with a rate of decline exceeding 90% in < 2 generations (Wallace et al. 2007)

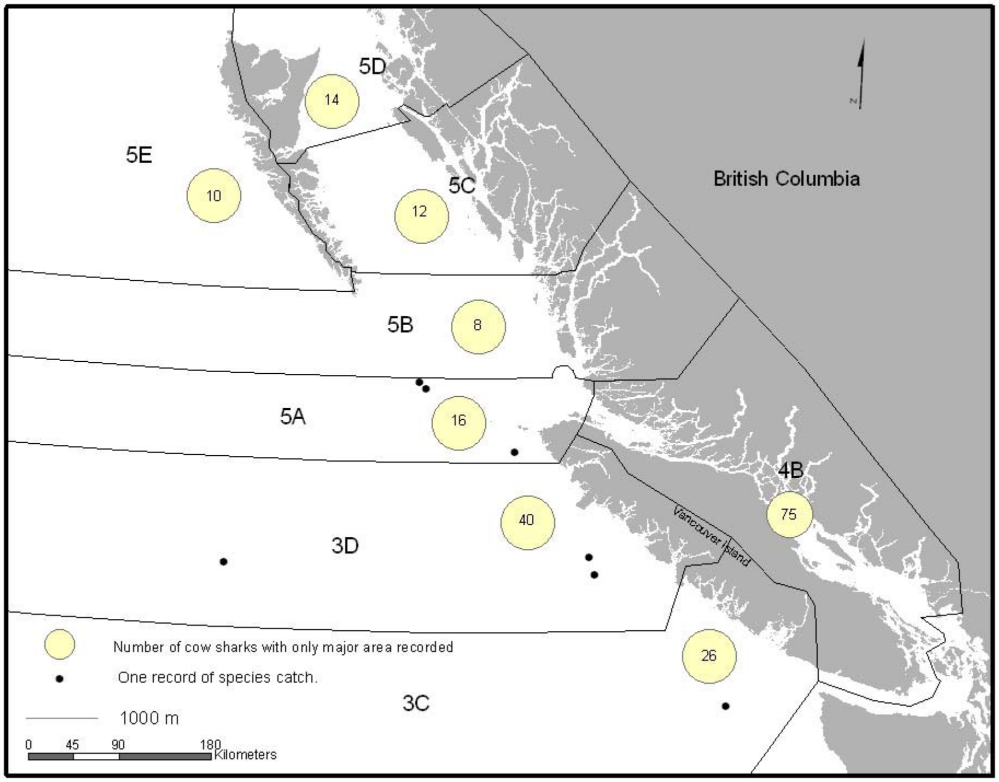
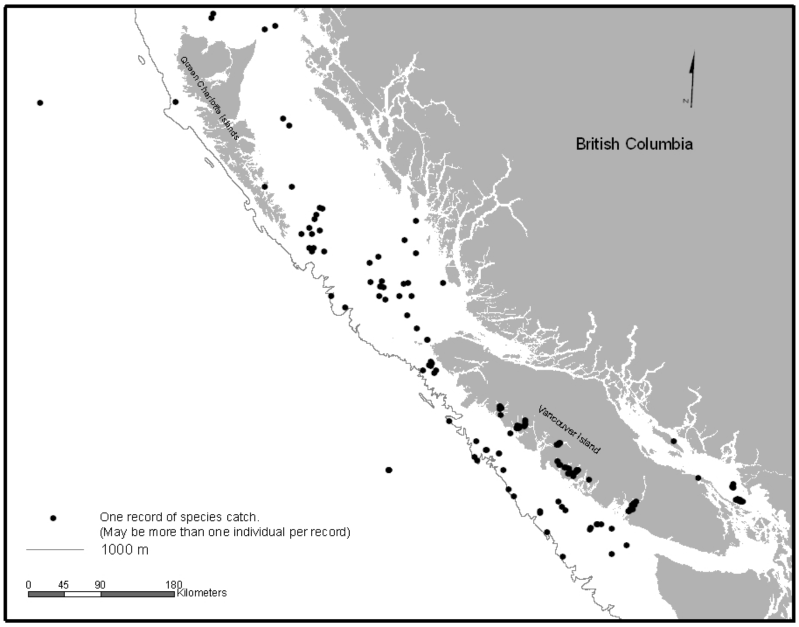


Figure 1. Distribution of **cow sharks** (sixgill shark, *Hexanchus griseus* or sevengill shark, *Notorynchus maculatus*) not identified to species off the west coast of Canada from 1984 to 2007. Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

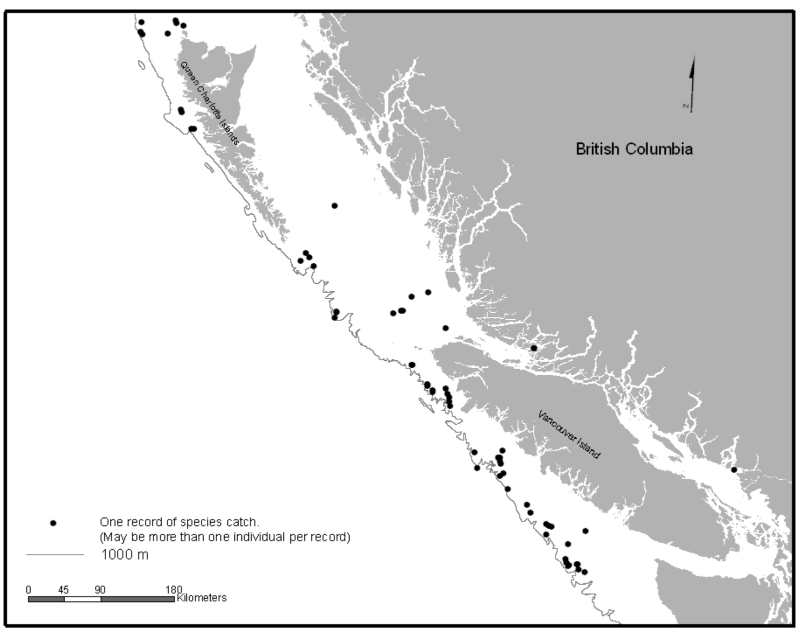


Figure 2. Distribution of **sixgill shark** (*Hexanchus griseus*) off the west coast of Canada from 1979 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

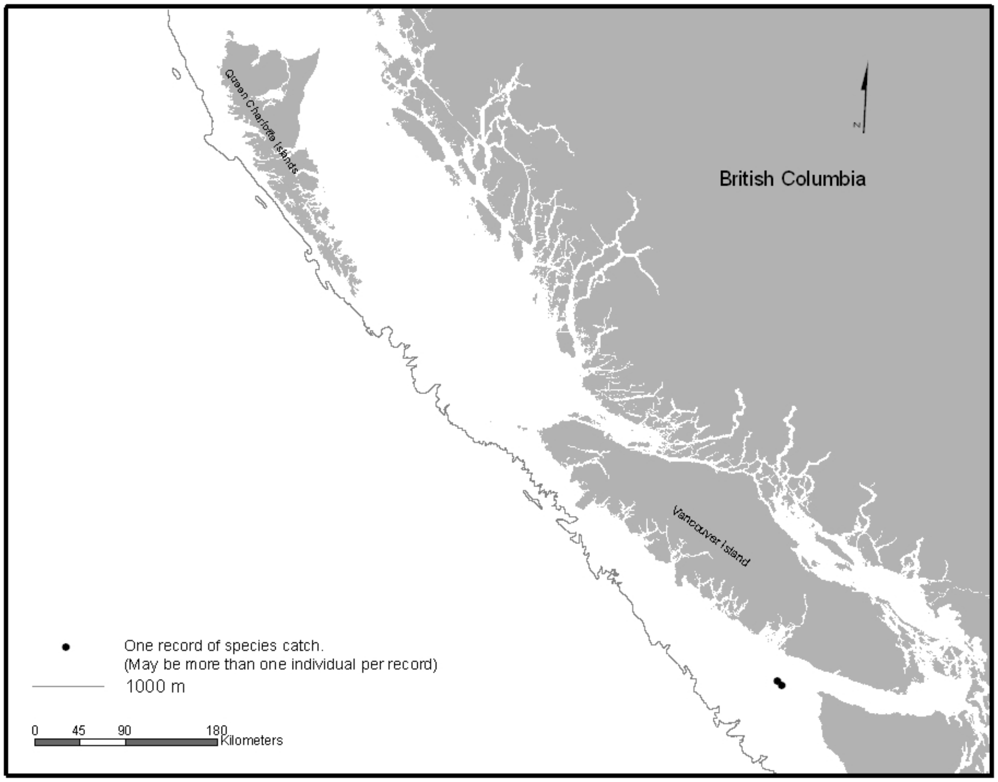
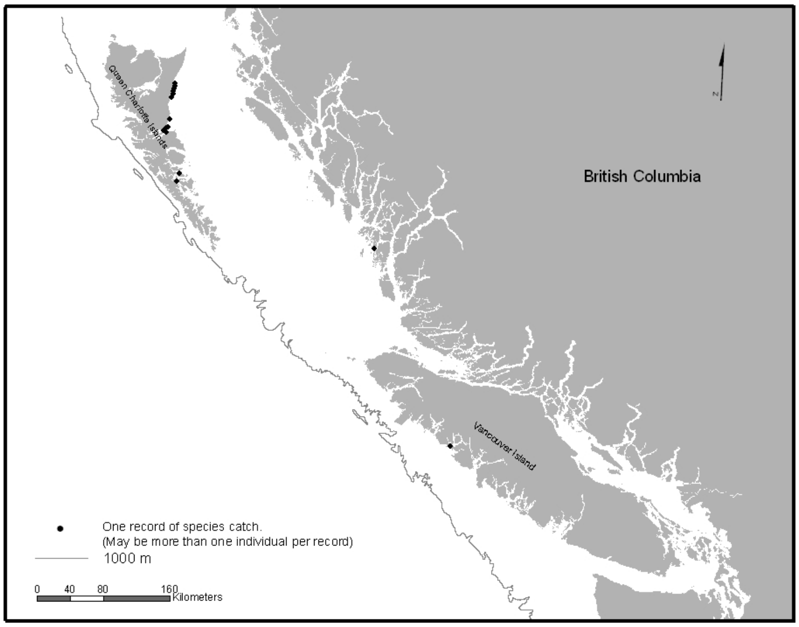


Figure 3. Distribution of **sevengill shark** (*Notorynchus cepdianus*) off the west coast of Canada from summer (June) 1991. There is no winter catch recorded for sevengill shark. Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

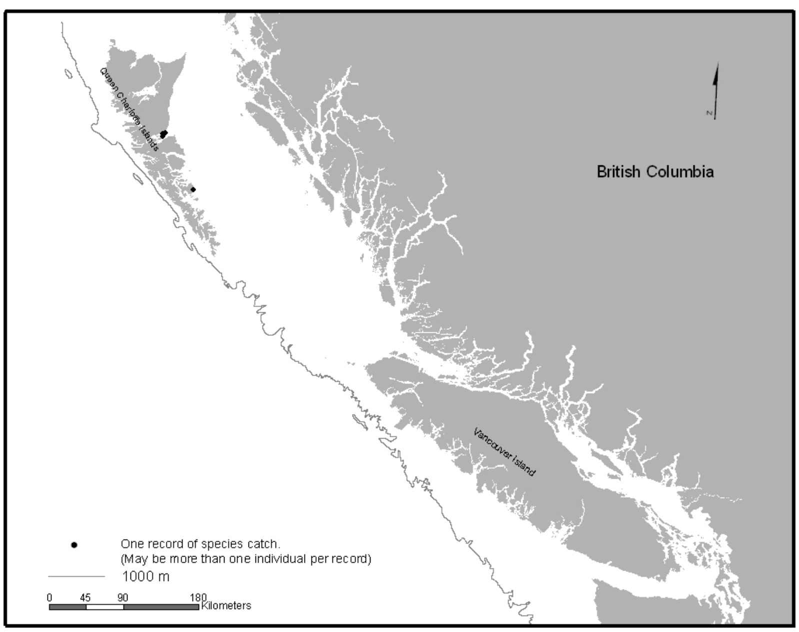


Figure 4. Historical distribution of **great white shark** (*Carcharodon carcharias*) off the west coast of Canada during A) the summer (May to October) and B) the winter (November to April). Positional data taken from Martin and Wallace (2005).

