2 Geography, Currents, and Fish Diversity of Japan

Hiromitsu Endo and Keiichi Matsuura

Abstract

The Japanese Archipelago has a unique geographic history related to tectonic activities in the western North Pacific Ocean, and it is influenced by two strong currents (the Kuroshio and Oyashio currents). Because it extends for 3000 km from north to south, covering the subboreal to subtropical climatic zones, there are various aquatic environments in seas and freshwaters that have resulted in a high diversity of fish species. We examined the components of Japan's fish diversity and recognized 4476 valid species, which represents 12.5% of the world's ichthyofauna; the top 35 most speciose families include 2571 species (57.4% of Japan's valid species). The top 10 most speciose families are as follows: Gobiidae (469 species), Serranidae (156), Labridae (153), Pomacentridae (111), Apogonidae (102); Cottidae (88), Myctophidae (88), Bleniidae (81), Cyprinidae (78), and Macrouridae (70), with the top five being shallow water marine fish groups from tropical to temperate waters. The two deep sea groups listed, Myctophidae and Macrouridae, indicate that deep trenches and troughs in the seas around Japan provide suitable habitats for deep-sea fishes.

Keywords

Tectonic plate · Current · Fish fauna · Taxonomy · Zoogeography · Japanese Archipelago

2.1 Introduction

Japan is a volcanic island country located in the western North Pacific Ocean and isolated from the eastern Eurasian Continent. It consists of four main islands (Kyushu, Shikoku, Honshu, and Hokkaido), three island chains [the Ryukyu, Izu-Ogasawara (=Bonin), and southern Chishima (Kuril) islands], and many small islands scattered around the main islands. Although Japan is one of the smallest countries in the world for land area, the Japanese Archipelago is somewhat long, extending for 3000 km from north to south and ranging from the subboreal to subtropical climatic zones (Fujikura et al. 2010: Fig. 2.1). Further, Japan faces the Pacific Ocean and its marginal seas, the East China Sea, Sea of Japan, and Okhotsk Sea. There are also small inland seas such as the Seto Inland Sea and Ariake Sound (the largest bay located along the west coast of Kyushu). The land area of Japan is relatively

H. Endo (✉)
Laboratory of Marine Biology, Faculty of Science and Technology, Kochi University, Kochi, Japan
e-mail: endoh@kochi-u.ac.jp

K. Matsuura
Department of Zoology, National Museum of Nature and Science, Tsukuba, Ibaraki, Japan
e-mail: matsuura@kahaku.go.jp

Y. Kai et al. (eds.), *Fish Diversity of Japan*, https://doi.org/10.1007/978-981-16-7427-3_2

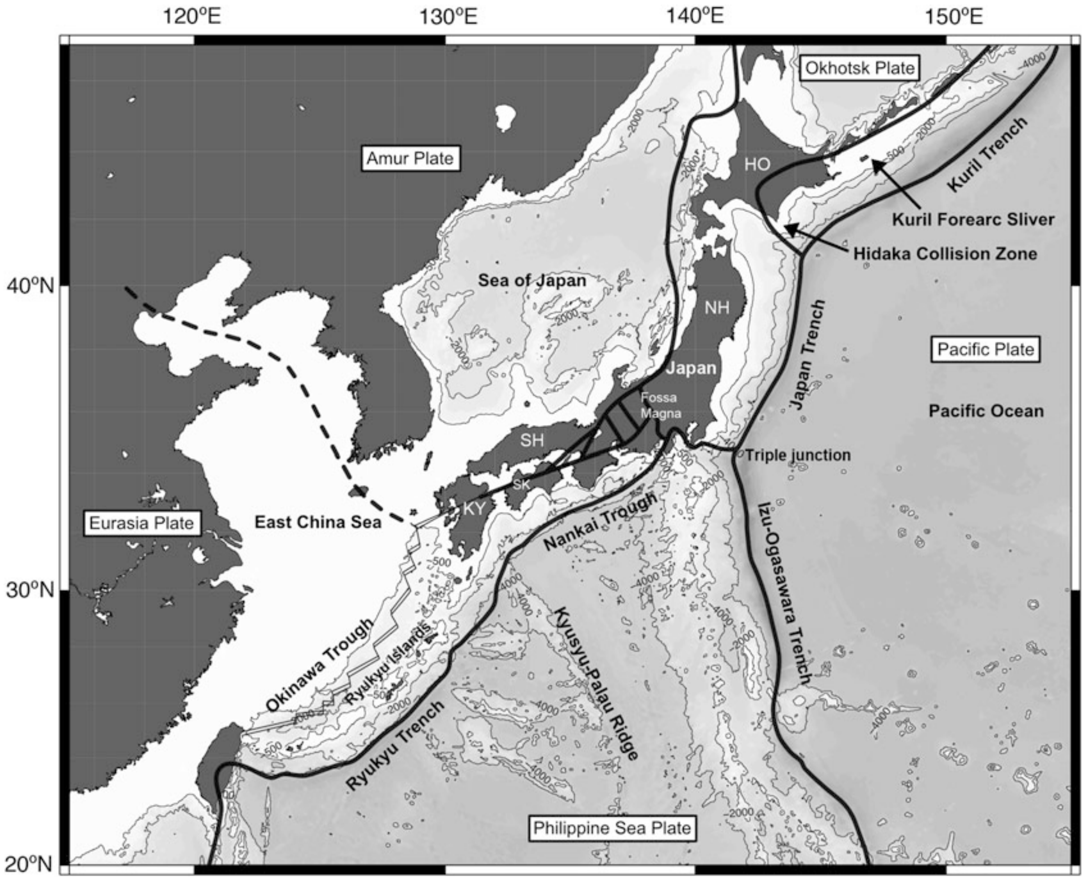

Fig. 2.1 Map of the western North Pacific around Japan showing Japanese Archipelago (*HO* Hokkaido, *NH* northern Honshu, *SH* southern Honshu, *SK* Shikoku, *KY* Kyushu), tectonic plates, trenches, and troughs (modified from Taira 2001: fig. 1c). The map was generated using the Generic Mapping Tools (GMT ver. 4.5.9; see Wessel et al. 2013), with bathymetric data obtained from ETOPO1 (Amante and Eakins 2009)

