Octocorallia as a key taxon in the vulnerable marine ecosystems of the Emperor Chain (Northwest Pacific): diversity, distribution and biogeographical boundary

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Seamounts and guyots are of interest to the scientific community because not only numerous mineral resources occurrences are associated with them, but also areas of increased biodiversity (Rogers, 1994; Samadi et al., 2007; Morato et al., 2010). Sea floor elevations can be both reference points for the settlement of deep-sea fauna, and refuges and faunistic centers, and can also serve as biogeographic barriers and have a significant impact on the formation of the ocean fauna (Zezina, 1984; Rogers, 1994).

In the Northwestern Pacific, the transfer of species through currents meets the Emperor Chain of seamounts and guyots, but its biogeographic role in this area is unclear. There is only one publication devoted to the biogeography of the ridge, which shows the differences between the fauna complexes of the brittle stars inhabiting the northern and southern parts of the chain, as well as suggesting the existence of a biogeographic border near 37° N at the chain (Sirenko, Smirnov, 1989). Meanwhile, long-lived and important representatives of deep-sea communities, such as corals and sponges, can expectedly make a significant contribution to understanding the deep-sea species dispersal in the Northern Pacific being a marker of the distribution of bottom organisms in the latitudinal direction and in depth.

Against the background of climate change, the activity of exploitation of biological resources in neutral waters is also increasing, including in the northern part of the Pacific Ocean, where significant biological resources are concentrated in the area of the Emperor Chain (Boretz, Darnitskiy, 1983). Fisheries in seamounts and guyots doubled in recent decades (Watson et al., 2007). In different zones of high seas, international regional fisheries management commissions operate in order to develop quotas for fisheries and establish restrictive measures in areas of fishery activity near seamounts, and to prevent damage to vulnerable marine ecosystems of seamounts (VME).

In the Atlantic, in particular the North Atlantic Fisheries Commission (NEAFC) established a limited fishing in some zones, and introduced a complete ban on bottom fishing in several areas. Deep-water corals and sponges were taken as indicator groups of VMEs (NEAFC, 1982). North Pacific Fisheries Commission (NPFC) acts basing on the Convention on the Preservation of Biological Resources of the High Seas, to which the countries fishing in this zone are parties. The Commission and Convention focus on deep-sea bottom VMEs (including coral gardens, soft coral and gorgonians) in the seamounts and guyots of the Emperor Chain as sources (and, at the same time, indicators) of high productivity of the region. At a meeting in March 2018 (Yokohama, Japan), the Commission recognized the lack of information on the location and population status of corals in the region and the urgent need for their research in seamounts. Indeed, so far there have been only two publications dedicated to the Octocorallia of the chain. Miyamoto et al. (2017) give a general list of Octocorallia genera of the southern part of the chain, obtained during trawl gatherings, but do not characterize the fauna of each seamount separately. Cairns et al. (2018) gives a list of 6 species of Primnoidae gorgonians, based on materials from trawl charges in the southern part of the chain. In connection with the above-discussed, the A.V. Zhirmunsky National Scientific Center of Marine Biology FEB RAS (Vladivostok, Russia) organized a comprehensive multidisciplinary expedition to the Emperor Chain in July–August 2019. The expedition, financially supported by the Ministry of Science and Higher Education of the Russian Federation, was carried out with the participation of a number of institutes of the Russian Academy of Sciences and Far Eastern Federal University. The main goals were planned in order to comprehensively study the VMEs of the chain – their biodiversity, the structure of planktonic and benthic communities, genetic, geological, hydrological and geochemical characteristics in a wide geographical range (Fig. 1).

Research methods included collection of bottom fauna, visual observations, photo and video filming using the remotely operated vehicle (ROV) Comanche 18. Visual observations were accompanied by continuous video recording, selective photographing and targeted sampling. During a series of dives, video transects were performed, which allowed for the first time to quantify the abundance of the leading groups of hydrobionts. A laser scale of 10 cm was used to estimate the population