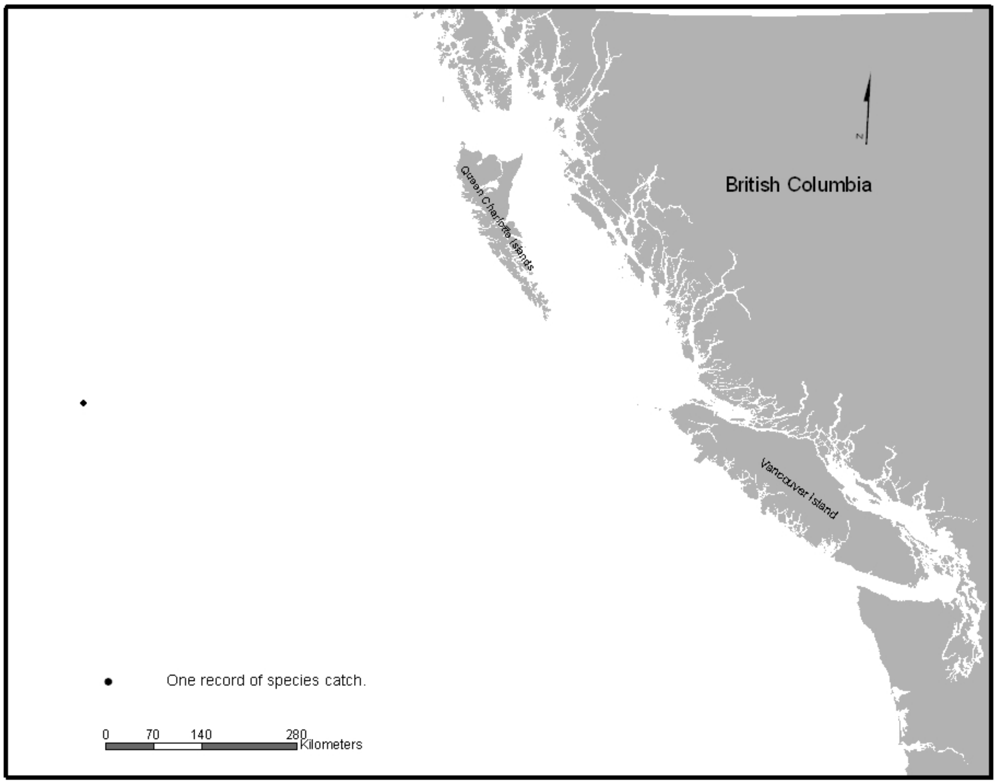
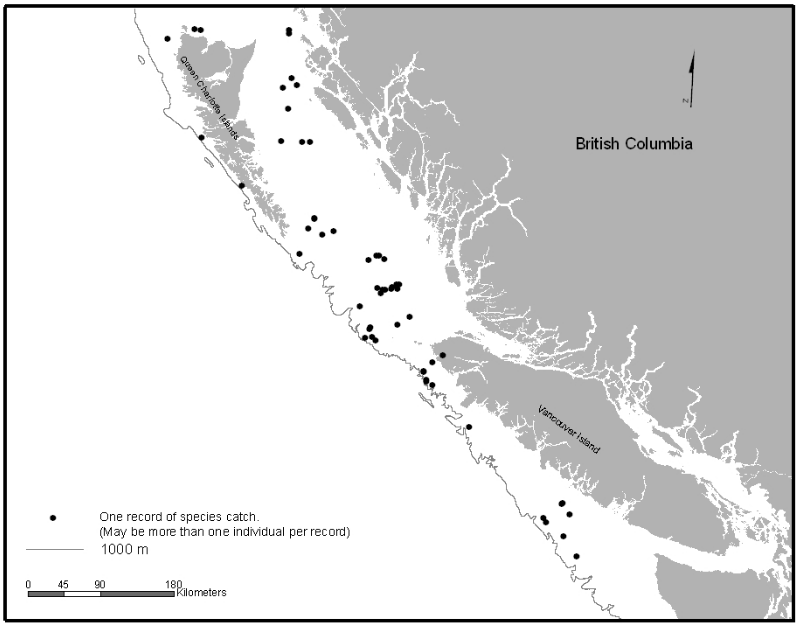


Figure 5. Single occurrence of **shortfin mako** (*Isurus oxyrinchus*) off the west coast of Canada. Positional data taken from: Gillespie, G.E. and Saunders, M.W. 1994. First verified record of the shortfin mako, *Isurus oxyrhinchus*, and second records or range extensions for three additional species, from British Columbia waters. Canadian Field Naturalist 108(30): 347-350.

A)



B)

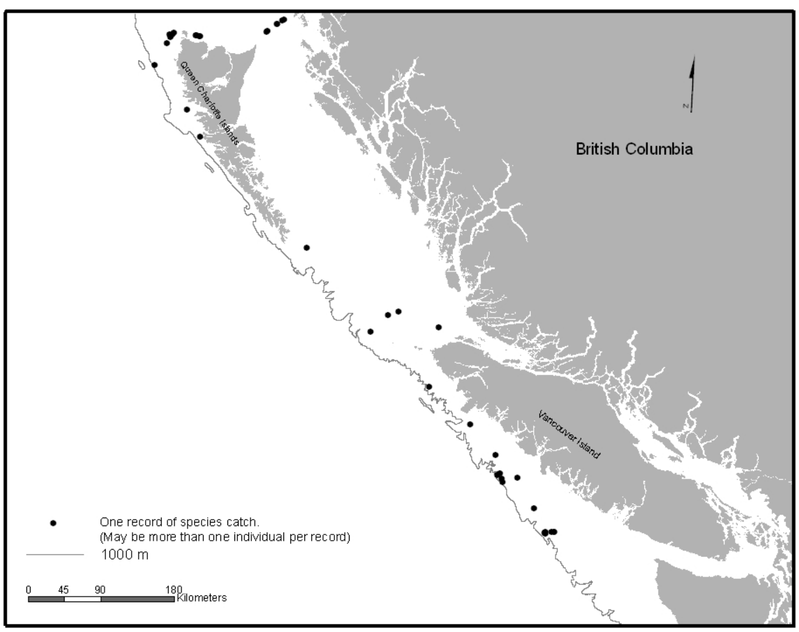


Figure 6. Distribution of **salmon shark** (*Lamna ditropis*) off the west coast of Canada from 1996 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

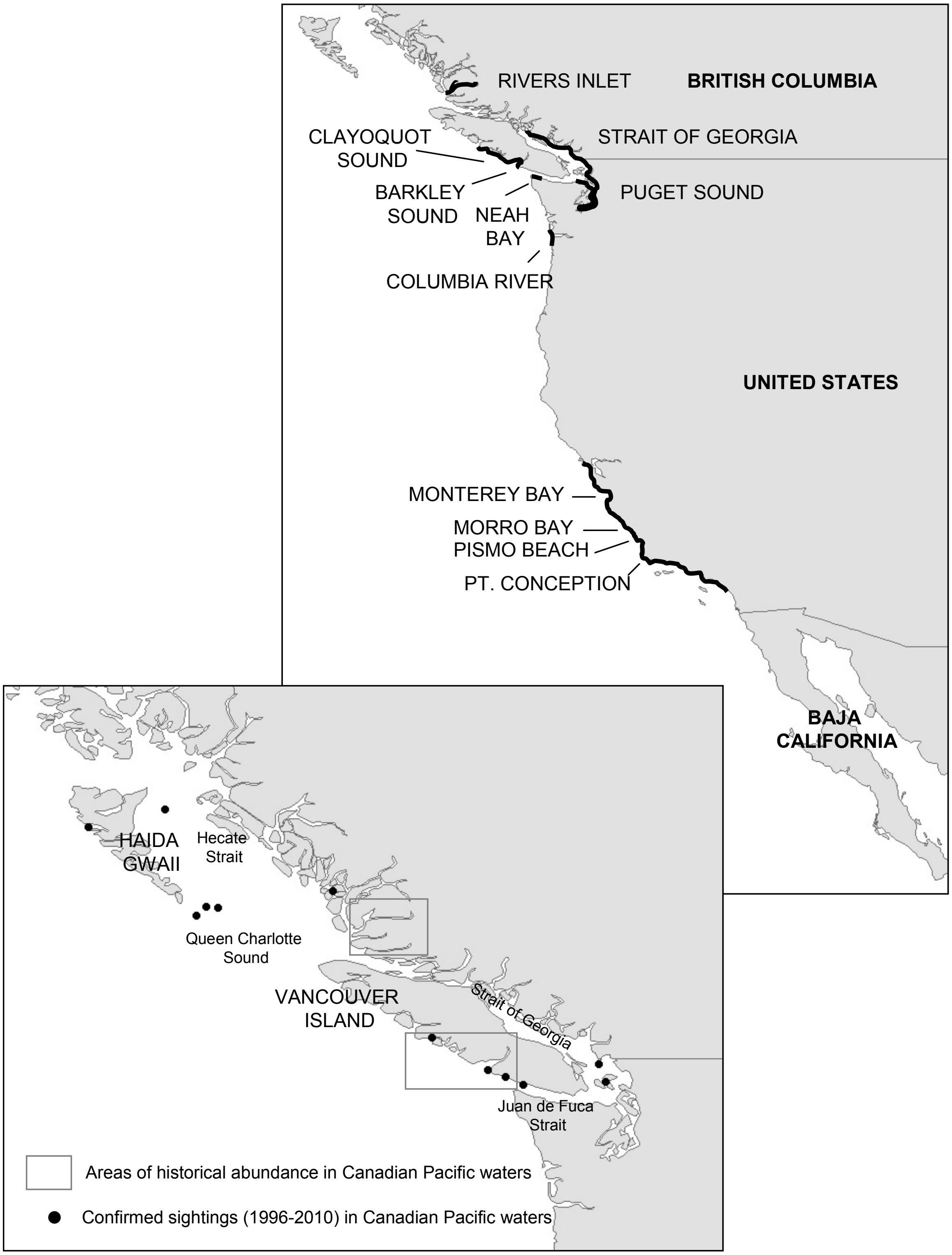
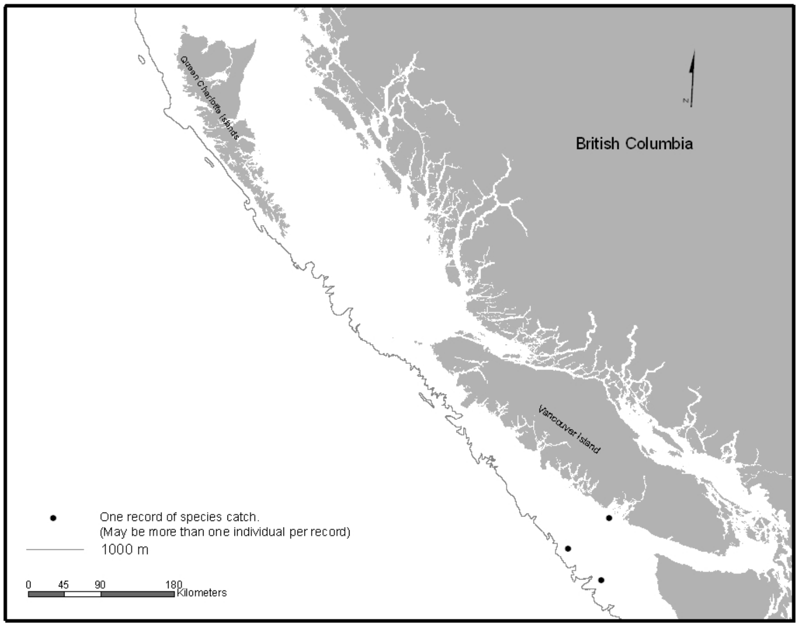


Figure 7. Areas of known historical abundance of **basking shark** (*Cetorhinus maximus*) from the 1900s onwards. Inset shows recent confirmed sightings in Canadian Pacific waters (i.e. from photo/ video identification or from an experienced source) from 1996-2010.

A)



B)

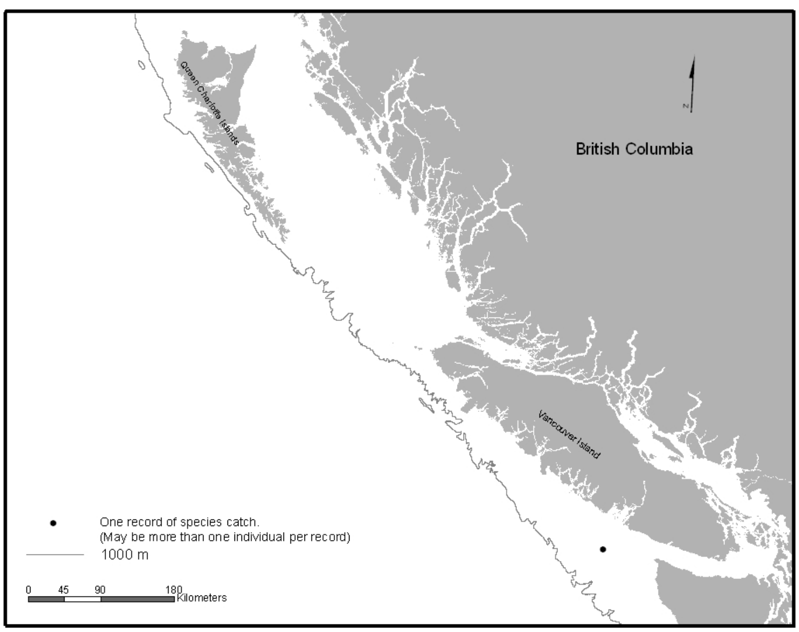
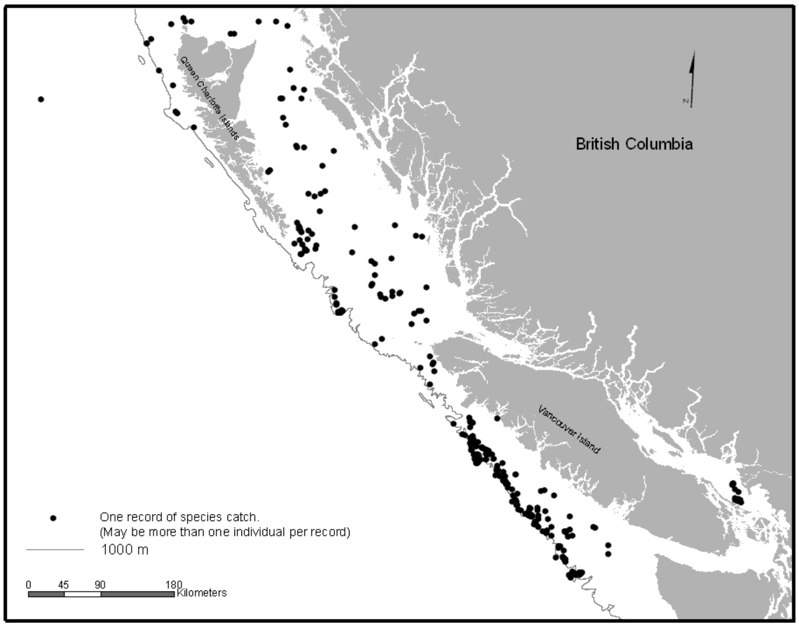


Figure 8. Distribution of **common thresher shark** (*Alopias vulpinus*) off the west coast of Canada from 1977 to 2000 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