small (about 5% of Australia's), but it has an enormous water surface area of 4,470,000 km^2, which is composed of inland, coastal, and offshore waters including the Exclusive Economic Zone (EEZ, 4,050,000 km^2) (Japan Coast Guard 2021: Fig. 2.2). Japan's EEZ is the sixth widest for the EEZ area by country and the fourth most expansive for volume in the world (Matsuzawa 2005). This large volume provides extensive habitats for deep-sea fishes in the seas around Japan. Also, two major warm and cold ocean currents (the Kuroshio and Oyashio currents), complicated coastlines, and complex submarine topography affect marine biota around Japan. According to the Census of Marine Life (CoML) project operated worldwide during the years between 2000 and 2010, the diversity of marine biota around Japan is assumed to be the second-highest next to that of Australia and one of the world's marine biodiversity hotspots (Fujikura et al. 2010).

Among 35,898 fish species recognized worldwide (Fricke et al. 2021), 4476 valid species (12.5% of all) were recorded from Japan (Motomura 2021; this study). Although most of them occur in marine and brackish waters (or are diadromous), 152 species inhabit only freshwaters (e.g., Watanabe et al. 2017; Hibino and Tabata 2018). Watanabe et al. (2017) reviewed and discussed the biogeography and

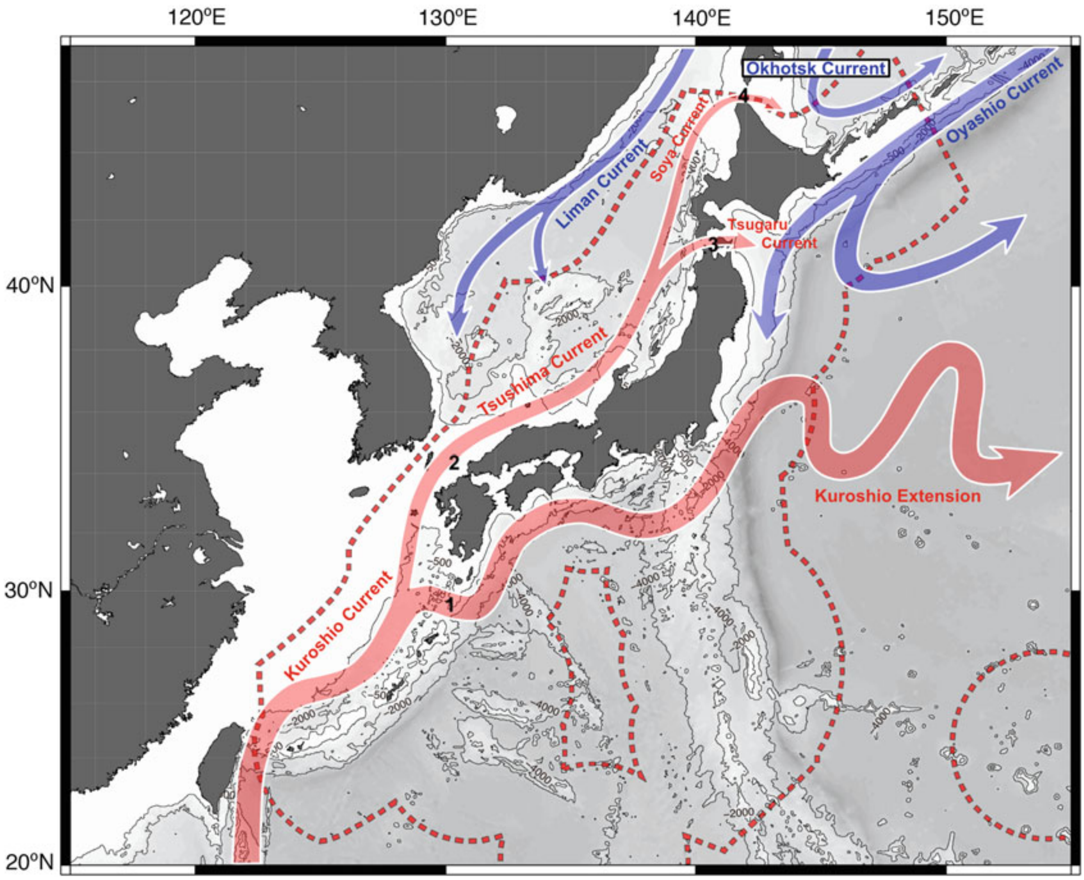

Fig. 2.2 Map of the western North Pacific around Japan showing the Exclusive Economic Zone (*dotted lines*), currents, and straits: *1* Tokara Strait; *2* Tsushima Strait; *3* Tsugaru Strait; and *4* Soya Strait (modified from Nakayama 2020: figs. 2, 3). The map was generated using the Generic Mapping Tools (GMT ver. 4.5.9; see Wessel et al. 2013), with bathymetric data obtained from ETOPO1 (Amante and Eakins 2009)

cryptic diversity of Japanese freshwater fishes. The Japanese fishes inhabit many aquatic environments, from mountain streams to deep-sea trenches and from coral reefs to the frozen sea covered by drift ice in winter (Nakabo 2013). We summarize the historical geography and currents in the Japanese region and the species composition of Japanese fishes by families.