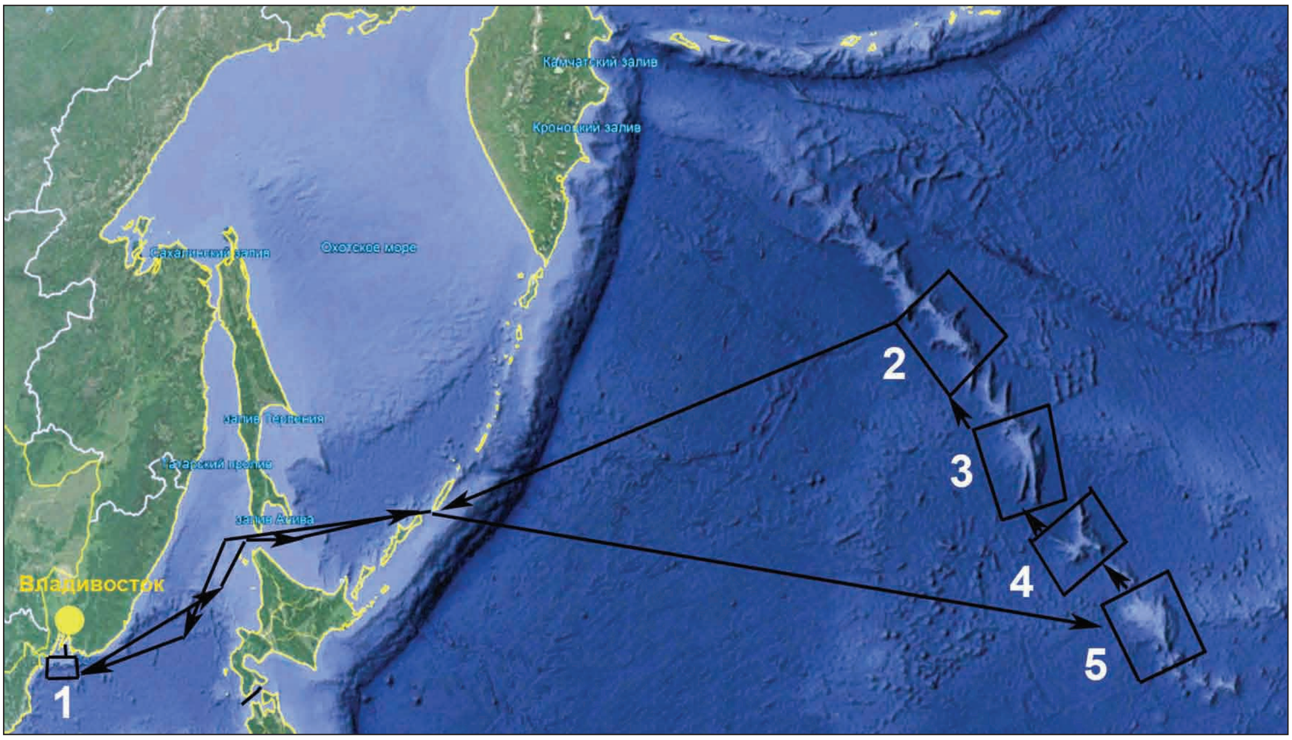

Fig. 1. Map of the working areas explored in the frame of the expedition of the A.V. Zhirmunsky National Scientific Center of Marine Biology FEB RAS jointly with other institutes of the Russian Academy of Sciences and the Far Eastern Federal University to the Emperor Chain (July–August 2019, RV *Akademik M.A. Lavrentiev*). **1** – starting site, Peter the Great Bay, Sea of Japan; **2** – guyot Suiko; **3** – guyot Nintoku; **4** – guyot Ojin and Jingu seamount; **5** – guyot Koko.

density of bottom animals. About 2000 photographs and 50 hours of video recording were obtained and analyzed. The landscape-ecological situation and the bottom fauna were studied in the depth range from 2182 to 338 m.

Preliminary results: coral distribution and a biogeographic boundary

Representatives of the several Anthozoa classes (Hexacorallia corals Scleractinia and Antipatharia, Octocorallia, sea anemones, and Ceriantharia) and Hydrozoa (Fam. Stylasteridae) were found in the studied areas (see Table). Of these, the most noticeable were Octocorallia and Scleractinia,

Preliminary data on the distribution of deep-water coral genera on the studied seamounts and guyots of the Emperor Chain in comparison with some areas of the temperate Northern Pacific

Coral genera (and *Paragorgia* species found)	[1]Alaska and Aleutian Islands	[2]Ojin, the Emperor Chain	[3]Jingu, the Emperor Chain	[4]Koko, the Emperor Chain	[5]Hawaii
			Hydrozoa, Anthoathecata		
Stylaster		+	+	+	+
			Hexacorallia, Scleractinia		
Caryophyllia	+	+	+	+	+
Falbellum	+	+	+	+	+
			Hexacorallia, Antipatharia		
Leiopathes				+	+
			Octocorallia, Alcyonacea		
Acanthogorgia		+	+	+	+
Calcigorgia	+				
Cyclomuricea					+
Muricella					+
Anthomastus		+	+	+	+
Bathyalcyon					+
Heteropolypus	+				
Pseudoanthomastus					+
Anthotela					+
Chrysogorgia		+			+
Iridogorgia					+
Metallogorgia				+	+
Pleurogorgia					+
Radicipes					+
Rhodaniridogorgia					+
Clavularia	+	+		+	+
Sarcodictyon	+				
Telestula					+
Corallium				+	
Hemicorallium	+				+
Acanella					+
Bathygorgia	+				
Isidella		+		+	+
Keratoisis				+	+
Lepidisis		+	+	+	+
Keroeides				+	+