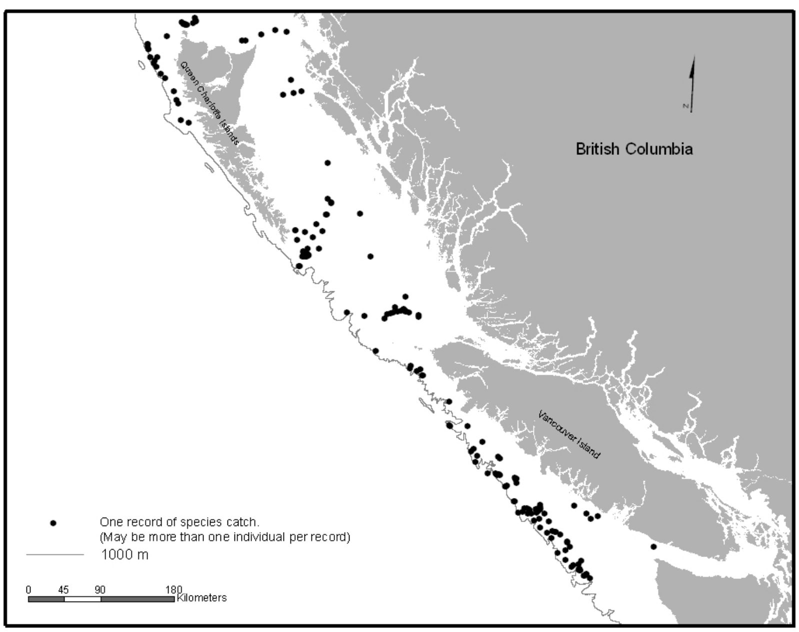
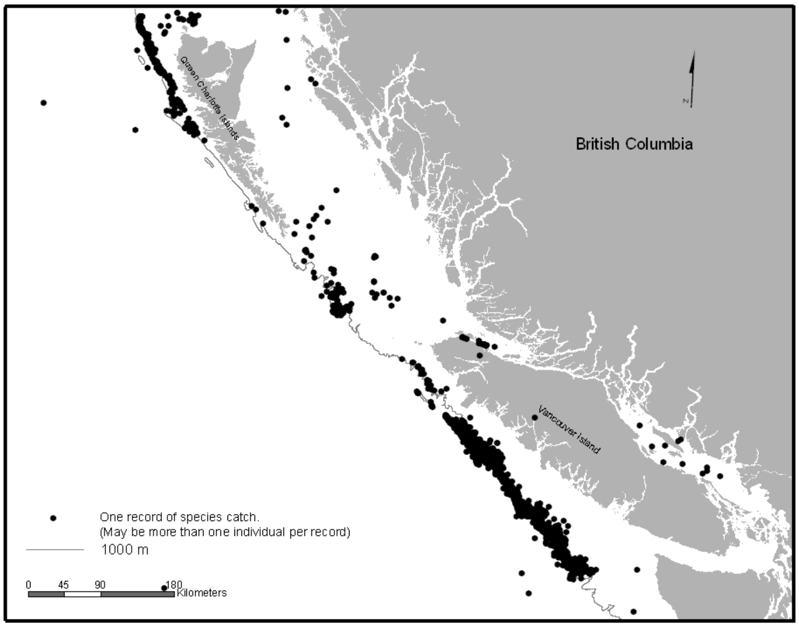


Figure 9. Distribution of **bigeye thresher** (*Alopias superciliosus*) off the west coast of Canada from 1977 to 2006 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

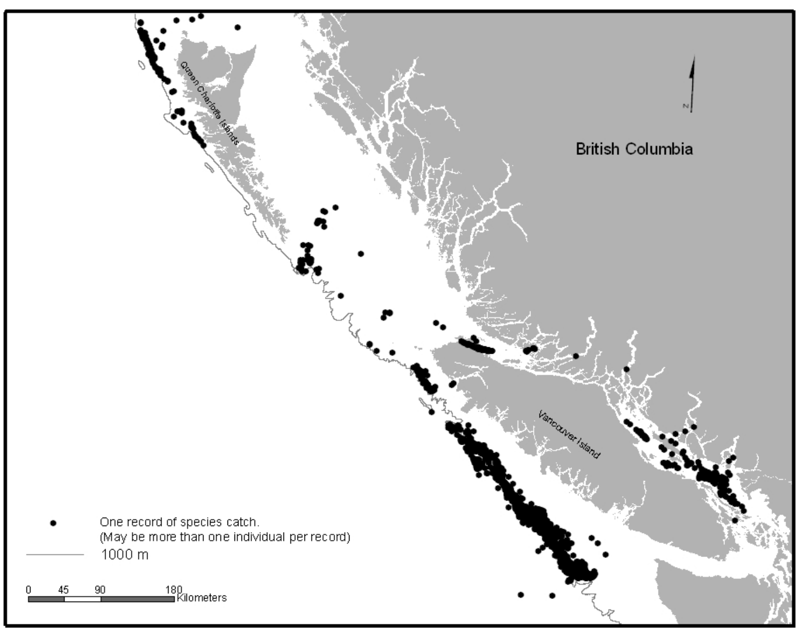
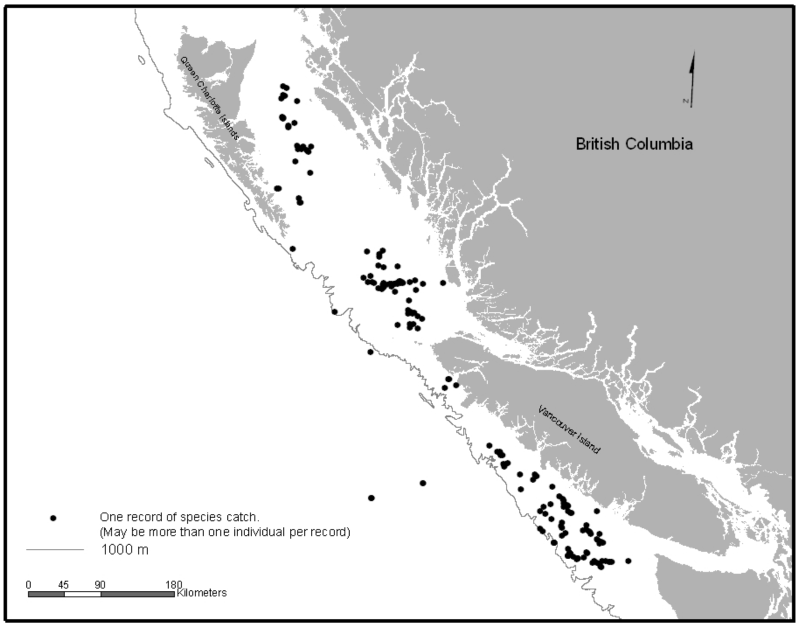


Figure 10. Distribution of **brown cat shark** (*Apristurus brunneus*) off the west coast of Canada from 1965 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

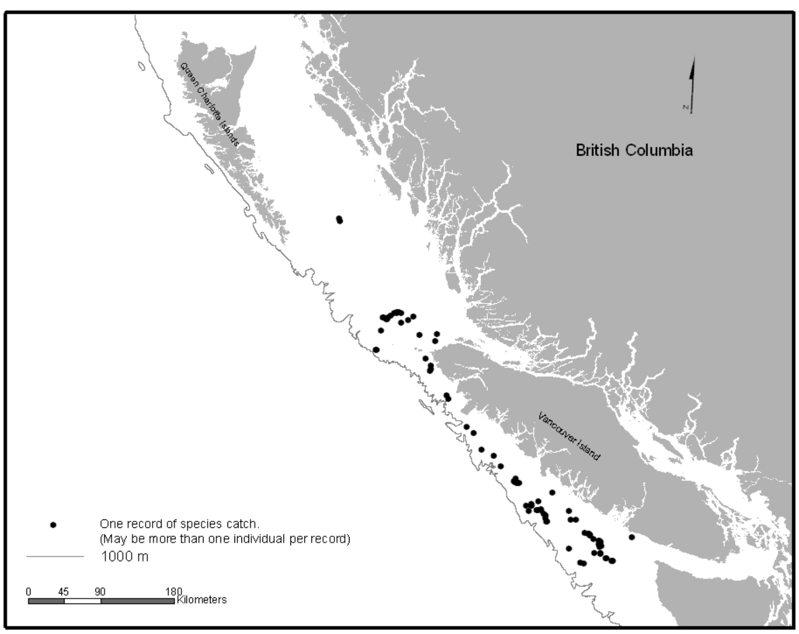


Figure 11. Distribution of **tope shark** (*Galeorhinus galeus*) off the west coast of Canada from 1994 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

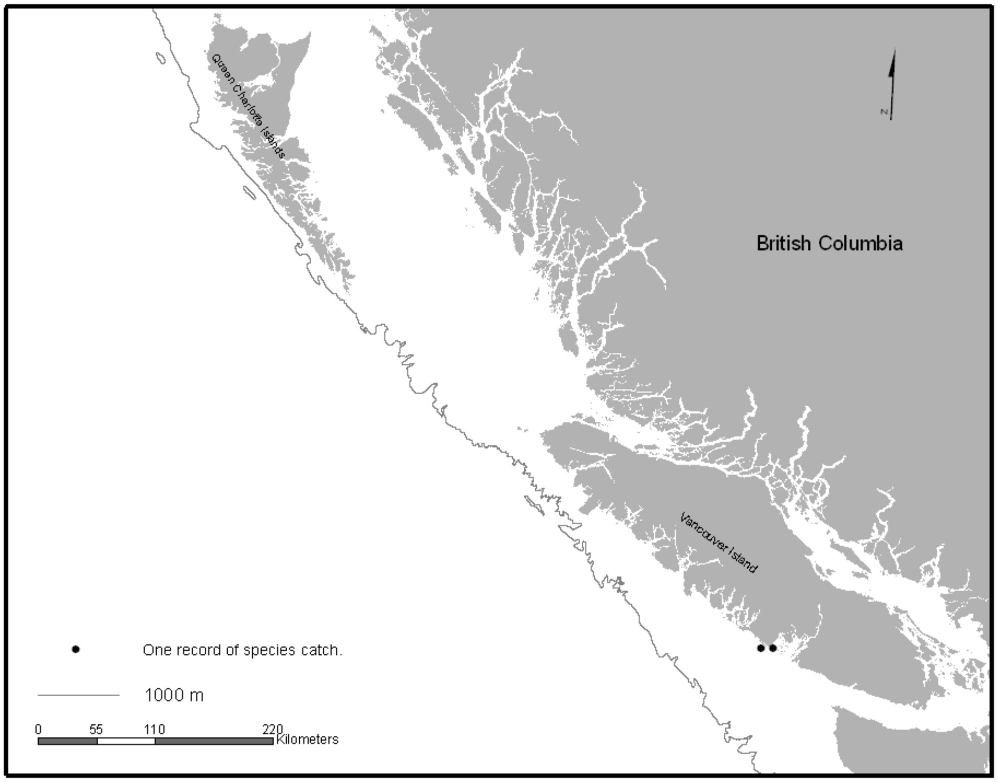
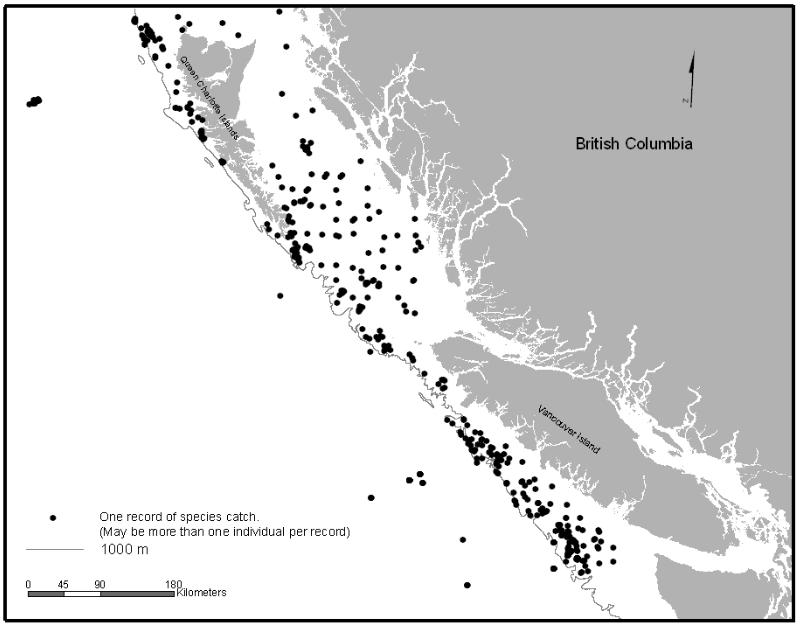


Figure 12. Historical landings of **smooth hammerhead shark** (*Sphyrna zygaena*) off the west coast of Canada in the 1950s. Positional data taken from: Carl, G.C. 1954. The hammerhead shark in British Columbia. Victoria Naturalist 11 (4).