2.2 Geography

The Japanese island arc system consists of four segments: the Kuril Arc, the Honshu Arc [divided into the Northeastern (NE) Japan Arc and Southwestern (SW) Japan Arc], the Ryukyu Arc, and the Izu-Ogasawara (=Bonin) Arc (Taira 2001; Mahony et al. 2011). These arcs are located along the subduction zones of the following tectonic plates (Taira 2001): the Pacific Plate and Okhotsk Plate (a small western part of the North American Plate); the Pacific Plate and Philippine Sea Plate (PSP); the PSP and Amur Plate (a small eastern part of the Eurasian Plate); and the PSP and Eurasian Plate (Fig. 2.1). Tectonic activities since 30 Ma including volcanic activity near the subduction zones have formed mountains on the land, islands, submarine ridges, troughs, basins, and trenches in the sea (Nakajima 2018). In Japanese waters, three trenches are located along the subduction zones on the Pacific Plate—the Kuril Trench (deepest point at 9550 m deep, 44°09′N, 150°30′E), Japan Trench (8058 m, 36°05′N, 142°46′E), and Izu-Ogasawara Trench (9780 m, 29°28′N, 142°42′E)—while the Ryukyu Trench (=Nansei-Shoto Trench, 7480 m, 24°52′N, 128°02′E) is located along the subduction zone on PSP (Taira 2001; National Astronomical Observatory of Japan 2020; Fig. 2.1). Also, three troughs run along the subduction zone of PSP from east to west [i.e., the Sagami Trough (from the "Triple junction" meeting point of the three tectonic plates to Sagami Bay), the Suruga Trough (from Suruga Bay to Enshu-nada sea), and the Nankai Trough (off the Kii Peninsula and Shikoku Island or including Suruga Trough in a broad sense)], while the Okinawa Trough in the East China Sea is an expanding back-arc basin of the Ryukyu Arc (Taira 2001; Mahony et al. 2011: Fig. 2.1). Further, the Kyushu-Palau Ridge, extending from north to south, is located on the center of the PSP off Shikoku and Kyushu and is regarded as a remnant of the proto-Izu-Ogasawara (Bonin) Arc (Mahony et al. 2011; Nishizawa et al. 2016).

Before 30 Ma, the Japanese region was part of the eastern margin of the Eurasian Continent. Subsequently, the opening of the Sea of Japan by the "back-arc expansion" began in ca. 30 Ma and finished in 15 Ma (Nakajima 2018; Tsutsumi 2021). At present, two models for explaining the opening of the Sea of Japan—the "double-door opening"and the "pull-apart basin"—are predominant (Tsutsumi 2021). Both are identical with respect to the formation of two island arcs [the Northeastern (NE) Japan Arc (=NE Honshu Arc) and Southwestern (SW) Japan Arc (=SW Honshu and Shikoku)], which migrated separately from the Eurasian Continent. During the period of 18–16 Ma, the NE and SW Japan arcs had rotated rapidly counterclockwise and clockwise, respectively (Nakajima 2018; Tsutsumi 2021). During 16–13 Ma, the volcanic front on the SW Japan Arc was active when the PSP began to subduct beneath the Eurasian Plate (Tsutsumi 2021).

After 3 Ma, the NE and SW Japan arcs rifted actively due to the east–west contraction related to the Pacific and PSP subducting underneath the Amur Plate (Takahashi 2017). The rifted arcs are bordered by the Fossa Magna area, marking a critical boundary of fauna and flora on land. For example, the Central Highlands formed by uplifting in this area is a significant and well-documented barrier for many primary freshwater fishes (Watanabe et al. 2017).

The Sea of Japan was wide open in 15 Ma, because most of the NE Japan Arc had not rifted above sea level (Tsutsumi 2021). This opening event formed three basins; the Japan Basin (maximum depth of ca. 3800 m) is the largest and located on the north side of the Yamato Basin, which is separated by the Yamato Bank from other areas of the Sea of Japan, and the Tsushima Basin located near the Tsushima Strait and surrounded by the Korean Peninsula and Honshu Island (Shinohara et al. 2011; Nakajima 2018). At present, the Sea of Japan is narrowly connected to the Pacific Ocean by four shallow straits, i.e., Mamiya (=Tatar, ~10 m maximum depth), Soya (=La Pérouse, 60 m), Tsugaru (140 m), and Tsushima (120 m), that act as barriers for most deep-sea fishes trying to enter the Sea of Japan (e.g., Nishimura 1992; Nakaya and Shirai 1992; Shinohara et al. 2011; Nakayama 2020). Also, the Tsugaru and Tsushima straits were probably not closed even at the lowest sea level (approximately −120 m) during the last glacial period in the Late-Quaternary (e.g., Ohshima 1990; Tsutsumi 2021). Furthermore, although a land bridge between Hokkaido and Sakhalin was formed over the present-day Soya Strait (Ono 1990; Watanabe et al. 2017), the Tsugaru and Tsushima straits were boundaries for freshwater fishes in Far East Asia. Hence, these geographical events have played an important role in the diversity and evolution of inshore marine and freshwater fishes of Japan during sea-level fluctuations of repeated glaciations in the Pleistocene (e.g., Watanabe et al. 2017; Kato et al. 2021; Hirase 2021).

