Keynote Address: The Sad History of Dogfish Management

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Abstract.—Spiny dogfish *Squalus acanthias* are not well liked by most humans. Their flesh is not esteemed, and they annoy commercial and recreational fishermen because when caught, dogfish delay the rate at which fishermen can catch desired species. This report reviews the remarkably poor treatment of dogfish. We identify some common misconceptions about dogfish held by both the general public and biologists. We discuss why dogfish should and must, by law, be properly managed like any other species. We conclude with a list of items that are needed to ensure that humans are good stewards of dogfish and the ecosystem they share with other species. Dogfish occur commonly off the Pacific coast of Canada and the United States and are a slow growing, long-lived fish that give birth to an average of about seven live babies after a pregnancy of almost 2 years. The role of dogfish in the marine ecosystem is not well understood, but their common abundance and long life indicates that the role is probably important.

Introduction

Spiny dogfish are a remarkable fish
Feeding on plankton as Pauly would wish.
Gluttony is a sin that is not on their souls,
And they grow so slowly they become very old.

Babies arrive all ready to play
After living in their moms for two years less a day.
Peaceful in life, they avoided confrontation
Until humans arrived with merciless exploitation.

Stewardship and respect was not in our game
As we fished and destroyed without any shame.
It is amazing how people with advanced education
Could plot or ignore attempts at extermination.

But citizens' concerns have given dogfish rights,
So it is now up to us to finish this poem.

Beginning a scientific article with an amateur poem may be highly unusual, but it draws one's attention to the highly unusual lack of attention paid to spiny dogfish *Squalus acanthias* by the stewards of our marine ecosystems. A general understanding of the biology of dogfish has been summarized in some excellent publications (Ford 1921; Bonham 1954; Ketchen 1975, 1986). Although the basic biology is known, there is no clear understanding of dogfish ecology. This is surprising considering the species' current and historical importance to the commercial fisheries. In 2002, dogfish in the commercial fishery averaged Can$0.66/kg ($0.30/lb); compare this to $1.29/kg ($0.59/lb) for Pacific cod *Gadus macrocephalus*, $0.34/kg ($0.15/lb) for pink salmon *Oncorhynchus gorbuscha*, or $1.93/kg ($0.88/lb) for lingcod *Ophiodon elongatus*. It is clear that the commercial value of spiny dogfish justifies more research to improve our understanding of the processes that regulate its production.

Their long life, late maturity, and slow growth mean that most spiny dogfish in the current commercial fishery were born before the mid-1970s and that individuals born now will be fished from about 2025 to 2050. (This also means that decisions we make today will be relevant through to the end of this century.) Consequently we must look back 20–50 years to understand the factors that produced the current exploitable biomass.

Ketchen (1986) reviewed the history of spiny dogfish management, and in this report we review his summary. Our viewpoint is that history has not

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been respectful of dogfish either as a species or as an animal sharing a common ecosystem. The reader is referred to Ketchen (1986) for his detailed account of the dogfish fishery, which was the largest fishery in British Columbia in 1944 (Figure 1) and the fourth largest in Canada. Since 1986, the catch of spiny dogfish has been relatively stable at approximately 5,000 metric tons (mt) per year. Approximately 30% of this catch is from the Strait of Georgia. Dogfish quotas of 15,000 mt (offshore stock) and 3,000 mt (Strait of Georgia stock) for Canadian Pacific waters have remained unchanged since the early 1980s. In 2000, total landings averaged less than 5,000 mt, of which 1,200 mt came from the Strait of Georgia. Longline catches in the strait account for over 95% of the landings.

Part I

Ketchen (1986) divided the history of the fishery into five stages. We have generally followed his stages, with some modification (Table 1). From time to time in this report we provide quotations from senior government officials or well-known fishermen of the day. The quotations are formatted with bold and italicized font but are not referenced as the intention is to indicate the general feeling people had–and still have–about this fish.

The oil fishery 1870–1916

Dogfish: A boundless resource that not only destroy valuable food fish but work havoc with fishermen's nets.