A)



B)

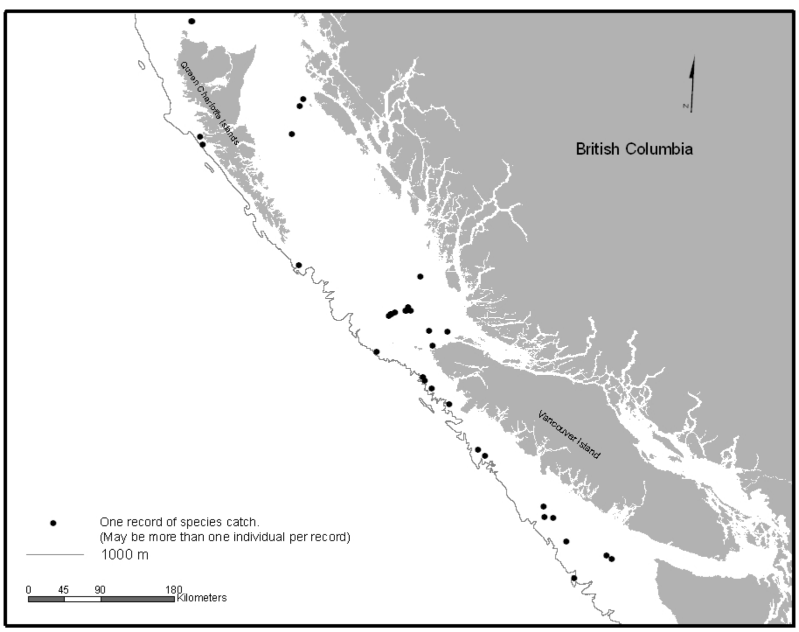
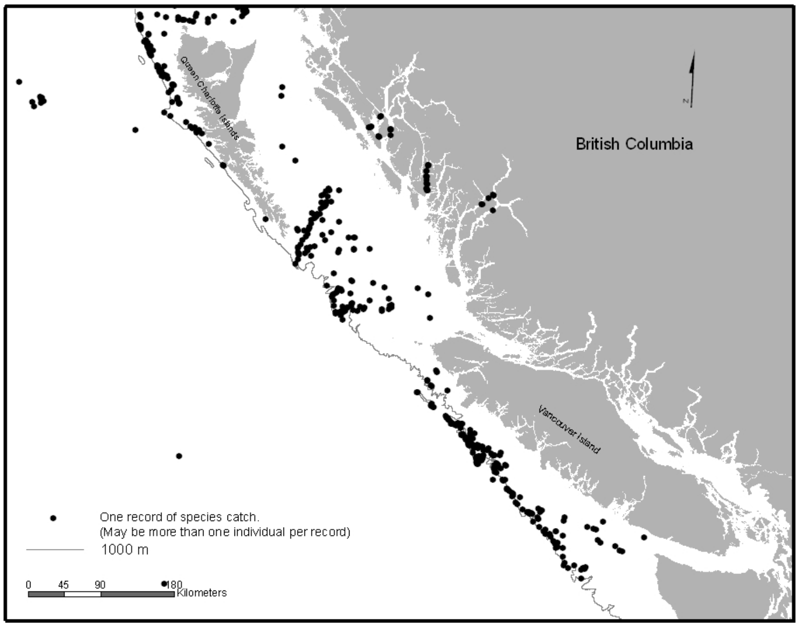


Figure 13. Distribution of **blue shark** (*Prionace glauca*) off the west coast of Canada from 1968 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

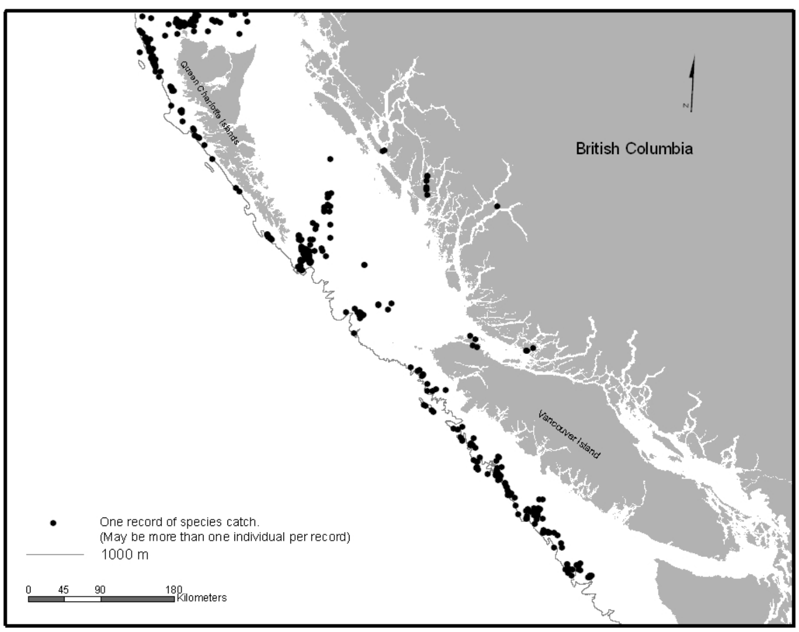
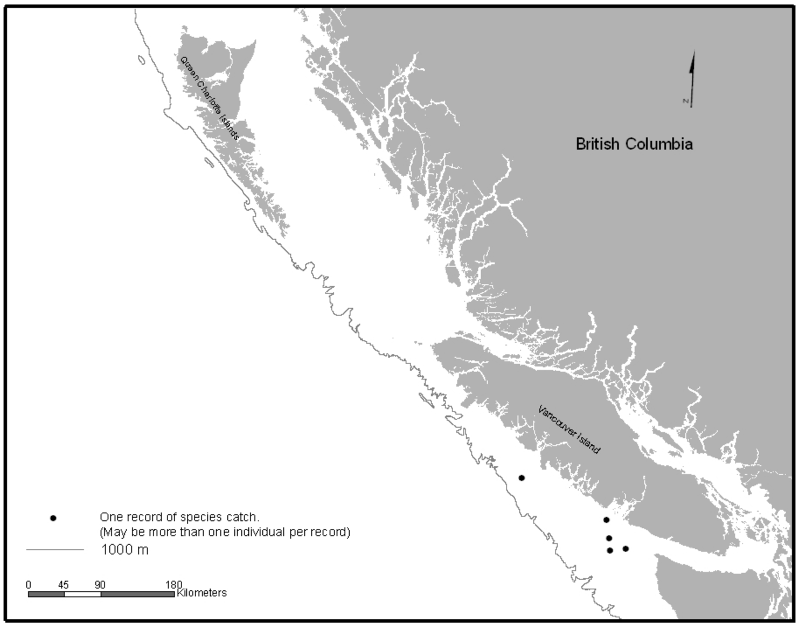


Figure 14. Distribution of **Pacific sleeper shark** (*Somniosus pacificus*) off the west coast of Canada from 1989 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

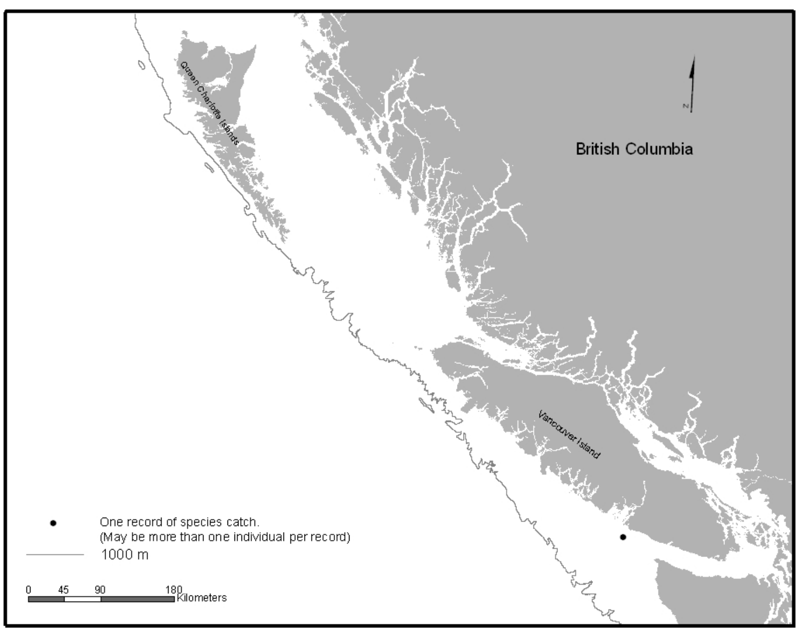
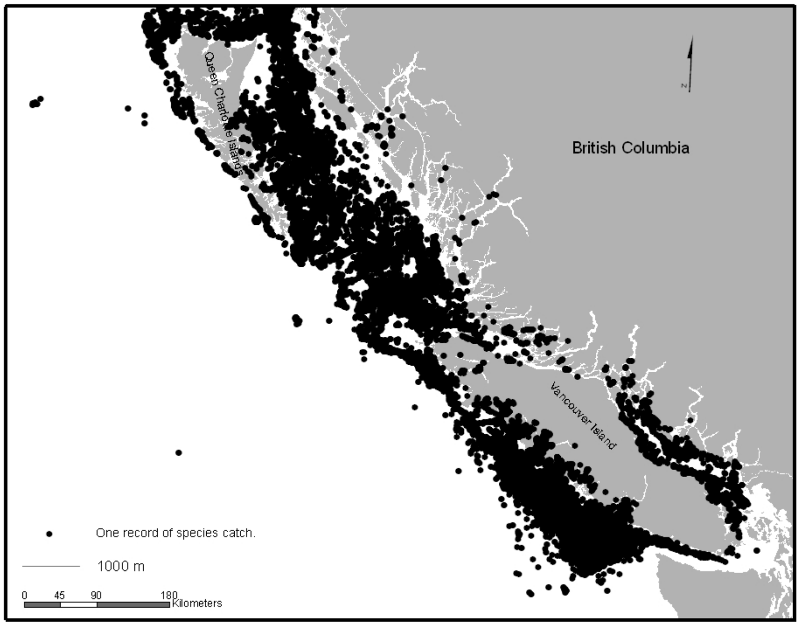


Figure 15. Distribution of **green-eye shark** (*Etmopterus villosus*) off the west coast of Canada from 1991 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

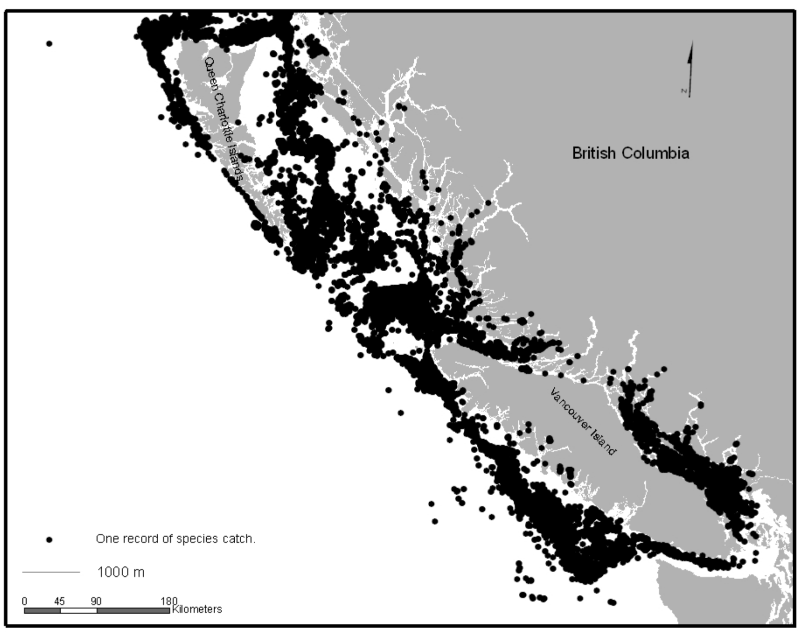
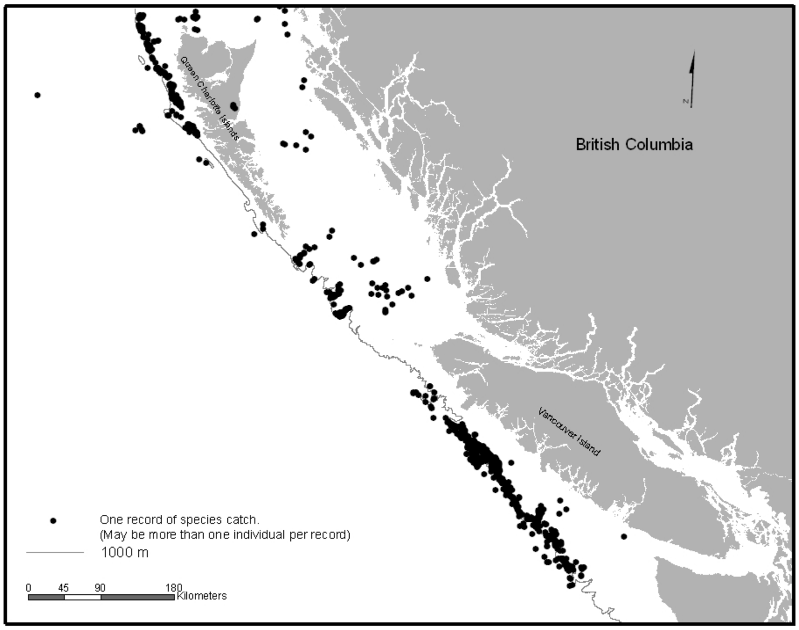


Figure 16. Distribution of **spiny dogfish** (*Squalus acanthias*) off the west coast of Canada from 1954 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



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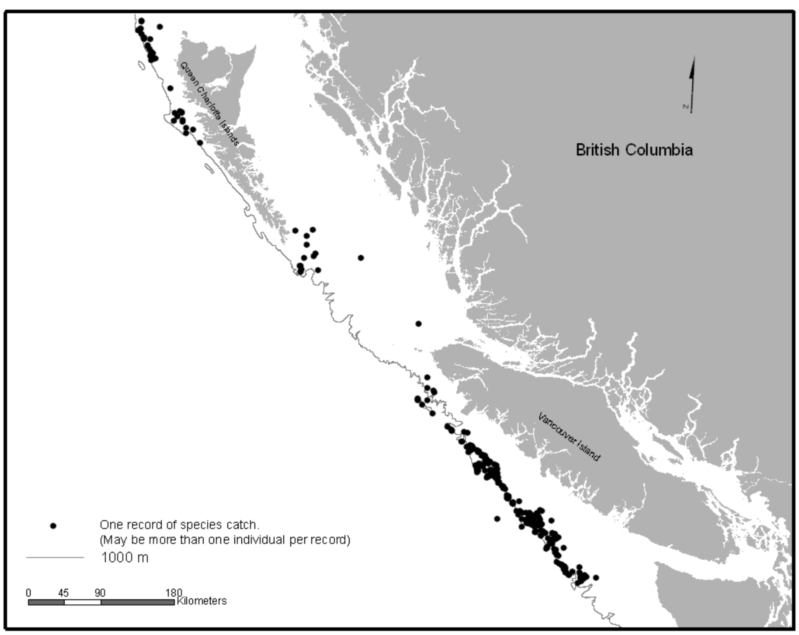
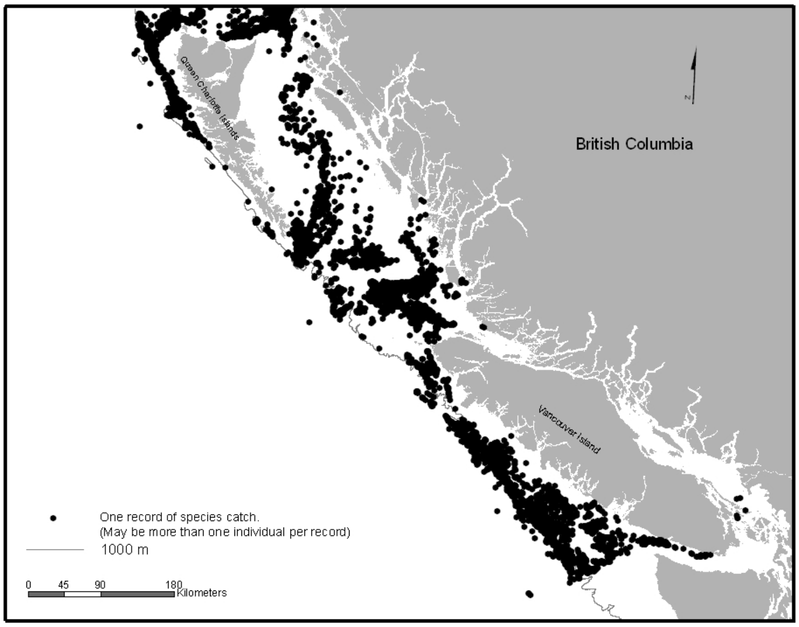