Hokkaido, located on the Okhotsk Plate, facing the Pacific Ocean, Sea of Japan, and Okhotsk Sea, was formed by two old arc-trench systems (i.e., old Japan and Kuril trenches) and related to movements of the North American, Pacific, and Amur plates, and the Kuril Forearc Sliver (a microplate of the Okhotsk Plate along the Kuril Trench, the western end of the Hidaka Collision Zone) (Taira 2001; Tsutsumi 2021; Fig. 2.1). The western part of Hokkaido belonging to the NE Japan Arc originated from the Eurasian Continent's margin, while the eastern part of Hokkaido was an island belonging to the Kuril Arc 20 Ma (Tsutsumi 2021). From 15 to 10 Ma, the eastern part of Hokkaido collided with the western part via the westward movement of the Kuril Forearc Sliver, resulting in the formation of the Hidaka Mountains (Tsutsumi 2021: Fig. 2.1). Also, the Kuril Basin (=Chishima Basin, 3521 m maximum depth) in the Okhotsk Sea was formed by a back-arc spreading from ca. 24 to 15 Ma (the late-Oligocene to middle-Miocene) in the same period of time the Japan and Shikoku Basins were formed (Nakajima 2018).

On PSP, the separation of the Kyushu-Palau Ridge (KPR) from the proto-Izu-Bonin Arc was caused by the southwest-northeast expansion of the Shikoku Basin (and Parece Vera Basin, located south of the former) from ca. 26 to 15 Ma (e.g., Mahony et al. 2011; Nishizawa et al. 2016). This expansion, which was linked to the origin and extension of the Nankai Trough started at the Shikoku Basin Spreading Center on PSP between KPR and the Izu-Ogasawara Arc, and the boundary of the Pacific Plate also moved toward the northeast (oblique against the zone) during the formation of the Shikoku Basin from 15 to 5 Ma (Mahony et al. 2011). Subsequently, the direction of subduction underneath the Amur Plate changed toward the northwest (vertical against the zone) in 3 Ma (Mahony et al. 2011; Tsutsumi 2021). On the other hand, the western area of the northern KPR, subducting at the Ryukyu Trench, is older than the eastern area (60–40 Ma), where the Amami Plateau, the Daito Ridge, and the Oki-Daito Ridge (remnants of paleo-island arcs) are located from north to south (Nishizawa et al. 2014; Tsutsumi 2021). These complex seafloors characterize the area.

2.3 Currents

The Kuroshio and Oyashio currents are the major warm and cold western boundary currents in the western North Pacific Ocean, which strongly affect climate and the marine biota around Japan (e.g., Nishimura 1992; Fujikura et al. 2010; Qiu 2019: Fig. 2.2). The Kuroshio Current acts as a conveyer for supplying eggs and larvae of various tropical and subtropical fishes and invertebrates, and warm water reef-building corals to southern Japan (Nishimura 1992). Conversely, it acts as a barrier for the dispersal of many temperate shore fishes from southern Japan to the Ryukyu Islands (Matsuura and Senou 2012). Also, the Oyashio Current (=Kuril Current) brings cold oxygen- and nutrient-rich waters to the Pacific coasts of northern Japan (Qiu 2019).

"Kuroshio" is a Japanese name meaning "black stream" and is derived from its blackish-blue water coloration that indicates the deficiency of nutrients and sediments, and resulting in high transparency and low biological productivity (Qiu 2019). The Kuroshio is a western flow of the North Pacific Gyre known as a wind-driven clockwise circulation between the equator and 50° N latitude (Gallagher et al. 2015; Qiu 2019). It originates from the western end of the North Equatorial Current in the gyre, flowing north along with the eastern Philippine Islands, to the East Taiwan Channel, entering the East China Sea, flowing northwest along the Ryukyu Arc to the Tokara Strait, and inflowing the open Pacific Ocean off southern Japan between 136° E and 140° E (off Kyushu, Shikoku, and Honshu). The Kuroshio Current displays frequent meanders of various scales and finally leaves Japan at central Honshu, and then running eastward to the Hawaiian Islands as the Kuroshio Extension (Gallagher et al. 2015; Qiu 2019).The Tsushima Current is separated from the Kuroshio Current in the East China Sea and flows along the western coast of Kyushu, continuing northward along the coasts of Honshu and Hokkaido in the Sea of Japan, and reaching the Sea of Okhotsk through the Soya Strait before re-entering the Pacific Ocean through the Tsugaru Strait (Gallagher et al. 2015; Qiu 2019).

With respect to the diversity of marine shore fishes, Carpenter and Springer (2005) estimated that the area of the Philippine Islands shows the highest species richness in the Indo-Malay-Philippines Archipelago (IMPA), which has been known as the area of highest marine biodiversity (e.g., Briggs and Bowen 2013; Gaither and Rocha 2013). In addition, the Coral Triangle (an area extending from the Philippines to the Solomon Islands), overlapping the IMPA, indicates the highest species richness for hermatypic (zooxanthellate, reef-building) corals, reaching more than 500 species (Venon et al. 2009). Because the upstream location of the Kuroshio Current is adjacent to this biodiversity hotspot, its warm water mass has been supplying eggs and larvae of tropical shore fishes and invertebrates, including hermatypic corals, to the coasts of Japan. The distribution of major coral reefs in Japanese waters is restricted to the Ryukyu Islands and Ogasawara Islands, ranging from 24° N to 30° N (lowest sea surface temperature is 18 °C in winter) (Gallagher et al. 2015). Although the previous southern limit of coral reefs along the Kuroshio Current is known at the northeast of Tanegashima Island (31° N), isolated coral reefs were found in inner bays of Iki Island (33°48′N), Nagasaki Prefecture, south of Tsushima Island (Yamano et al. 2012).