This early fishery exploited spiny dogfish primarily for reduction to oil for lubrication, lighting, and fertilizer. Dogfish oil was preferred by coal miners because it produced a clear, bright light. Early fisheries managers considered the dogfish supply to be practically inexhaustible. Ketchen (1986) provides estimates of round weights from the commercial fisheries that show a maximum average annual weight of 4,690 mt or 1.4 million fish, 65% of which came from the Strait of Georgia. Recognizing the large numbers that were removed from a relatively small, discrete ecosystem, we can now only speculate how

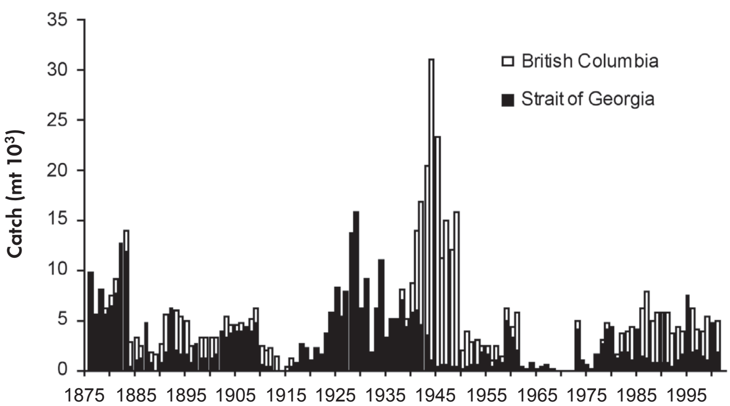

Figure 1. Spiny dogfish catch 1876 to 2001 (metric tons, mt). The solid bars are catch from the Strait of Georgia and open bars are total British Columbia catch.

Table 1. Stages of the spiny dogfish fishery.

Years	Stages
1870–1916	Oil fishery
1917–1939	Reduction fishery
1939–1950	Liver fishery for vitamin A
1959–1974	Eradication fishery
1975–present	Beginning of management
2002–present	Dogfish have rights period

these removals affected the dynamics of the Strait of Georgia ecosystem. Furthermore, the standard fishing gear would also have captured other species, adding to the impact on the ecosystem. The removals of dogfish were large, exceeding the catches of all species of Pacific salmon in the Strait of Georgia through 1950 (Table 2). Today we are beginning to appreciate the effect of early fisheries for Pacific salmon on freshwater and marine ecosystems, but there has been virtually no consideration of the consequences of this early fishery on the trophic relationships within the Strait of Georgia.

The reduction fishery 1917–1939

Dogfish are a bloody nuisance.

During the reduction fishery period, 148,038 mt or approximately 43.5 million spiny dogfish were caught in the Strait of Georgia. The average annual catch was 4,486 mt or 1.3 million fish. Given that the 22 years from 1917 to 1939 represent perhaps one-third or one-quarter of the life span of a dogfish, these removals would have affected the dynamics of the population in the Strait of Georgia (Figure 1). At the beginning of the reduction fishery period, Ketchen (1986) reports that there were seven reduction plants around the Strait of Georgia processing fish, primarily for oil for a variety of purposes and meal for cattle and poultry. By the late 1930s only two plants remained. No management existed either for dogfish or for the method of fishing, which used baited longlines and sunken gill nets left over from salmon fisheries. Neither method is selective, so we can assume that other species were captured. Some indication of the catches of these other species is available from studies during the period of the "liver fishery."

Table 2. Average annual catches (mt) of spiny dogfish and Pacific salmon in the Strait of Georgia.

Years	Stages	Annual catch of dogfish (mt)	Pacific salmon (mt)[a]
1870–1916	Oil fishery	4,690	1,174
1917–1939	Reduction fishery	4,486	3,208
1937–1950	Liver fishery	5,151	3,266

[a] From Argue and Shepard 2005

The liver fishery 1939–1950

Predation by dogfish was of such intensity that it reduced significantly the abundance of other more valuable species.

Ketchen (1986) refers to this period as "The Great Vitamin Liver Fishery." The potency of spiny dogfish liver oil for vitamin A was 5 to 10 times greater than in cod liver oil, making dogfish a desirable and profitable catch. By 1944 the landings of dogfish peaked at 31,000 mt or about 9.1 million fish, which represented the largest catch of all species in British Columbia.

