Distribution of Pelagic Elasmobranchs Caught by Salmon Research Gillnets in the North Pacific

Hideki Nakano and Kazuya Nagasawa

National Research Institute of Far Seas Fisheries,
Orido, Shimizu, Shizuoka 424, Japan

(Received December 14, 1995)

The distribution of pelagic elasmobranchs was analyzed using bycatch data from the high seas salmon surveys by research gillnets from 1981 to 1991 in the North Pacific Ocean and the Bering Sea. Five species of sharks and one stingray were reported. Blue and salmon sharks and spiny dogfish were dominant and constituted 98% of the total shark catch. It is considered that the research area includes the southern part of the distribution for spiny dogfish and salmon sharks and the northern part of that for blue, shortfin mako, cookiecutter sharks and pelagic stingrays. These elasmobranchs showed spatial segregation by species in distribution according to oceanographic conditions. Intraspecific sexual and growth dependent segregations were also confirmed. Length frequency distributions of blue and salmon sharks suggest that their nursery grounds exist around the transitional domain of the subarctic boundary.

Key words: distribution, elasmobranchs, salmon survey, segregation, nursery ground, North Pacific

The Japanese high-seas salmon fishery ceased in 1992 after some 40 years of industrial fishing from 1952 because of international concern about the impact of this fishery upon the oceanic ecosystem. The Fisheries Agency of Japan has conducted salmon research for the rational use of salmon stocks for a long time. It also started bycatch research in the 1970s using several research vessels. Bycatch research data collected by the research vessels of Hokkaido University and chartered vessels for scientific research from 1981 to 1991 were used for the present analysis. The research area is widely distributed from 35°N–63°N from the northern coast of Japan to the Gulf of Alaska and the Bering Sea.

The spatial distribution and migration of pelagic elasmobranchs are still poorly known, although several surveys were conducted in the North Pacific Ocean.^{1–6)} Many of those studies partly described their distributions and migrations due to the limitation of research area, season and gear selectivity. Therefore, more detailed biological and ecological information is necessary for the conservation and stock management of pelagic elasmobranchs. This paper describes the distribution of pelagic sharks and rays in the North Pacific, north of the subarctic boundary.

Materials and methods

Sharks were caught using salmon research gillnets and commercial gillnets during the research periods. Salmon research gillnets consisted of 30 *tan* (*tan* is a unit of net in Japanese) and were a combination of 10 kinds of geometric series mesh size nets from 48–157 mm, while commercial gillnets used 50 to 102 *tan* with 112–121 mm mesh size. One *tan* of net is about 50 m in length and 7–10 m in depth. The gear was set before sun set and retrieved near sun rise.

The date, position, number of *tan* used and number of catch by species were recorded for each fishing operation. Sea surface temperature (SST) at the surface was also recorded. Elasmobranchs caught during the research were salmon sharks *Lamna ditropis*, blue sharks *Prionace glauca*, spiny dogfish *Squalus acanthias*, shortfin mako sharks *Isurus oxyrinchus*, cookiecutter sharks *Isistius brasiliensis*, and pelagic stingrays *Dasyatis violacea*. In general, precaudal length (cm) by sex was recorded. Total length was measured for spiny dogfish and cookiecutter sharks, because these species do not have a precaudal pit.

The nominal CPUE (catch in number/1,000 *tan*) by 1° latitude × 1° longitude geographical area and by month (all years combined) was calculated for the analysis of distribution except for cookiecutter sharks and pelagic stingrays. The relation between CPUE by SST of each species was analyzed. Length frequency data of blue and salmon sharks were compiled by sex and by SST.

Results

Research Period and Season

A total of 2,923 salmon research operations were reported during 11 years from 1981 to 1991 (Table 1). The total research efforts were 320,810 *tan* and 3,986 sharks and rays were caught during the period. Blue shark catch was the largest, 2,498 in number, salmon shark the second (724), and spiny dogfish the third (667). These three species accounted for 98% of the total shark catch. The surveys were conducted from April to August but chiefly in June and July, which accounted for 70% of the total operations. Salmon sharks and spiny dogfish were caught throughout the season. Blue and shortfin mako sharks were caught from April to July. Few cookiecutter sharks and pelagic stingrays were caught, 7 and 4 each, from June

Table 1. Catch of elasmobranchs caught during salmon research cruises from 1981–1991

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	Total
operation	287	317	322	345	261	262	262	232	224	219	192	2923
effort (tan)	40739	40268	39858	45073	33946	25992	23625	21991	17020	17102	15196	320810
species												
<i>Squalus acanthias</i>	28	23	18	86	120	76	44	13	77	50	132	667
<i>Isistius brasiliensis</i>	0	1	0	0	2	1	2	0	0	1	0	7
<i>Isurus oxyrinchus</i>	0	2	4	3	12	14	5	13	6	0	1	60
<i>Lamna ditropis</i>	182	160	46	92	74	26	48	29	24	13	30	724
<i>Prionace glauca</i>	370	350	380	293	143	143	268	102	262	55	132	2498
<i>Dasyatis violacea</i>	0	0	0	4	0	0	0	0	0	0	0	4

Fig. 1. Average CPUE (catch in number/1,000 tan) distribution by $1^\circ \times 1^\circ$ geographical area during 1981–1991 for spiny dogfish (left) and salmon sharks (right).

to July, and in July, respectively.