In the Pliocene and middle Pleistocene, the Kuroshio Current is estimated to have flowed along the Ryukyu Islands fluctuating north to south, on the basis of various paleoceanographic proxies collected in the area (e.g., microfossils and geochemical data) (Gallagher et al. 2015; Ujiié et al. 2016). During the lowest sea level of the Last Glacial Maximum, the Kuroshio Current did not flow in the East China Sea because of the East Taiwan Channel restriction (Gallagher et al. 2015). Until 3 Ma, the Kuroshio Current reached its present latitude (35° N), and a weak Tsushima Current started flowing into the Sea of Japan when the southern Tsushima channel narrowly opened by transgression (the sea level was estimated 40 m higher than the present) in interglacial periods (Gallagher et al. 2015). After 2 Ma, crustal expansion in the northern Okinawa Trough deepened the Tsushima Strait, which enabled continuous inflowing of the Tsushima Current to the Sea of Japan. This expansion of the Okinawa Trough was caused by that change in the Philippine Sea Plate subduction (Gallagher et al. 2015). Until 1 Ma, the intensity and flow path of the Kuroshio Current became the same as the present by increased glacial and interglacial periods, and the coral reef front along the Ryukyu Arc advanced to 31° N; subsequently, the coral reef front of the islands fluctuated from 24 to 31° N (Gallagher et al. 2015).

According to Venon (1992), 400 hermatypic coral species were recorded from the Ryukyu Islands and the Pacific coasts of southern Japan from Tanegashima Island, Kagoshima to Tateyama (southernmost part of Boso Peninsula, Chiba Prefecture, Honshu). The distributional limits of hermatypic corals on rocky reefs in Japan were found in Sado Island, Niigata (Sea of Japan), and Katsuura located on the east coast of Boso Peninsula, Honshu (Pacific side) (e.g., Sugihara et al. 2009; Zayasu et al. 2017). On the other hand, occurrences of tropical and subtropical fishes in temperate rocky reefs of the Pacific coasts of southern Japan have been recently increasing (e.g., Hirata et al. 2011; Nakamura et al. 2013; Tose et al. 2017). These facts strongly indicate that global warming has been affecting marine organisms in the sea around Japan.

The Japanese name “Oyashio” means “child-raising parent” and refers to the high biological productivity of the oxygen- and nutrient-rich water in the current. In the northern North Pacific Ocean, the cold-water mass of the Oyashio Current originates from a subarctic westward flow of the Alaskan Stream, including rejoined waters from the Bering Sea and the Sea of Okhotsk, and the Alaska Gyre and Western Subarctic Gyre (Qiu 2019). The Alaskan Stream is located north of, and connects, the two gyres, flowing along the southern side of the Aleutian Islands, reaching the eastern side of the Kamchatka Peninsula (Qiu 2019). Also, this stream partly flows into the western Bering Sea, forming the Bering Sea Gyre, and turns southwestward as the East Kamchatka Current, passing along the eastern coast of the Kamchatka Peninsula to the southern side of the Kuril Islands. Water from this current partly intrudes the northern Sea of Okhotsk, circulates in a counterclockwise gyre inside the Kuril Basin, outflows through the Bussol Strait (46.5° N, 151.5° E), and rejoins the East Kamchatka Current (Qiu 2019). The downstream East Kamchatka Current south of the Bussol Strait is renamed as the Oyashio Current because of the different water properties compared with those upstream (Qiu 2019). Recent observations of the water in the southern part of the Oyashio Current off Hokkaido revealed a well-defined annual cycle: increase in winter and spring [20–30 Sverdrup (Sv), surface to bottom] and decrease in summer and fall (3–4 Sv, restricted upper of 2000 m depth) (Qiu 2019). Further, the Oyashio Current is divided into two paths off Hokkaido: the first turns off-shoreward and joins the east-northeastward flowing Subarctic Current; the second path flows along with Tohoku District, its front showing fluctuation from 38.5 to 41.5° N (Qiu 2019; Fig. 2.2).

The area off the Pacific coast of Tohoku District is known as the world's most significant fishing grounds with high biological productivity, where the Oyashio and Kuroshio currents supply nutrient-rich and warm waters, respectively. In addition, the Tsugaru Warm Current, an offshoot of the Tsushima Current outflowing through the Tsugaru Strait, intrudes southward along the coast of Tohoku. As a result, this food-rich area has various habitats for marine fishes from coasts to deep bottoms, down to the Japan Trench. Although the diversity of marine fishes in the area has been investigated mainly by bottom trawls, new species and additional records of deep-sea or deep demersal fishes were often reported (e.g., Shinohara et al. 2009; Misawa et al. 2020; Kai et al. 2021).

2.4 Species Diversity of Fishes of Japan

As stated above, the Japanese Archipelago is located on the western side of the Pacific Ocean and extends for 3000 km from the northern tip of the Soya Peninsula (45°31′N) in Hokkaido Island to Hateruma-jima Island (24°03′N) in the Ryukyu Islands. Although the terrestrial realm of Japan is included in the temperate zone, the marine environments are more diverse. The northeastern coast of Hokkaido Island, facing the Okhotsk Sea, is covered by ice in winter. However, in the Ryukyu Islands, there are well-developed coral reefs similar to the coral reefs in the tropical western Pacific (Allen and Erdmann 2012). Between these two extremes, there exists a wide variety of marine habitats such as sandy beaches, mud flats, mangroves, estuaries, rocky shores, kelp beds, and very deep trenches exceeding 8000 m in depth (e.g., Japan Trench on the Pacific side of Honshu Island). Contrary to the marine environments, the freshwater habitats in Japan are less diverse, being composed of short rivers and small- to medium-sized lakes (except for Lake Biwa). These aquatic environments have resulted in a great diversity of fishes. According to Motomura (2021), the number of valid fish species in Japan has reached 4476 representing 12.5% of the 35,898 valid species worldwide (Fricke et al. 2021). Motomura (2021) also included 141 species that are considered distinct by Japanese ichthyologists and have been given Japanese names, but are undescribed scientifically. This makes the total number of fish species in Japan 4617.