While longlines were the most common gear, sunken gill nets were also used. The bycatch in these gill nets was of concern, even though the mesh was large (18 cm), and in 1944 gill nets were banned in the Strait of Georgia. Barraclough (1948) reported the catch of other species as including soles, Pacific cod *Gadus macrocephalus*, skates Rajidae, Pacific halibut *Hippoglossus stenolepis*, lingcod, and black cod *Anoplopoma fimbria*. One set of approximately 460 m of 16.5 cm mesh made in the Strait of Georgia, captured 132 lingcod and 11 dogfish. Another set of five strings of 25 sunken gill nets made in Hecate Strait captured 514 dogfish, 166 butter sole *Isopsetta isolepis*, 125 sand sole *Psettichthys melanostictus*, 38 rock sole *Lepidopsetta bilineata*, and 1 Pacific halibut. It is not known how common these catches of other species were, but there can be no doubt that other species were captured. Certainly the use of sunken gill nets outside the Strait of Georgia became a more common method of fishing dogfish during this period. By 1944 there was concern that dogfish stocks were showing signs of being overfished. It was concluded, however, that indisputable evidence of overfishing did not exist even though in 1945 fishermen observed that larger female dogfish were difficult to find. The fishery for dogfish collapsed after synthetic Vitamin A was introduced in 1950.

Eradication fishery 1959–1974

Thousands of people employed in the commercial and recreational fisheries deplore the very existence of dogfish.

Even after the liver fishery for vitamin A collapsed, the government remained under pressure to support fisheries for spiny dogfish. Ketchen (1986) details the various initiatives that governments took under the general objective of reducing the perceived harm caused by dogfish. Seven identifiable programs subsidized the killing of dogfish simply to get them out of the ecosystem (Table 3). In the Strait of Georgia, 22,872 mt or 6.7 million fish were removed. The eradication fishery lasted from 1959 to 1974 and probably killed about 6.7 million fish, or about three dogfish for every citizen living in British Columbia at the time.

This is a most disturbing chapter in the history of fisheries management on Canada's Pacific coast: dogfish were regarded as a pest, serving no useful purpose in the Strait of Georgia ecosystem, and management decisions were made with very little debate within the science community or the general public. There was some attempt to find new markets, but in general more money was available to eradicate the animal than was available to determine whether the accusations of harm to other species were valid. During the 1960s, fishermen complained to managers that dogfish had become a serious nuisance; this was puzzling, because a long-lived species that had shown signs of overfishing 20 years earlier would not be expected to rebuild so quickly. The explanation was that juvenile dogfish lived in the midwater for approximately the first 15 years of life (Beamish and Smith 1976; Beamish et al. 1982; Beamish and Sweeting 2009, this volume). According to this explanation, the accumulated abundance of juvenile dogfish residing in the midwater was approximately equal numerically to the abundance on the bottom. As these juveniles matured and became demersal they rebuilt the population on the bottom. The heavy exploitation into the 1940s would have introduced oscillations into the age structure; this theory was confirmed in Wood et al. (1979).

Table 3. Major programs to kill spiny dogfish.

Year	Months	Description of program
1959	Jan–Mar	Subsidy to kill dogfish. 78% were fished in the Strait of Georgia.
1959–1960	Jul–Mar	Subsidy for liver sales.
1960	Oct–Dec	Subsidy for liver sales. 79% were fished in the Strait of Georgia.
1961–1962	Jan–Mar	Subsidy for liver sales. About 40% were fished in the Strait of Georgia.
1966–1967	Nov–Mar	Subsidy for skinned belly flaps from dogfish caught in the Strait of Georgia.
1973	Jan	A licence to catch 2 mt of herring for the roe fishery was was given for each mt of dogfish processed by fishing companies. About 85% of the dogfish were fished from Strait of Georgia.
1974	Apr	Subsidy to catch dogfish in the Strait of Georgia
Total dogfish eradicated		22,900 mt or 6.7 million fish

The Beginning of Management

I went fishing, and all I could catch was a dogfish.

The Wood et al. (1979) study was the first major attempt at stock assessment and can be considered the "beginning of management." Wood was a young student fresh from the University of British Columbia School of Fisheries. Working in the R. Beamish laboratory, he produced an age-structured model that could be used to examine the effects of fishing in the past and in the future. The study concluded that natural mortality is self regulating: in periods when abundance or density is low, the natural mortality is low, resulting in an increase in the rate of growth of the population. The opposite would occur when the numbers of spiny dogfish were large. The mechanism regulating natural mortality remains to be discovered.