Figure 17. Distribution of **deep sea skate** (*Bathyraja abyssicola*) off the west coast of Canada from 1992 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

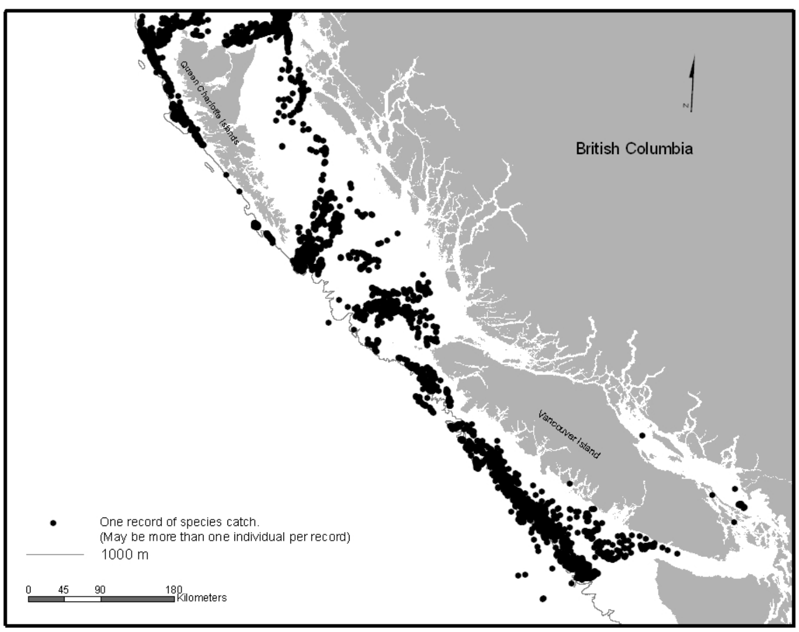
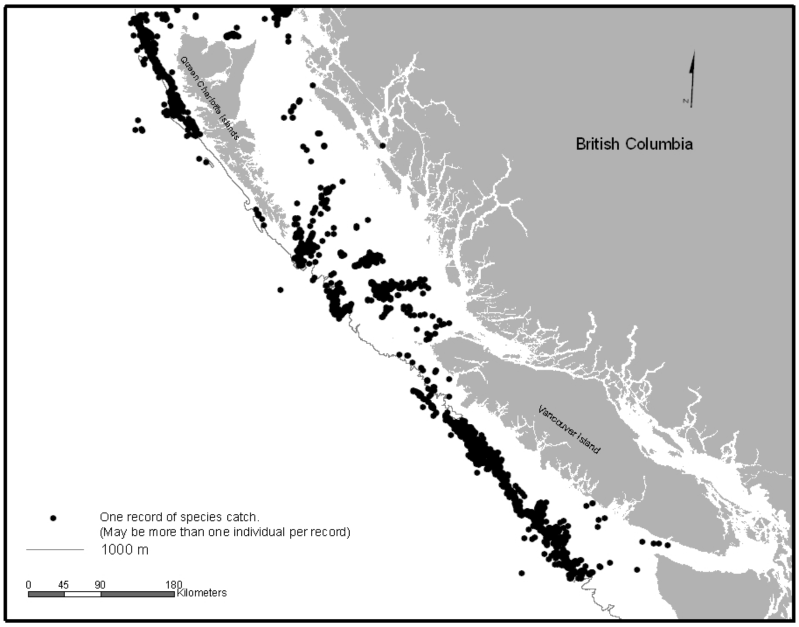


Figure 18. Distribution of **sandpaper skate** (*Bathyraja interrupta*) off the west coast of Canada from 1979 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

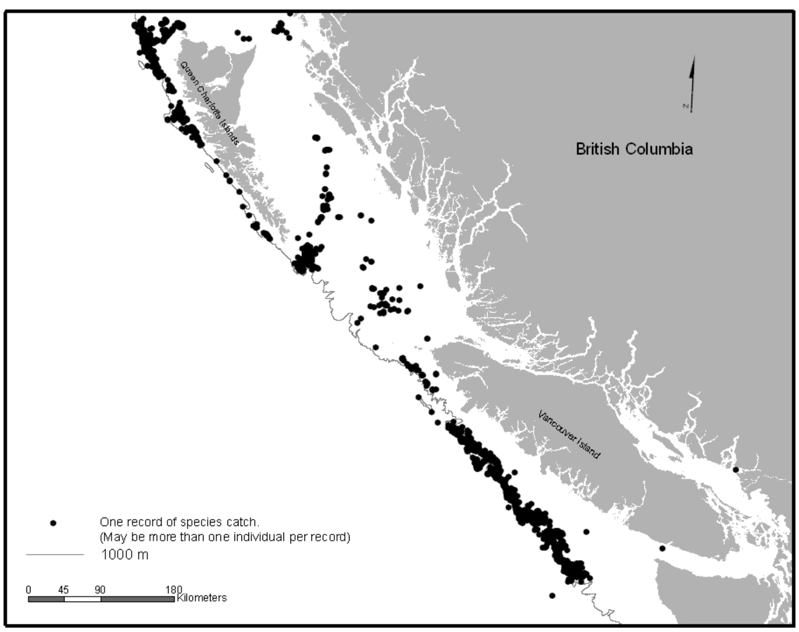


Figure 19. Distribution of **roughtail skate** (*Bathyraja trachura*) off the west coast of Canada from 1996 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

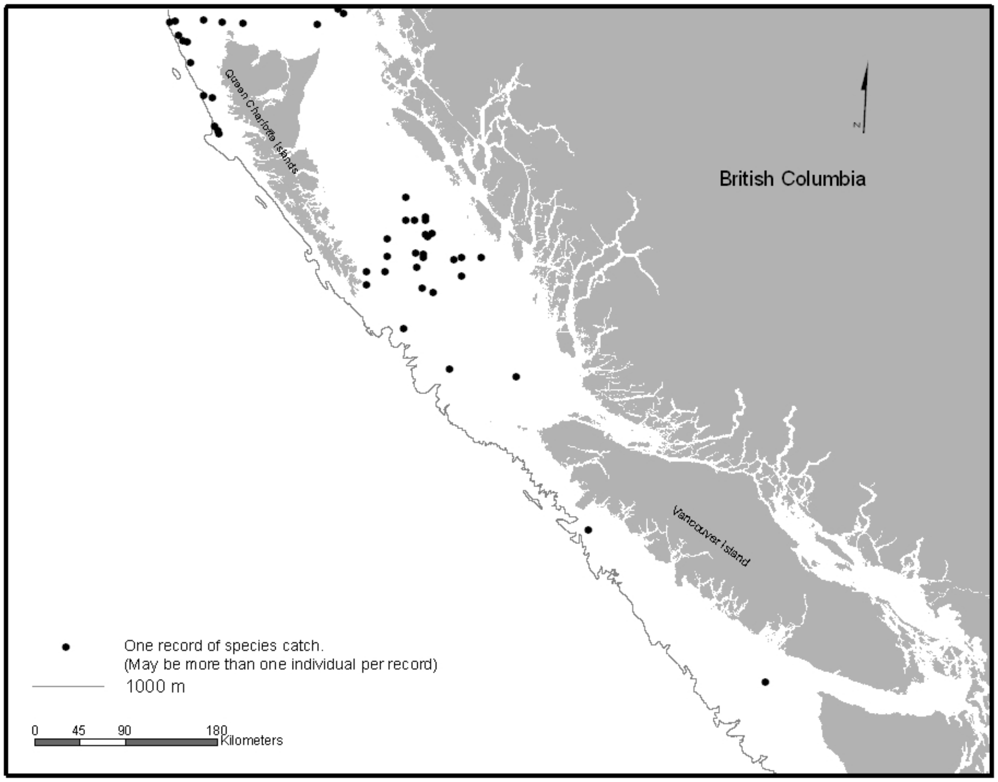
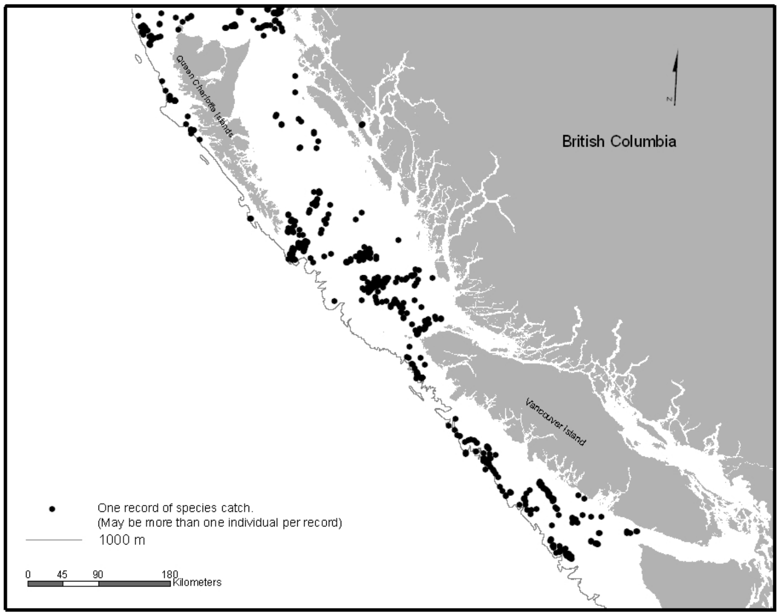


Figure 20. Distribution of the **Aleutian skate** (*Bathyraja aleutica*) off the west coast of Canada from 2004 to 2007 during the summer (May to October). There is no winter (November to April) catch recorded for Aleutian skate. Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

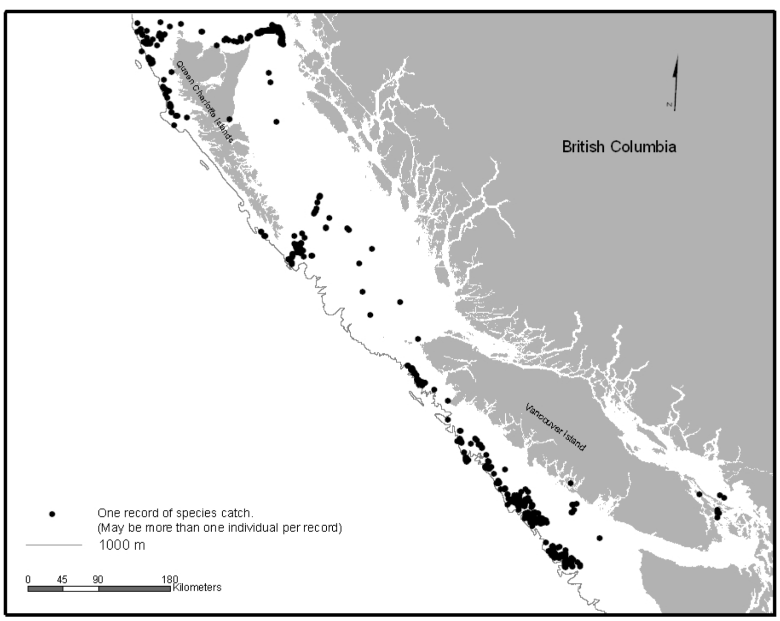


Figure 21. Distribution of **Alaska skate** (*Bathyraja parmifera*) off the west coast of Canada from 1975 to 2007 during A) the summer (May to October) and B) the winter (November to April). Some records (esp. southerly and/or shallower records) may be **starry skate** (*Raja stellulata*). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