Geographical Segregation by Species

Monthly average distributions of spiny dogfish and salmon sharks are shown as CPUE by $1^\circ \times 1^\circ$ geographical area in Fig. 1. Spiny dogfish occurred in four major areas i.e., off northern Japan, the open sea south of the Aleutian Islands, adjacent waters of the Aleutian Islands, and the Gulf of Alaska. Their high CPUE areas existed in a narrow latitudinal band, ranging from 42°N – 52°N in the open sea south of the Aleutian Islands. Salmon sharks showed a similar distribution pattern as spiny dogfish, and high CPUE areas occurred somewhat to the south of the distribution of spiny dogfish with some overlapping.

Monthly distributions of blue and shortfin mako sharks are shown in Fig. 2. High CPUE areas of blue sharks appeared along the southern parts of the research area 34°N – 48°N from offshore waters of Japan to the Gulf of Alaska. Shortfin mako sharks were caught at the south edge of the research area. The number of shortfin mako caught was

small, 60 in total. Neither a clear high CPUE area nor movement was observed.

From the geographical analysis of CPUE distribution, a high CPUE band was noticed for each species. CPUE by SST also suggested segregation by species as is shown later. Spiny dogfish occurred in the northernmost part, followed by salmon, blue and shortfin mako sharks in order from north to south.

Few cookiecutter sharks and pelagic stingrays were caught. Cookiecutter sharks were caught at 4 stations in June and 3 stations in July, which were located, respectively, from $35^\circ00'\text{N}$ – $38^\circ33'\text{N}$ and from $155^\circ01'\text{E}$ – $175^\circ33'\text{E}$. Pelagic stingrays were caught only at two stations ($38^\circ00'\text{N}$, $155^\circ00'\text{W}$; $39^\circ29'\text{N}$, $154^\circ59'\text{W}$) in July.

Distribution Related to Sea Surface Temperature

Since the depth of gillnet gear was only 7–10 m from the sea surface, the observed SSTs at sampling stations were considered fairly close to those of capture. CPUEs of sharks and rays by 1°C of SST are shown in Fig. 3. Opera-

Fig. 2. Average CPUE (catch in number/1,000 tan) distribution by $1^\circ \times 1^\circ$ geographical area during 1981–1991 for blue sharks (left) and shortfin mako sharks (right).

Fig. 3. CPUE (catch in number/1,000 tan) of pelagic elasmobranchs by sea surface temperature.

tions were conducted at SSTs ranging from 1.0–23.0°C and, a large proportion of the efforts was set at SSTs ranging from 3.0°–11.0°C. The spatial segregation by species appears to depend on SST. Spiny dogfish mainly occurred at 6.0°–12.0°C. High CPUEs of salmon sharks were observed at 9.0°–16.0°C. Blue sharks occurred in warmer waters, with high CPUEs at 13.0°–22.0°C. High CPUEs of shortfin mako sharks appeared at both 13.0°–14.0°C and 18.0°–21.0°C. Cookiecutter sharks and pelagic stingrays occurred at SSTs above 18.0°C.

Distribution by Sex and Growth

A total of 719 sharks (11 spiny dogfish, 78 salmon sharks, 621 blue sharks, 8 shortfin mako sharks, and 6 cookiecutter sharks; 18.2% of total catch) were measured. Spiny dogfish ranged from 51–75 cm, salmon sharks from 70–185 cm, blue sharks from 35–200 cm, shortfin mako sharks from 70–130 cm, and cookiecutter sharks from 45–60 cm.

Length frequency distributions of blue sharks by sex and by 2°C of SST are shown in Fig. 4. Blue shark females were caught at 8°–21°C and males at 12°–21°C. Full-term sharks (below 50 cm) were caught at 12°–19°C for both sexes. Larger females over 90 cm were caught over a wide range from 8°–21°C, while larger males in warmer waters ranging from 14°–21°C than smaller sharks. Larger fe-

Fig. 4. Length frequency distributions of blue sharks by sex and by sea surface temperature.

Fig. 5. Length frequency distributions of salmon sharks by sex and by sea surface temperature.

males tended to occur in cooler waters than males.

Length frequency distributions of salmon sharks are shown in Fig. 5. Full-term sharks (below 100 cm) were mostly caught at 14°–19°C for both sexes. Larger sharks over 100 cm occurred over a wide range from 12°–19°C.