Beginning in the late 1980s, attempts to manage spiny dogfish focused on setting quotas based on the Wood et al. (1979) model. Quotas were modest, and total catches were not really dependent on quotas but rather on markets and effort. Catches in the Strait of Georgia represented about 30% of the total catches in British Columbia from 1980 to 2001 (Figure 1). The concept of regulating catches of a species that was disliked by fishermen required tactful explanations that were based on the need to have a stable fishery rather than the moral responsibility of humans to be responsive stewards of marine ecosystems.

Dogfish have rights

Dogfish: a plague on many of the British Columbia fishing grounds.

Fisheries management is generally moving away from thinking about how the population dynamics of a single species is affected by fishing and toward understanding how individual species are affected by conditions within the ecosystem and how fishing affects that relationship. This approach, sometimes referred to as ecosystem management or ecosystem-based management, is a step forward in stewardship, as it recognizes the need to understand the natural processes that regulate populations.

We do not yet understand the role of spiny dogfish in the marine ecosystem because research on dogfish has been opportunistic and unfocused. In the Strait of Georgia, an ECOPATH model (Beamish et al. 2001) placed dogfish at a trophic level of four. In this model, there were no known predators of dogfish and dogfish diet consisted primarily of grazing invertebrates (15%), carnivorous zooplankton (11%), and predatory invertebrates (23.5%) with smaller contributions of shellfish (5%), euphausiids (8%), chum salmon *O. keta* (5.5%), coho salmon *O. kisutch* (7%), Chinook salmon *O. tshawytscha* (7%), and Pacific hake *Merluccius productus* (5.6%). In the model, the removal of dogfish caused insignificant reductions in the predation mortality of river lamprey *Lampetra ayresii*, chum salmon, coho salmon, Chinook salmon, and Pacific hake. A doubling of dogfish biomass slightly increased the predation pressure on the salmon species. An obvious conclusion is that the model probably does not accurately capture the role of dogfish in the Strait of Georgia ecosystem, because the historical abundance, slow growth, longevity, and method of reproduction are all indications that dogfish have evolved to occupy a specialized role in marine ecosystems. We propose that the role is analogous to a scavenger in terrestrial ecosystems, perhaps equivalent to a vulture or a crow.

In Canada, the Species At Risk Act (SARA) (Government of Canada 2002) is now law. This law allows any citizen to report a species that needs to be protected. If the report is accepted, the appropriate agency must protect the listed species and may have to establish plans to help restore the numbers of the listed species. There could never be an eradication program for spiny dogfish under this legislation. The legislation also can be viewed as treating all species equally. Recently the Deputy Minister for Fisheries & Oceans Canada informed the science staff that a holistic, multispecies approach to stock assessment is needed to provide a more accurate picture of the state of the fisheries resource.

For spiny dogfish, the important issue is that they must now be managed. It must be recognized that we are managing a species that begins to reproduce after about 30 years and lives naturally to ages of 50–100 years. Dogfish have a low reproductive capacity relative to other fishes, which means that decisions we make today will affect dogfish well beyond our own generation. SARA also means that the public can speak on behalf of dogfish if they are not managed properly. Failure to manage dogfish in the future could also affect other commercial fisheries that may catch dogfish incidentally. One way or another, dogfish are about to receive responsible stewardship.

Part II

Fortunately, fishery management appears to have moved past the stage of trying to eliminate spiny dogfish from marine ecosystems in general and the Strait of Georgia in particular. However, there are some misconceptions about dogfish that affect how they are regarded and how they are managed. In this part of the report, we briefly describe some of the key misconceptions.

Misconception #1: Dogfish are voracious predators and limit the supply of species valuable to other fisheries.