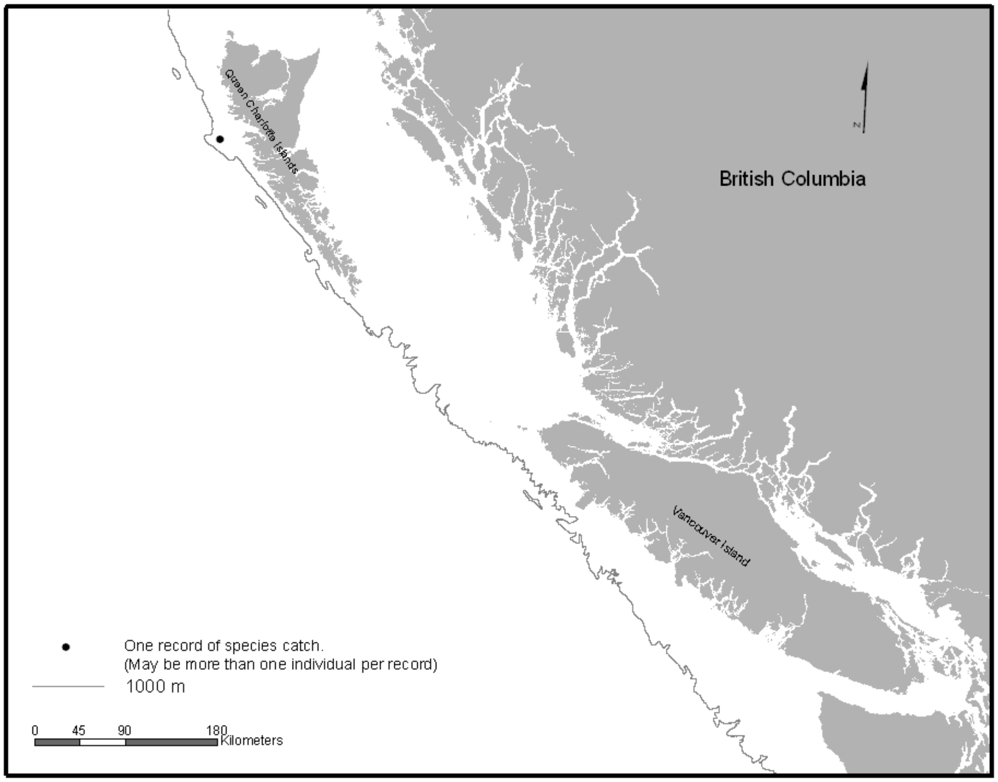
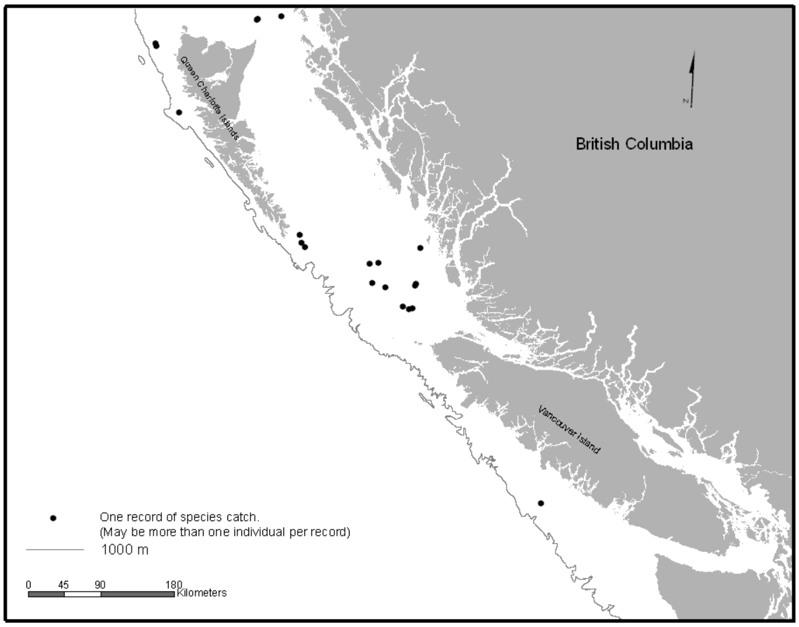


Figure 22. Single incidence of **whitebrow skate** (*Bathyraja minispinosa*) off the west coast of Canada. Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

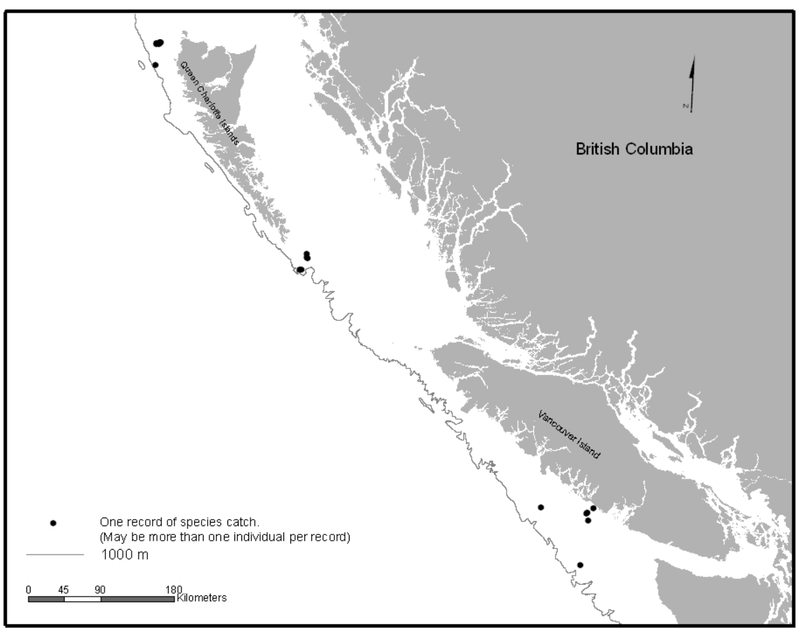
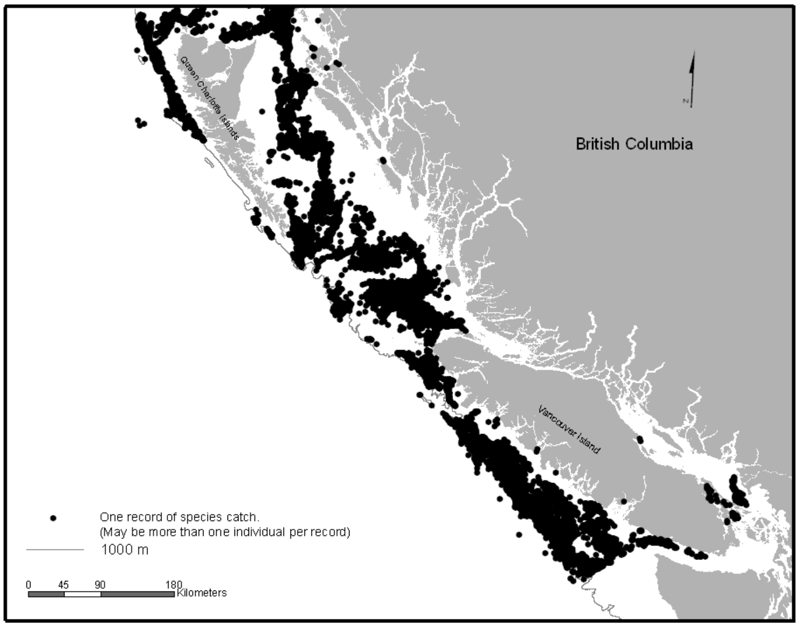


Figure 23. Distribution of **broad skate** (*Raja badia*) off the west coast of Canada from 1994 to 2004 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

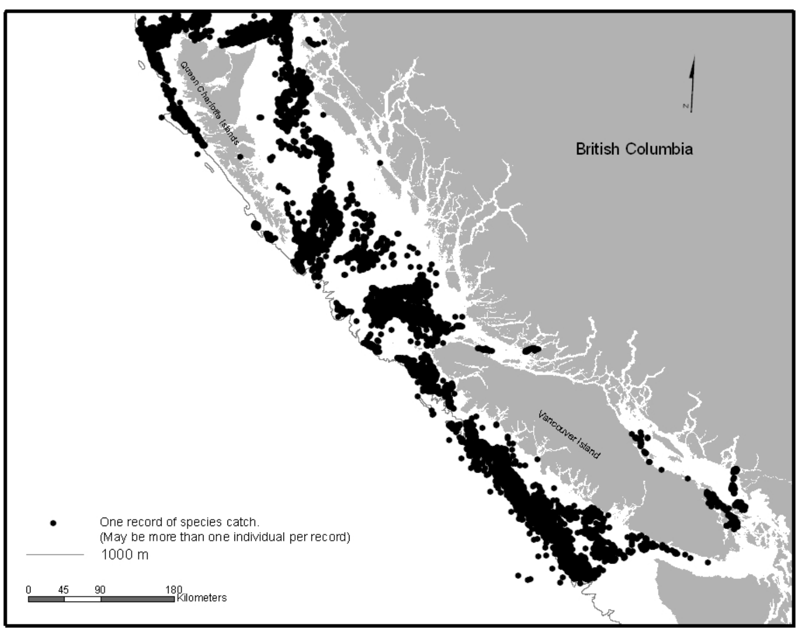


Figure 24. Distribution of **longnose skate** (*Raja rhina*) off the west coast of Canada from 1975 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

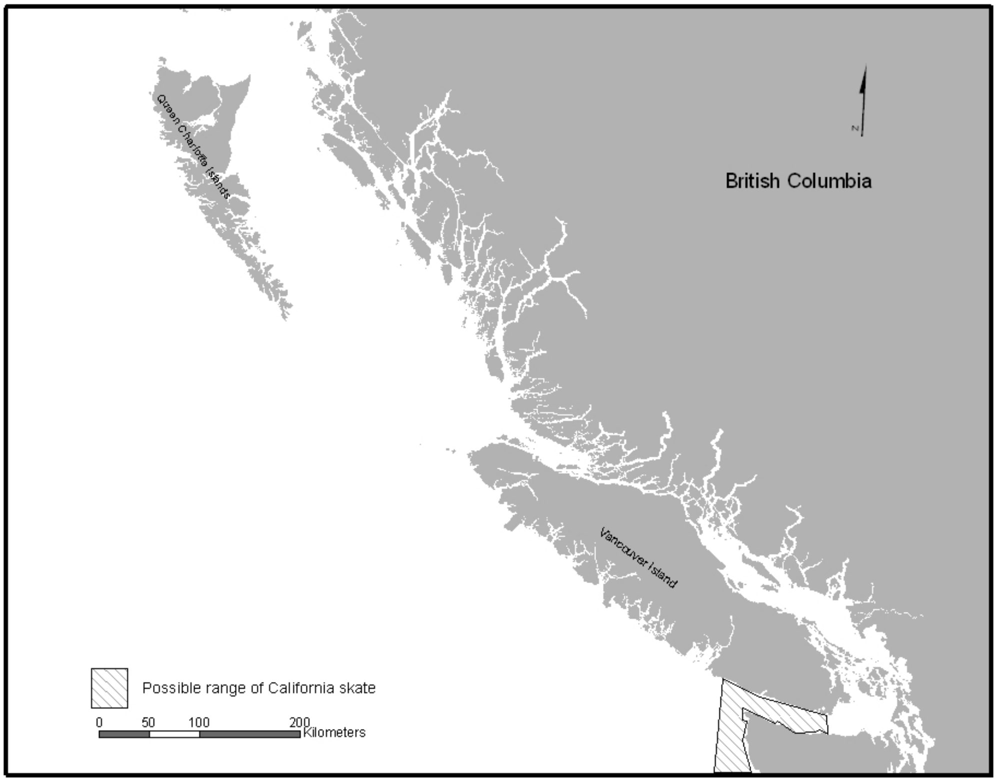
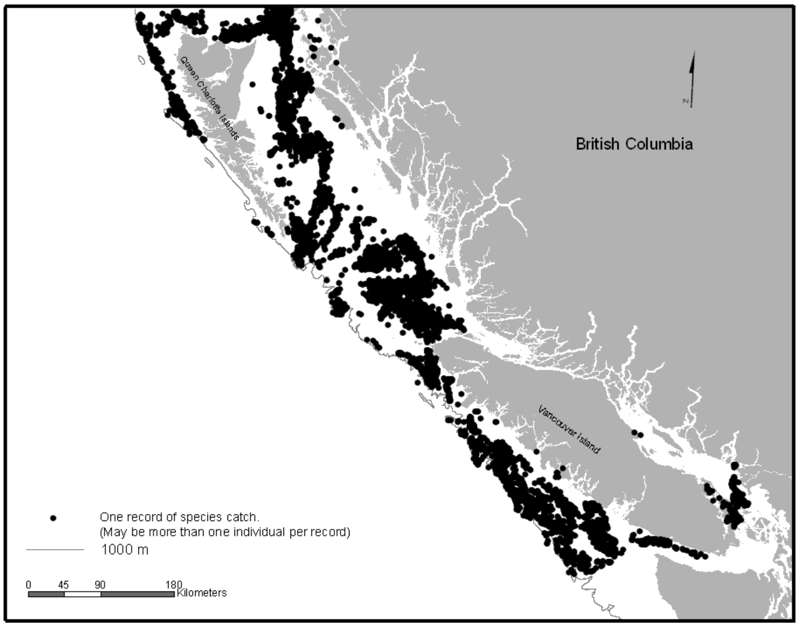


Figure 25. Possible range of **California skate** (*Raja inornata*) off the west coast of Canada taken from: Eschmeyer, W.N., Herald, E.S., and Hammann, H. 1983. A Field Guide to Pacific Coast Fishes of North America. Houghton Mifflin Co., Boston, MA. 336 p.

A)



B)

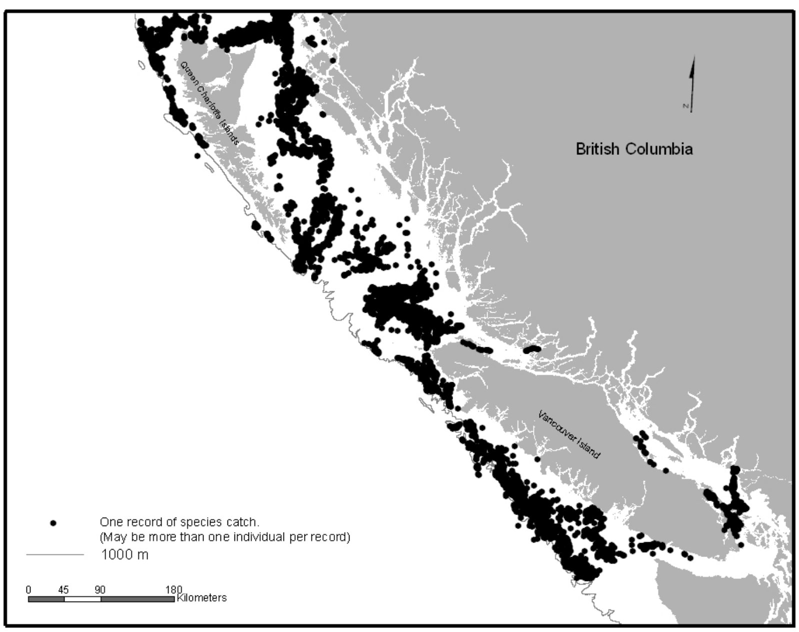
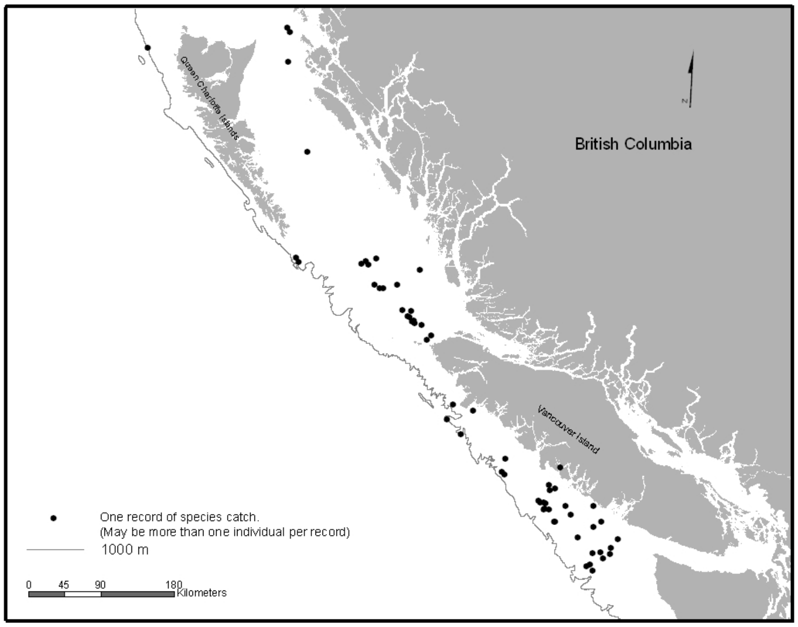