Discussion

Spiny dogfish are mainly distributed on the continental shelves of North America and northern Japan and are considered inshore species.⁷⁾ However, Ketchen⁹⁾ reported their trans-Pacific migration: two spiny dogfish tagged off the west coast of Canada were recaptured in Japan. He also noted the distribution of spiny dogfish in the open sea in the North Pacific Ocean (off Japan, south of the Aleutian chain, and the Gulf of Alaska) based on the incidental catch records from Japanese, Canadian and United States research vessels conducting surface gillnet and longline explorations for Pacific salmon on the high seas during the summer months. The present study has proven that many spiny dogfish occurred in the open sea, ranging from north of 40°N to south of the Aleutian chain. Eleven spiny dogfish captured in the open sea (59 cm for males and 51–75 cm for females) are considered immature or just mature sharks, based on the reported mature size from both sides of the Pacific Ocean, i.e. about 70 cm for males and 72–94 cm for females.^{9,10)} It is possible that immature spiny dogfish extend their habitat to offshore waters and some of them use these waters for the trans-Pacific migration.

Salmon sharks mainly occurred in waters north of 35°N in the open ocean.⁴⁾ This species is abundant around the Aleutian Islands and south of 47°N.⁵⁾ Blagoderov¹¹⁾ described that smaller salmon sharks occurred south of their range and suggested that potential parturition grounds may be situated in open waters of the North Pacific, in-

shore waters of both Japan and the southern Kuril Islands. The length frequency distributions by SST obtained in the present study indicate small salmon sharks (70–110 cm) were concentrated to a SST range from 14°–16°C, which were recorded from the north of the subarctic boundary in summer. This area is adjacent to a parturition ground supposed by Blagoderov.¹¹⁾ Therefore, the southern boundary area of their distribution is considered a nursery ground of this species (Fig. 6).

Blue sharks have a wide range of distribution from the equator to 55°N in the Gulf of Alaska.^{2,3)} The length frequency distributions by sex and by SST indicate both segregation by sex and growth patterns reported by previous researchers for large-sized sharks.^{1,2)} Nakano¹²⁾ made a migration model of blue sharks and indicated their nursery ground is located in the subarctic boundary area. Almost all blue sharks captured in the transitional domain and south of the subarctic boundary consisted of both young and immature sharks. The area where these blue sharks were captured is considered a nursery ground for the young.

The life history of shortfin mako sharks is not well known. The size at birth is about 70 cm in total length and parturition occurs in November off New South Wales, Australia in the South Pacific.¹³⁾ The small shortfin mako sharks caught by our research were fairly close to this birth size.

Little is known about the life history and distribution of cookiecutter sharks and pelagic stingrays. Cookiecutter sharks inhabit the bathypelagic and epipelagic zones of tropical to subtropical oceans.⁴⁾ Nakano and Tabuchi¹⁴⁾ showed their wide occurrence in the central North Pacific and indicated that the northern limit of their distribution is nearly equivalent to the south of the subarctic boundary. Considering this information, our specimens of

Fig. 6. Schematic map for supposed nursery grounds of salmon sharks and blue sharks in the North Pacific.

cookiecutter sharks were captured at the northern edge of their habitat. Pelagic stingrays are often caught as bycatch of longline fishery of which the fishing ground is further south than our research area.¹⁵⁾ Although the distribution of pelagic stingrays is not well known, the locations of pelagic stingrays captured might indicate the northern edge of their habitat.

The subarctic boundary is a huge oceanic front existing between the subtropical and subarctic waters. The areas where epipelagic sharks and rays occurred are classified as follows by the oceanographic description of Dodimead *et al.*¹⁶⁾ Spiny dogfish occurred in the subarctic region only. Salmon sharks were caught in the subarctic region and part of the transitional domain. Blue sharks were caught along the transitional domain and in the subtropical waters. Shortfin mako sharks appeared south of the subarctic boundary. Cookiecutter sharks and pelagic stingrays occurred only in the subtropical region. Following these results, it is considered that the research area includes the southern edge of their distribution for spiny dogfish and salmon sharks and the northern distribution limit for blue, shortfin mako, cookiecutter sharks, and pelagic stingrays.

It is interesting that a zone of high CPUEs by species around the transitional domain consists of both nursery grounds for salmon, blue, and mako sharks, and extension of the distribution of spiny dogfish (Fig. 6). It is also noticed that abundant pelagic sharks, such as salmon and blue sharks, have adjoining nursery grounds in the oceanic frontal area. Springer¹⁷⁾ noted with reference to the life history of inshore species that habitat segregation of elasmobranchs is adaptation for avoiding predation by large sharks including the same species. Similar segregations are noticed for the offshore species examined in the present study. These nursery grounds are separated from the adult habitats. Adult salmon sharks are distributed in the northern area, and adult blue sharks occur in southern waters.^{2,5,12)} Another adaptive advantage is that those sharks use a high productive area, such as the transitional domain and the subarctic front, as nursery grounds and get enough energy for growth.¹²⁾ Percy¹⁸⁾ reviewed the biology of the transition region located between the subtropical and subarctic waters. He noticed that migrants can utilize the high productivity of the subarctic waters and feed on large nutritious prey, such as gonatid squids, Pacific saury, and sardine.

Acknowledgments We are grateful to the crews and scientific staff of the research vessels and the staff of the National Research Institute of Far Seas Fisheries and the Fisheries Agency of Japan who were involved in this research. Without their cooperation, the collection of catch data, as well as biological measurements would have been difficult.

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