The history of spiny dogfish is littered with claims that dogfish predation is a serious threat to species that are important to commercial and sport fisheries. Jones and Geen (1977), for example, examined the stomach contents of 14,796 dogfish and reported that 55% consisted of teleosts, 35% of crustaceans, and 5% of mollusks. A calculation of stomach volumes and an estimate of dogfish abundance resulted in the statement that "preliminary analysis suggests that dogfish consume five times the commercial catch of herring, but insignificant quantities of salmon." Ketchen (1986) showed that it is most unlikely that these calculations were valid. In reality dogfish are omnivorous feeders, opportunistically preying on items that present themselves. During the juvenile pelagic phase, which may last 15–20 years, dogfish feed primarily on plankton, including jellyfish (Beamish and Sweeting, 2009). Older dogfish do feed on fish, however. A study of dogfish predation in the vicinity of Big Qualicum hatchery showed that dogfish could be a major predator of juvenile Pacific salmon (Beamish et al. 1992). The abundance of dogfish averaging 70 cm (Figure 2) in the estuary of the hatchery's river increased about tenfold during the period the hatchery released their fish (Beamish et al. 1992; Figure 3), indicating that there were some cues that dogfish used to determine that prey

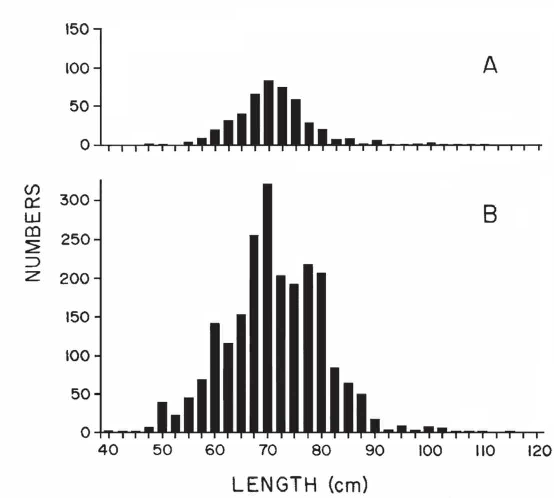

Figure 2. Length-frequency distributions of spiny dogfish caught in the Strait of Georgia by (A) bottom gill net and (B) bottom trawl in 1988.

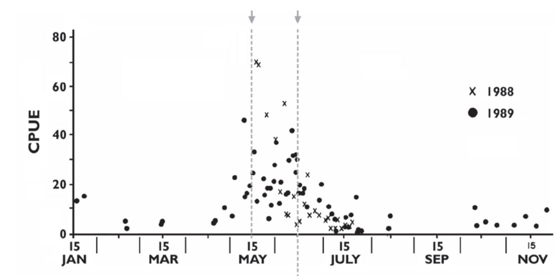

Figure 3. Average standardized catch per unit effort (CPUE) by day of spiny dogfish caught by gill nets in the estuary in the Strait of Georgia adjacent to the Big Qualicum Hatchery (Beamish et al. 1992). Vertical dotted lines indicate the period when most dogfish were in the area.

was available. Juvenile, hatchery-reared salmon were an important prey in 1988, but not in 1989 (Table 4). Brett and Blackburn (1978) determined that the total annual food consumption of a dogfish would be between about one-and-one-half and two times its body weight. The exceptionally slow growth of only millimeters a year is additional evidence that dogfish do not consume large amounts of prey annually. Dogfish are not voracious; rather they are opportunistic, omnivorous feeders. Indeed, it is possible that dogfish predation is an important part of maintaining healthy ecosystems. Future research should identify the role of dogfish in ecosystems, focusing in particular on the possibility that dogfish are the equivalent of scavengers.

Misconception #2: We have a reasonably accurate method of age determination for dogfish.

Authors reporting ages of spiny dogfish, including us, have reported on the accuracy and precision of the method of using the second dorsal spine to estimate age. The method originally described by Kaganovskaia (1933), perfected by Ketchen (1975), and evaluated by Beamish and McFarlane (1985) essentially requires the ability to identify and count enamel ridges, or annuli, that form around the spine as it grows over the life of the dogfish. Beamish and McFarlane (1985) confirmed that the ridges were formed annually and that counting the closely spaced ridges could be difficult. Additionally, as a fish ages and its second dorsal spine grows, ridges at the tip of the spine are abraded and lost. (The abrasion of the spine may occur during reproduction, but immature fish also have worn spines; thus the reason for the abraded spine tips remains to be discovered.) A calculation must be made to determine the number of ridges (or annuli) that have been eroded away (Figure 4). We changed the terminology used by Ketchen from “no wear point” to “wear point” and differentiated the “unworn” spine from the spine base (Figure 4). Ketchen (1975) carefully described how the calculation of missing annuli can be made using

Table 4. Diet of spiny dogfish collected in the 1988 and 1989 Big Qualicum study.