We examined the number of species in all families found in Japan to produce a list of the top 35 most speciose families in Japan (Table 2.1). This list shows that the members of 35 families represent 57.4% of the total valid species reported from Japan. Within the top 35 families (Table 2.1), many are represented by species occurring in shallow water (here defined as depths shallower than 200 m). In addition, most of the shallow water fishes live in warm waters, although some of them (e.g., Stichaeidae, Sebastidae and Pleuronectidae) also include species living in cold waters. The typical shallow water fishes found in warm waters are as follows: Gobiidae, Serranidae, Labridae, Pomacentridae, Apogonidae, Blenniidae, Scorpaenidae, Muraenidae, Syngnathidae, Carangidae, Lutjanidae, Tetraodontidae, Chaetodontidae,

Table 2.1 A list of top 35 most speciose families in Japan

Family	No. of species	% of total valid species in Japan	Habitat
Gobiidae	469	10.5	Shallow water
Serranidae	156	3.5	Shallow water
Labridae	153	3.4	Shallow water
Pomacentridae	111	2.5	Shallow water
Apogonidae	102	2.3	Shallow water
Cottidae	88	2.0	Shallow water/deep sea
Myctophidae	88	2.0	Deep sea
Blenniidae	81	1.8	Shallow water
Cyprinidae	78	1.7	Freshwater
Macrouridae	70	1.6	Deep sea
Liparidae	68	1.5	Deep sea/shallow water
Scorpaenidae	68	1.5	Shallow water
Muraenidae	64	1.4	Shallow water
Ophichthidae	64	1.4	Shallow water/deep sea
Syngnathidae	64	1.4	Shallow water
Carangidae	62	1.4	Shallow water
Zoarcidae	62	1.4	Deep sea
Lutjanidae	54	1.2	Shallow water
Tetraodontidae	54	1.2	Shallow water
Chaetodontidae	52	1.2	Shallow water
Ophidiidae	49	1.1	Shallow water
Stichaeidae	48	1.1	Shallow water
Acanthuridae	45	1.0	Shallow water
Bothidae	42	0.9	Shallow water
Holocentridae	41	0.9	Shallow water
Sebastidae	40	0.9	Shallow water/deep sea
Callionymidae	36	0.8	Shallow water
Melanostomiidae	36	0.8	Deep sea
Scaridae	36	0.8	Shallow water
Monacanthidae	33	0.7	Shallow water
Pleuronectidae	33	0.7	Shallow water
Pomacanthidae	32	0.7	Shallow water
Tripterygiidae	32	0.7	Shallow water
Lethrinidae	30	0.7	Shallow water
Pinguipedidae	30	0.7	Shallow water
Total	2571	57.4	

"Shallow water/deep sea" indicates that the family includes many shallow water species and a small number of deep-sea species. "Deep sea/shallow water" indicates that the family includes many deep-sea species and a small number of shallow water species

Acanthuridae, Bothidae, Holocentridae, Callionymidae, Scaridae, Monacanthidae, Pomacanthidae, Tripterygiidae, Lethrinidae, and Pinguipedidae. These 23 families are composed of 1847 species representing 72% of the total number of species in the top 35 most speciose families. This figure suggests that the shallow water fishes living in warm waters are the main components of Japan's fish diversity.

On the other hand, Table 2.1 clearly shows that among the top 35 most speciose families in Japan, primary freshwater fishes are represented only by Cyprinidae. In addition to Cyprinidae, there are 24 families that include primary freshwater fish species, although nine families are represented

Table 2.2 The number of primary freshwater fish species in 24 families in Japan

Family	Number of species	Remarks
Cyprinidae	68	
Cobitidae	19	
Poeciliidae	7	All species invasive
Nemacheilidae	6	
Salmonidae	6	Including only landlocked forms
Bagridae	5	
Cichlidae	4	All species invasive
Gasterosteidae	4	
Odontobutidae	4	
Siluridae	4	
Centrarchidae	3	All species invasive
Channidae	3	All species invasive
Gobiidae	3	
Lepisosteidae	3	All species invasive
Adrianichthyidae	2	
Osphronemidae	2	All species invasive
Sinipercidae	2	
Amblycipitidae	1	
Atherinidae	1	Invasive
Botiidae	1	
Clariidae	1	
Ictaluridae	1	Invasive
Loricariidae	1	Invasive
Synbranchidae	1	
Total	152	

only by invasive species. The total number of the primary freshwater fish species (here defined as fishes strictly confined to freshwater) is 152 (Table 2.2), occupying only 3.4% of the total valid species in Japan. If only the native primary freshwater fishes are counted, the total number of species decreases to 125. However, Hosoya (2015) showed that there are 498 species (including the species given only Japanese names without scientific names) of freshwater fishes in Japan, including not only the primary freshwater fishes but also diadromous fishes, brackish-water fishes, and those occasionally entering freshwater. When we follow Hosoya's (2015) definition of freshwater fishes, the percentage of freshwater fish species in the total number of Japanese fish species is 10.8%, significantly higher than the figure of 3.4% based on the primary freshwater fishes. These figures are low when compared to the number of freshwater fish species in the world, which is 18,132 and is half the total number of fish species (Fricke et al. 2021).