Figure 26. Distribution of **big skate** (*Raja binoculata*) off the west coast of Canada from 1968 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

A)



B)

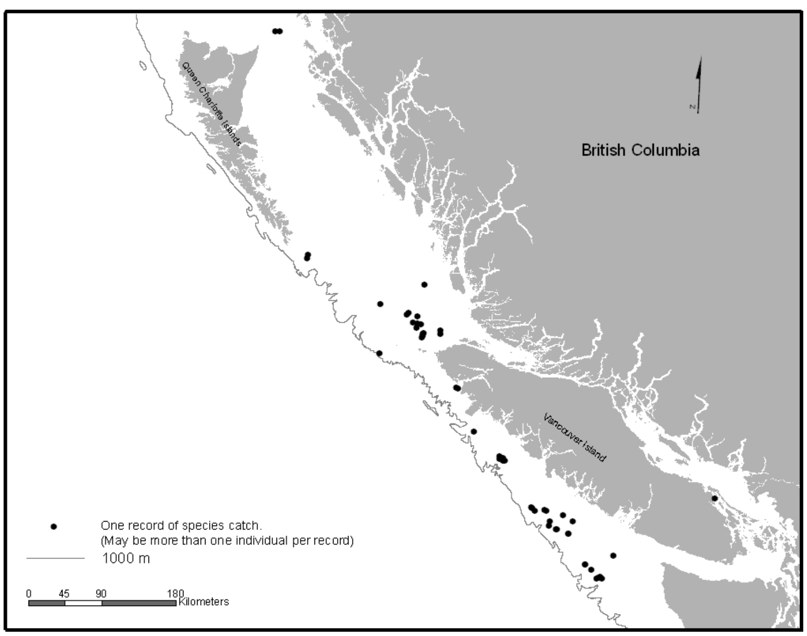


Figure 27. Distribution of **pacific electric ray** (*Torpedo californica*) off the west coast of Canada from 1965 to 2007 during A) the summer (May to October) and B) the winter (November to April). Positional data of catches retrieved from fisheries databases and other data sources at the Pacific Biological Station (see methods).

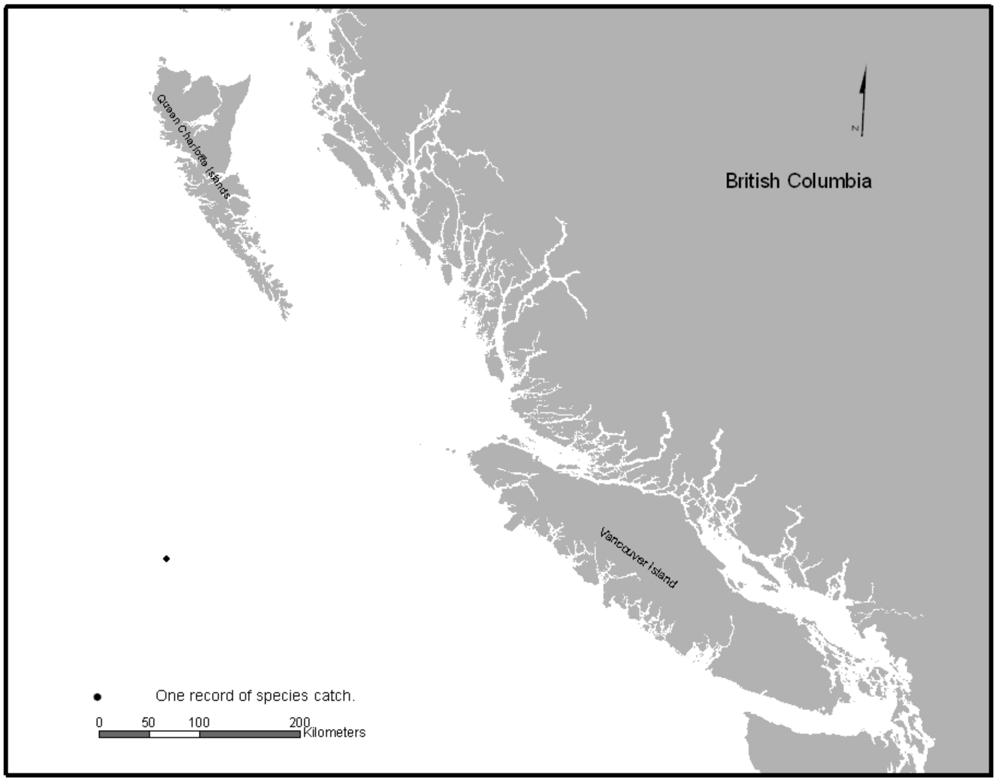


Figure 28. Only record of **pelagic stingray** (*Dasyatis violacea*) off the west coast of Canada. Positional data from: Peden, A.E. and Jamieson, G.S. 1988. New distributional records of marine fishes off Washington, British Columbia and Alaska. Canadian Field Naturalist 102: 491-494.

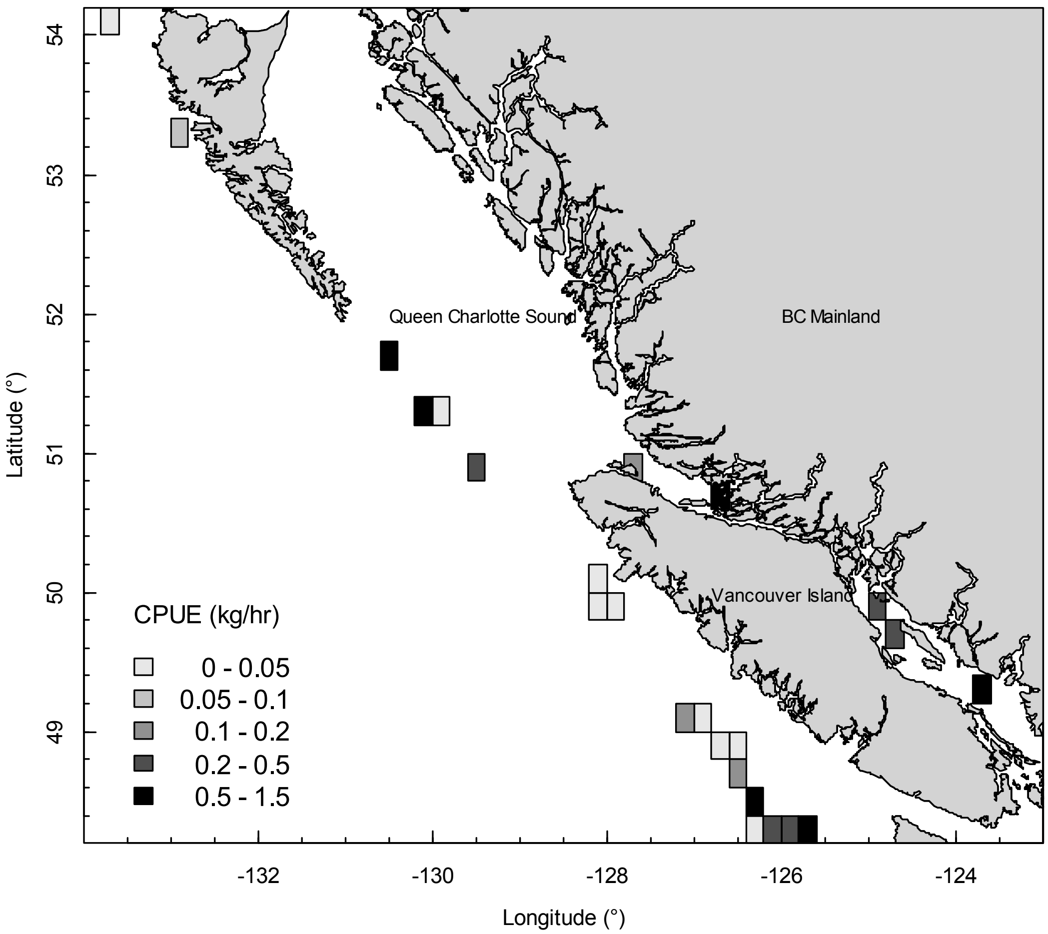


Figure 29. Mean catch per unit effort (CPUE) within 0.2° by 0.2° grid for trawl landed **brown cat shark** (*Apristurus brunneus*) from 2000-2006 (data source PacHarvTrawl).

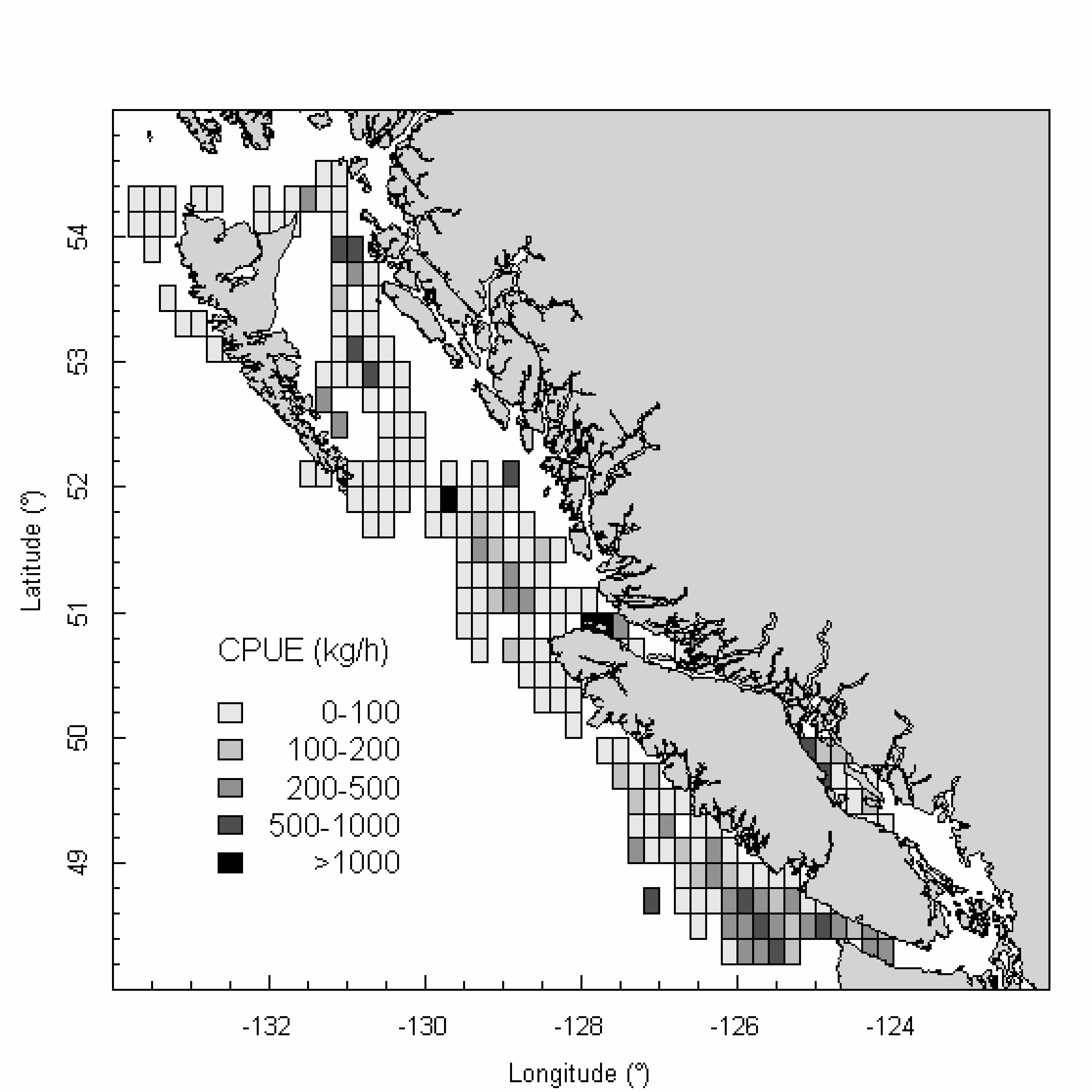


Figure 30. Mean catch per unit effort (CPUE) within 0.2° by 0.2° grid for trawl landed **spiny dogfish** (*Squalus acanthias*) from 1996-2006 (data source PacHarvTrawl).