Year	Sample size	% empty	% w/contents	Contents
1988	558	38	62	20% of the dogfish with contents in their gut contained juvenile Chinook or coho salmon.
1989	1,470	33	67	1% of the dogfish with contents in their gut contained juvenile Chinook or coho salmon.

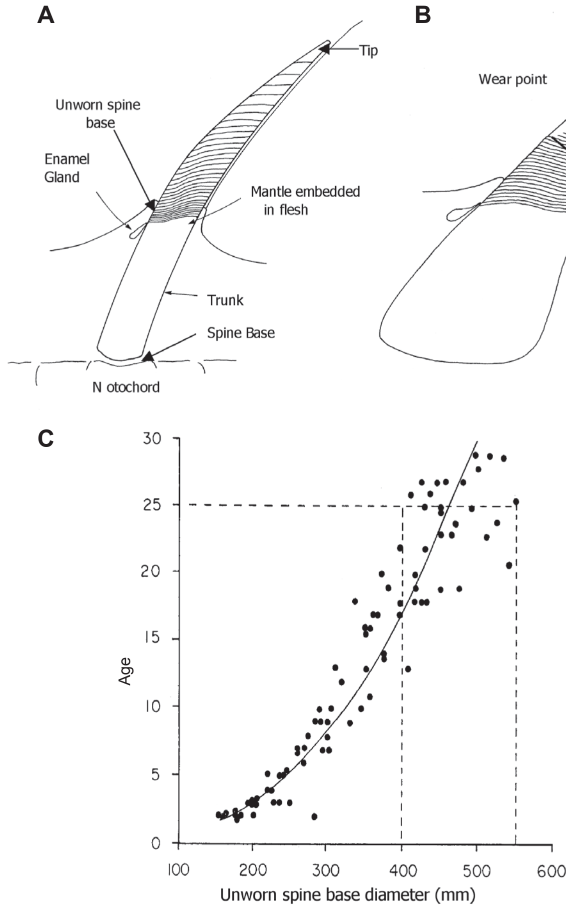

Figure 4. (A) Diagram of dogfish spine showing the location of annuli in relation to spine structure. (B) Worn spines are shown to identify how (C) lost annuli are estimated.

an estimate of the average number of annuli that occur on average diameters of a spine. This method of correcting for lost annuli is essentially equivalent to using an age and length graph to determine age.

Estimating ages for older fish can be especially difficult, as the number of missing annuli can be quite large. In addition, aging techniques for older fish combine methods that are validated (annuli counts) with methods that are approximations (calculations using spine diameters). It is possible to evaluate the accuracy of age estimates that are based on annuli counts, but not estimates calculated using spine diameters. Furthermore, if the method using spine diameter is effective in estimating the average number of annuli that have been lost, it should be possible to simply measure the spine diameter at the last annulus formed at the spine base and use this measurement to estimate age without having to count annuli. This problem relates only to older fish, but it means that reports on ages must be clear about how the ages were determined. It also means that biologists still have work to do to find a more reliable method of age determination (see also McFarlane and King, 2009; Rice et al. 2009, both this volume).

In 1933, Kaganovskaia wrote in Russian that one of the most important parameters in studying the potential production of spiny dogfish is the determination of the age composition of the stocks and the growth rate of individuals. After 70 years we still need to find a method of doing this.

Misconception #3: Dogfish are semimigratory

It is essential to understand the movements of spiny dogfish, as they have exceptional longevity. The excellent tagging program in British Columbia has used a variety of tags, including one specially designed for dogfish (McFarlane and Beamish 1986). This tag was used in the Big Qualicum study described in Beamish et al. (1992). A total of 820 dogfish were tagged in 1988; as of 2002, 30 had been recovered (Figure 5). Most of the recoveries (83%) were in the Strait of Georgia; the remaining recoveries were off the west coast of Vancouver Island or Washington State (Figure 6). The Qualicum study concluded that most dogfish are resident and that only a small number move out of the general tagging area over a period of decades.