We examined the number of deep-sea fishes in Japan to recognize 1005 species belonging to 155 families; deep-sea fishes are defined here as those usually occurring in depths exceeding 200 m, and depth records are taken from the literature (Carpenter and Niem 1998–2001; Mundy 2005; Nakabo 2013). These species represent about 22.5% of the total valid species of Japan, clearly showing that deep-sea fishes have diversified broadly in Japan. This is not surprising due to the many deepwater habitats in seas around Japan (e.g., the Japan Trench off the Pacific coast of Honshu Island exceeding 8000 m, and the Sea of Japan at 3700 m). Our examination of Japanese fishes also listed the 26 most speciose families of deep-sea fishes (Table 2.3). The total number of deep-sea species in 26 families is 607, about one-third of the total number of shallow water

Table 2.3 A list of 26 most speciose deep-sea families among 155 deep-sea families found in Japan

Family	Number of deep-sea species found in Japan	Number of total species of family found in Japan	% of deep-sea species in total species of family found in Japan
Myctophidae	88	88	100
Macrouridae	70	70	100
Ophidiidae	48	49	98.0
Liparidae	36	68	52.9
Melanostomiidae	36	36	100
Zoarcidae	33	62	53.2
Alepocephalidae	26	26	100
Ogcocephalidae	21	21	100
Arhynchobatidae	19	19	100
Paralepididae	19	19	100
Astronesthidae	17	17	100
Sternoptychidae	17	17	100
Oneirodidae	15	15	100
Acropomatidae	14	17	82.4
Melamphaidae	14	14	100
Moridae	14	16	87.5
Peristediidae	14	20	70.0
Chiasmodontidae	13	13	100
Etmopteridae	13	13	100
Gempylidae	12	13	92.3
Gonostomatidae	12	12	100
Sebastidae	12	40	30.0
Bothidae	11	42	26.2
Psychrolutidae	11	11	100
Scopelarchidae	11	11	100
Synaphobranchidae	11	11	100
Total	607	740	82.0

species in the top 35 most speciose families as shown above.

Acknowledgments We thank the following ichthyologists for providing valuable information on fishes of Japan: Y. Kai (Kyoto University), H. Motomura (Kagoshima University Museum), M. Nakae (National Museum Nature and Science), and N. Nakayama (Tokai University). We are also grateful to D. Yuki (Kochi University) for preparing the figures and G. Yearsley (Hobart, Australia) for editing an earlier version of the English text.

References

Allen GR, Erdmann MV (2012) Reef fishes of the East Indies—volumes I–III. Tropical Conservation International Indonesia, Bali

Amante C, Eakins BW (2009) ETOPO1 1 arc-minute global relief model: procedures, data sources and analysis. NOAA Technical Memorandum ESDIS NGDC-24. National Geophysical Data Center, NOAA, Boulder. https://doi.org/10.7289/V5C8276M. Accessed 31 Oct 2019

Briggs JC, Bowen BW (2013) Marine shelf habitat: biogeography and evolution. J Biogeogr 40:1023–1035

Carpenter KE, Niem VH (eds) (1998–2001) FAO species identification guide for fishery purposes. The living marine resources of the western central Pacific—volumes 1–6. FAO, Rome

Carpenter KE, Springer VG (2005) The center of the center of marine shore fish biodiversity: the Philippine Islands. Environ Bio Fish 72:467–480

Fricke R, Eschmeyer WN, Van der Laan R (eds) (2021) Eschmeyer's catalog of fishes: genera, species, references (electronic version). http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp. Accessed 20 June 2021

Fujikura K, Lindsay D, Kitazato H, Nishida S, Shirayama Y (2010) Marine biodiversity in Japanese waters. PLoS One 5(8):e11836

Gaither MR, Rocha LA (2013) Origin of species richness in the Indo-Malay-Philippine biodiversity hotspot:

evidence for the centre of overlap hypothesis. J Biogeogr 40:1638–1648
Gallagher SJ, Kitamura A, Iryu Y, Itaki T, Koizumi I, Hoiles PW (2015) The Pliocene to recent history of the Kuroshio and Tsushima Currents: a multi-proxy approach. Prog Earth Planet Sci 2:17
Hibino Y, Tabata R (2018) Description of a new catfish, *Silurus tomodai* (Siluriformes: Siluridae) from central Japan. Zootaxa 4459:507–524
Hirase S (2021) Comparative phylogeography of coastal gobies in the Japanese Archipelago: future perspectives for the study of adaptive divergence and speciation. Ichthyol Res. https://doi.org/10.1007/s10228-021-00824-3
Hirata T, Oguri S, Hirata S, Fukami H, Nakamura Y, Yamaoka K (2011) Seasonal changes in fish assemblages in an area of hermatypic corals in Yokonami, Tosa Bay, Japan. Jpn J Ichthyol 58:49–64
Hosoya K (2015) Freshwater fishes of Japan. Yamakei Publishers, Tokyo. (In Japanese)
Japan Coast Guard (2021) Pamphlet. Japan Coast Guard, Tokyo, pp 1–34. https://www.kaiho.mlit.go.jp/e/pdf/R02_panfu_eng.pdf. Accessed 12 Jul 2021
Kai Y, Endo H, Tashiro F, Nakayama N (2021) Two new species of snailfishes of the genus *Careproctus* (Cottoidei: Liparidae) from the western North Pacific Ocean with a range extension of *Careproctus brevipectoralis*. Zootaxa 4951:361–371
Kato S, Arakaki S, Kikuchi K, Hirase S (2021) Complex phylogeographic patterns in the intertidal goby *Chaenogobius annularis* around Kyushu Island as a boundary zone of three different seas. Ichthyol Res 68:86–100
Mahony SH, Wallace LM, Miyoshi M, Villamor P, Sparks RSJ, Hasenaka T (2011) Volcano-tectonic interactions during rapid plate-boundary evolution in the Kyushu region, SW Japan. GSA Bull 123:2201–2223
Matsuura K, Senou H (2012) Introduction of fishes in the Kuroshio Current. In: Matsuura K (ed) Fishes in the Kuroshio Current. Tokai Univ Press, Hadano, pp 3–16
Matsuzawa T (2005) What is the volume of Japan's 200-nm exclusive economic zone? Ship Ocean Newslett Selected Pap 8:20–21
Misawa R, Kimura K, Mizumachi K, Hattori T, Narimatsu Y, Suzuki Y, Morioka E, Tokioka S, Nagano J, Shibata Y, Endo H, Tashiro F, Kai Y (2020) New distributional records of trawled fishes off the Pacific coasts of Tohoku District, northern Japan. Jpn J Ichthyol 67:265–286
Motomura H (2021) List of Japan's all fish species. Current standard Japanese and scientific names of all fish species recorded from Japanese waters. Online ver. 9. Kagoshima University Museum, Kagoshima. https://www.museum.kagoshima-u.ac.jp/staff/motomura/jaf.html. Accessed 7 Apr 2021
Mundy BC (2005) Checklist of the fishes of the Hawaiian Archipelago. Bishop Mus Bull Zool 6:1–704
Nakabo T (ed) (2013) Fishes of Japan with pictorial keys to the species, 3rd edn. Tokai Univ Press, Hadano
Nakajima T (2018) Tectonics of sedimentary basins in and around Japan since the opening of the Sea of Japan. J Geol Soc Japan 124:693–722
Nakamura Y, Feary DA, Kanda M, Yamaoka K (2013) Tropical fishes dominate temperate reef fish communities within Western Japan. PLoS One 8(12): e81107
Nakaya K, Shirai S (1992) Fauna and zoogeography of deep-benthic chondrichthyan fishes around the Japanese Archipelago. Jpn J Ichthyol 39:37–48
Nakayama N (2020) Grenadiers (Teleostei: Gadiformes: Macrouridae) of Japan and adjacent waters, a taxonomic monograph. Megataxa 3:1–383
National Astronomical Observatory of Japan (2020) Chronological scientific tables. Maruzen, Tokyo
Nishimura S (1992) Guide to seashore animals of Japan with color pictures and keys, vol I. Hoikusha Pub Co Ltd, Osaka
Nishizawa A, Kaneda K, Katagiri Y, Oikawa M (2014) Wide-angle refraction experiments in the Daito Ridges region at the northwestern end of the Philippine Sea plate. Earth Planets Space 66:25
Nishizawa A, Kaneda K, Oikawa M (2016) Crust and uppermost mantle structure of the Kyushu-Palau Ridge, remnant arc on the Philippine Sea plate. Earth Planets Space 68:30
Ohshima K (1990) The history of straits around the Japanese islands in the Late-Quaternary. Quat Res 29:193–208
Ono Y (1990) The Northern landbridge of Japan. Quat Res 29:183–192
Qiu B (2019) Kuroshio and Oyashio Currents. In: Steele JH (ed) Encyclopedia of ocean sciences, 3rd edn. Academic Press, pp 358–369
Shinohara G, Narimatsu T, Hattori M, Ito M, Takata Y, Matsuura K (2009) Annotated checklist of deep-sea fishes from the Pacific coast off Tohoku District, Japan. Natl Mus Nat Sci Monogr 39:683–735
Shinohara G, Shirai SM, Nazarkin MV, Yabe M (2011) Preliminary list of the deep-sea fishes of the Sea of Japan. Bull Natl Mus Nat Sci Ser A 37:35–62
Sugihara K, Sonoda N, Imafuku T, Nagata S, Ibusuki T, Yamano H (2009) Latitudinal changes in hermatypic coral communities from west Kyushu to Oki Islands in Japan. J Jpn Coral Reef Soc 11:51–67
Taira A (2001) Tectonic evolution of the Japanese island arc system. Ann Rev Earth Planet Sci 29:109–134, 14 figs
Takahashi M (2017) The cause of the east-west contraction of Northeast Japan. Bull Geol Surv Jpn 68:155–161, 5 figs
Tose K, Hirata T, Kotera Y, Kanda M, Nakamura Y (2017) Occurrence and reproduction of tropical fishes in ocean warming hotspots of Japanese temperate reefs. Environ Biol Fish 100:617–630
Tsutsumi Y (2021) An illustrated guide to birth of the Japanese islands. New edition. Kodan-sha, Tokyo
Ujiié Y, Asahi H, Sagawa T, Bassinot F (2016) Evolution of the North Pacific Subtropical Gyre during the past

190 kyr through the interaction of the Kuroshio Current with the surface and intermediate waters. Paleoceangr 31:1498–1513

Venon JEN (1992) Conservation of biodiversity: a critical time for the hermatypic corals of Japan. Coral Reefs 11:13–21

Venon JEN, Devantier LM, Turak E, Green AL, Kininmonth S, Stafford-Smith M, Peterson N (2009) Delineating the coral triangle. Galaxea J Coral Reef Stud 11:91–100

Watanabe K, Tominaga K, Nakajima J, Kakioka R, Tabata R (2017) Japanese freshwater fishes: biogeography and cryptic diversity. In: Motokawa M, Kajihara H (eds) Species diversity of animals in Japan. Springer, Tokyo, pp 183–227

Wessel P, Smith WHF, Scharroo R, Luis J, Wobbe F (2013) Generic mapping tools: improved version released. Eos Trans AGU 94:409–410

Yamano H, Sugihara K, Watanabe T, Shimamura M, Hyeong K (2012) Coral reefs at 34°N, Japan: exploring the end of environmental gradients. Geology 40:835–838

Zayasu Y, Yokochi H, Kajiwara K, Kimura T, Shimada G, Shimoike K, Suzuki G, Tachikawa H, Nagata T, Nomura K (2017) Research activities by Japanese Society for coral taxonomy. Taxa Proc Jpn Soc Syst Zool 41:10–15