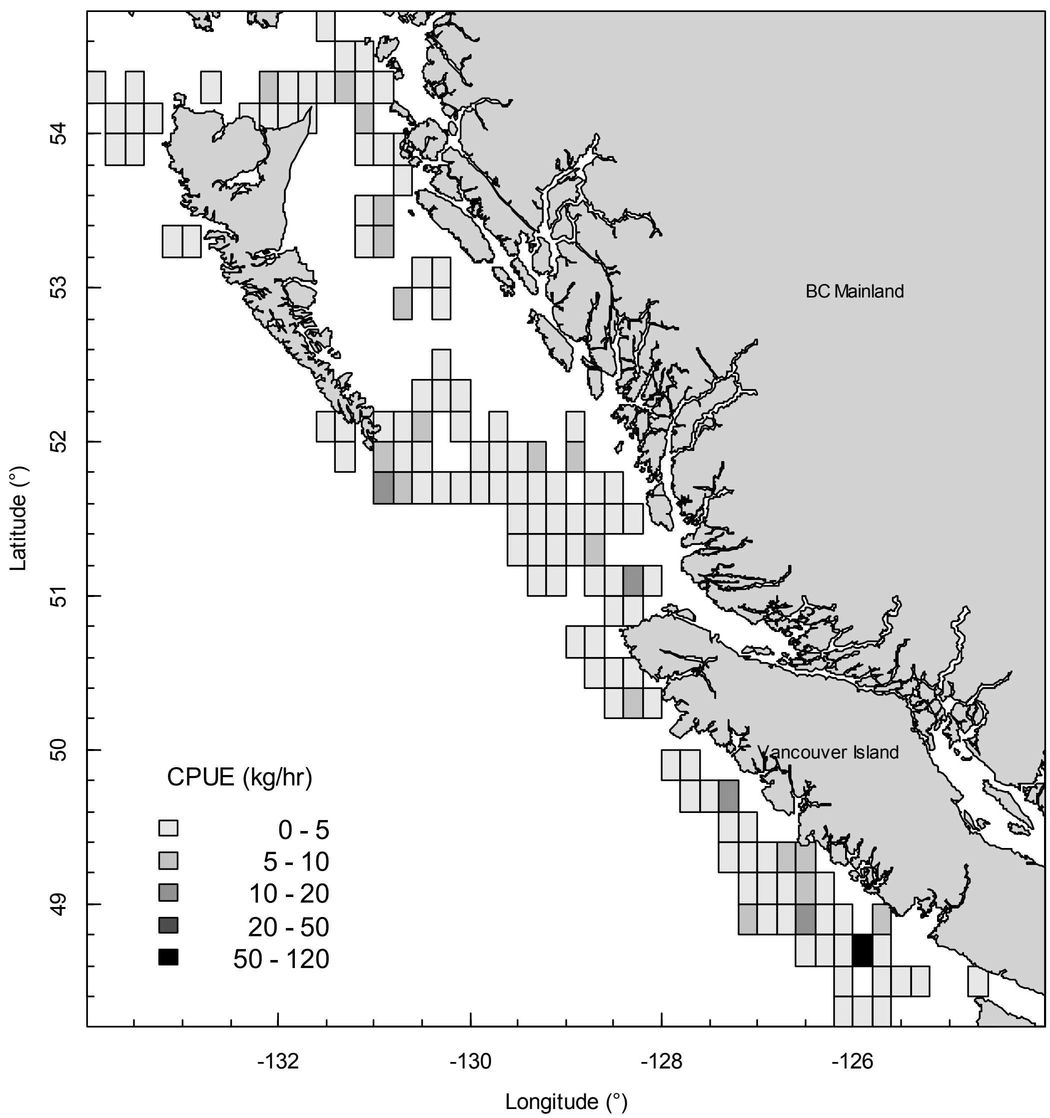


Figure 31. Mean catch per unit effort (CPUE) within 0.2° by 0.2° grid for trawl landed **sandpaper skate** (*Bathyraja interrupta*) from 1996-2006 (data source PacHarvTrawl).

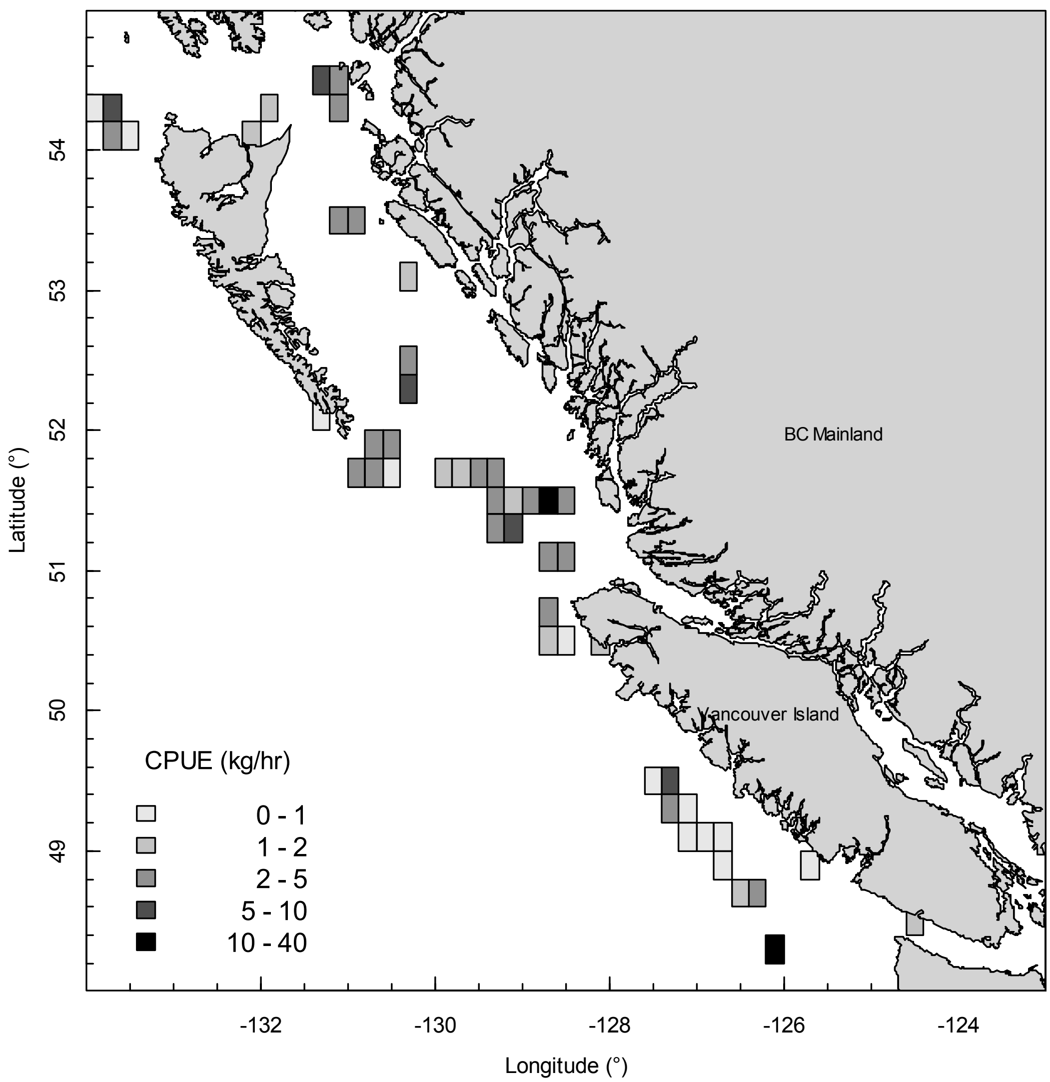


Figure 32. Mean catch per unit effort (CPUE) within 0.2° by 0.2° grid for trawl landed **roughtail skate** (*Bathyraja trachura*) from 2000-2006 (data source PacHarvTrawl).

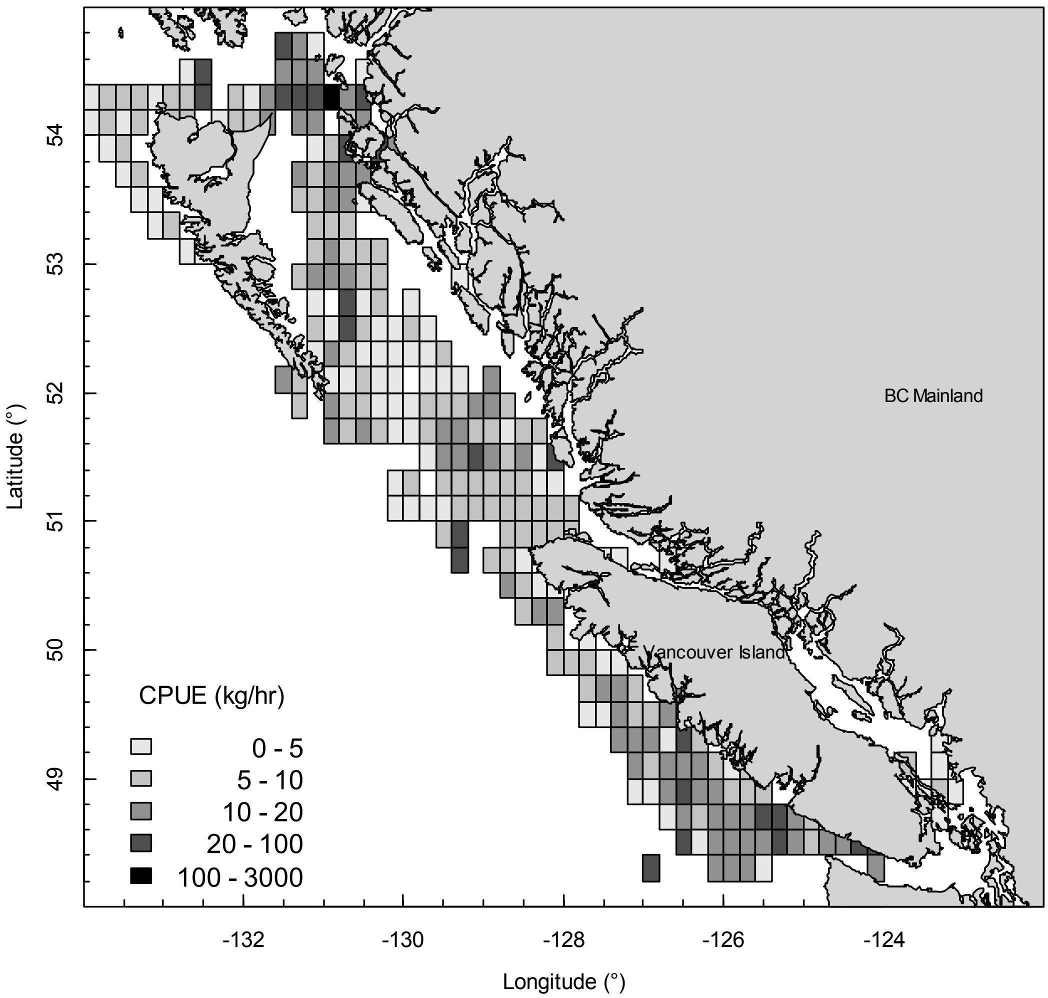


Figure 33. Mean catch per unit effort (CPUE) within 0.2° by 0.2° grid for trawl landed **longnose skate** (*Raja rhina*) from 1996-2006 (data source PacHarvTrawl).

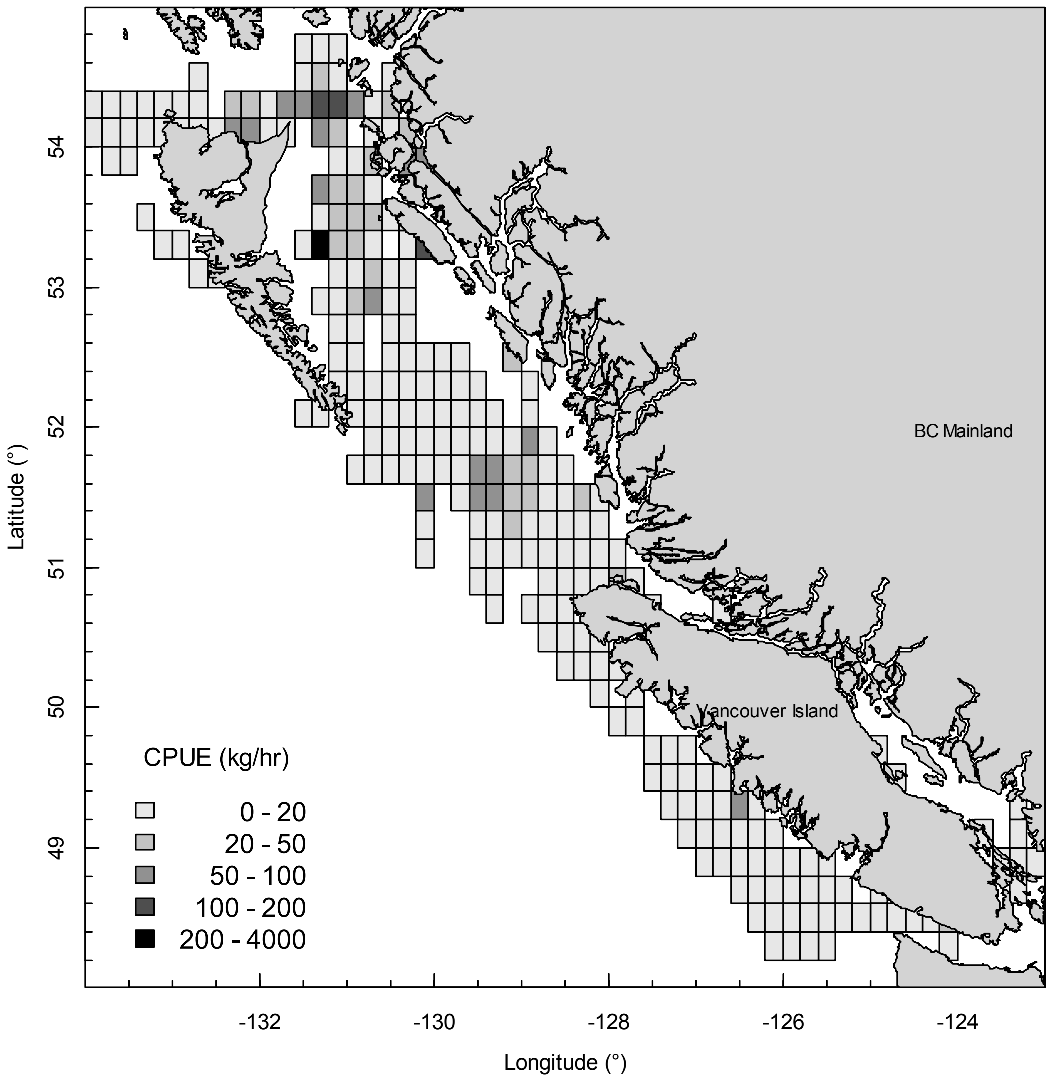


Figure 34. Mean catch per unit effort (CPUE) within 0.2° by 0.2° grid for trawl landed **big skate** (*Raja binoculata*) from 1996-2006 (data source PacHarvTrawl).

APPENDIX 1: SHARK REFERENCES

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