An analysis of all tagged spiny dogfish released in British Columbia waters from 1978 to 1987 (McFarlane and King 2003) identified 51,063 fish tagged in the Strait of Georgia, of which 2,454 were recovered between 1978 and 2000. Most (91%) fish recaptured up to five years after release were recaptured in the Strait of Georgia; 8% were recaptured in nearby areas. Three tagged dogfish moved farther, being recaptured in Japan, Alaska, and Oregon. The conclusion, for the Strait of Georgia, would be that most dogfish remain in the tagging areas and, for management purposes, could be considered to be resident. Certainly, there is little evidence of a migration. When movement out of the tagging area

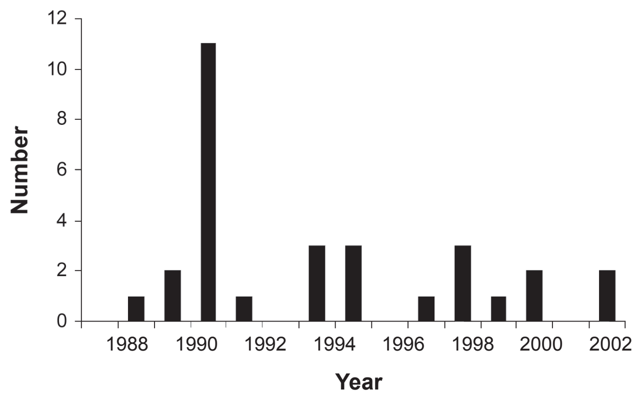

Figure 5. The number of spiny dogfish tag recoveries by year from the 1988 tagging program in the Strait of Georgia.

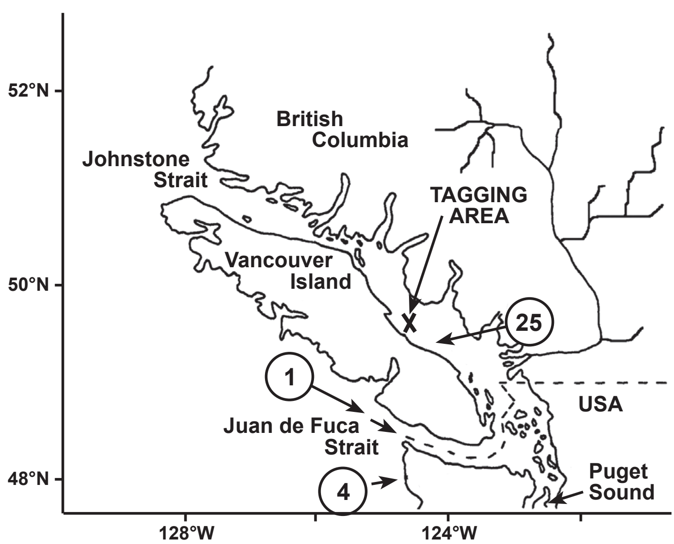

Figure 6. Location and number of spiny dogfish tag recoveries from 1988 to 2002 from dogfish tagged in the Big Qualicum study in the Strait of Georgia in 1988.

occurs, it may be more appropriately considered straying than semi-migration (for an Atlantic coast perspective, see Campana et al. 2009, this volume; for a current Pacific perspective, see McFarlane and King, 2009; Taylor et al. 2009, this volume).

Part III

A bill of rights and responsibilities for spiny dogfish. Dogfish assessment and management has been identified as a priority by both management and conservation organizations (for the West Atlantic situation, see Fordham 2009, this volume); however, no new assessments have been developed for Pacific stocks that support active fisheries. Future integrated approaches for fisheries management will require that bycatch of dogfish in other fisheries be considered and actively managed. After years of sad and perhaps even cruel management of dogfish, it is time to recognize that there must be equality among the fishes that share our marine ecosystems. In recognition of our responsibility as stewards, we propose the following Bill of Rights and Responsibilities for Spiny Dogfish.

1. Ensure that there is an effective stock assessment program before commercial fishing is allowed.
2. Establish an effective monitoring program.
3. Establish a reliable method of age determination.
4. Establish an integrated program to share biological data throughout the range of spiny dogfish.
5. Return spiny dogfish from commercial and research catches to the ocean as quickly as other species, such as halibut, are returned to reduce bycatch mortality.
6. Identify the natural sources of mortality in the first marine year.
7. Identify the role of spiny dogfish in the ecosystem.
8. Establish an international tagging program to monitor long-term migrations using archival tags.
9. Consider that animal cruelty laws should apply to spiny dogfish, and stop mutilating dogfish.
10. Inform people about the biology and importance of spiny dogfish.

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