TABLE (*Continued*)

Coral genera (and *Paragorgia* species found)	[1]Alaska and Aleutian Islands	[2]Ojin, the Emperor Chain	[3]Jingu, the Emperor Chain	[4]Koko, the Emperor Chain	[5]Hawaii
Gersemia	+				
Siphonogorgia				+	+
Paragorgia	+	+	+	+	
P. arborea	+	+	+		
P. coralloides				+	
P. regalis		+			
Sibogagorgia	+				
Echinomuricea			+	+	
Alaskagorgia	+				
Anthomuricea					+
Bebryce					+
Cryogorgia	+				
Muriceides	+				+
Paracis					+
Paramuricea					+
Placogorgia					+
Swiftia	+	+		+	+
Thesea					+
Villogorgia					+
Arthrogorgia	+				
Callogorgia				+(+)	+
Calyptrophora	+				+
Candidella				(+)	+
Fanellia	+			+(+)	+
Narella	+			+(+)	+
Paracalyptrophora					+
Parastenella	+				+
Plumarella	+			+	+
Primnoa	+				
Thouarella	+			+	+
Pennatulacea					
Anthoptilum	+				+
Calibelemnon					+
Echinoptilum					+
Halipteris	+				+
Kophobelemnon				+	
Pennatula				+	+
Ptilosarcus	+				
Umbellula	+			+	+
Cavernularia	+				
Stylatula	+				
Virgularia	+	+		+	+
Total genera number	28	9	5	22	47

Note. Sources for different regions: 1 – Heifetz et al. (2005); Stone, Cairns (2017); Wing, Barnard (2004); Herrera et al. (2010); 2–4 – results of the present expedition of the NSCMB FEB RAS to the Emperor Chain (2019, RV *Akademik A.M. Lavrentiev*) with using the additional data from Dautova (2012) and Cairns (2018) (these are shown in parentheses); 5 – Cairns, Hourigan (2017); Parrish et al. (2017).

which were found in the entire range of studied depths and on all types of substrate, including soft sandy grounds (Fig. 2), calcareous outcrops (Fig. 3), rocky biotopes (Fig. 4B) and old lava flows (Fig. 4C). The greatest coral diversity was recorded on the Koko guyot in the southern part of the ridge – 22 genera of Octocorallia (4 genera – Pennatulacea, Fig. 2B, 22 genera – Alcyonacea). Only 5 to 8 genera of Octocorallia have been found on the Ojin, Nintoku and Jingu. Only on the guyot Ojin, 1 genus of Pennatulacea was observed, and the remaining 8 genera of Octocorallia discovered here belong to Alcyonacea – 7 genera of gorgonians, most of which are also found in the Aleutian Islands, and 1 genus of soft corals *Anthomastus* (Fig. 4A) (see Table). Scleractinia of the genera *Caryophyllia* and *Flabellum* were found almost everywhere and do not bring information for biogeographic conclusions. However, the discovery of the black coral of the genus *Leiopathes* on the Koko, previously noted only in the southern latitudes, is very remarkable (see Table).

The fauna complex Octocorallia on Koko can be characterized as very close to that of the Hawaiian Ridge, with a noticeable participation of the bamboo corals (gorgonians Isididae, Fig. 2A) and Chrysogorgiidae (including *Iridogorgia* and *Metallogorgia*, Fig. 4B), characteristic of the tropical and subtropical regions of the Pacific (see Table).

In Koko, there are three species of the genus *Chrysogorgia*, which was not previously observed north of the Hawaiian Islands, including *C. stellata* Nutting, 1908 (previously only observed in Hawaii, Cairns (2001)) and *C. ramosa* Versluys, 1902 (previously noted only in the Philippines, Cairns (2001)). Also noteworthy is the presence of the gorgonaria *Paragorgia coralloides* Bayer, 1993, previously found in the Pacific only near the Palau (Philippine Sea, Sánchez (2005)). On Ojin and Jingu, the composition of chrysogorgiids is depleted, *Iridogorgia* and *Metallogorgia* are absent, only *C. stellata* is noted (see Table). The discovery of the *Paragorgia arborea* in Ojin and Jingu extends its range in the northwestern Pacific and seems quite expected in connection with previous records near the eastern Kamchatka and the Aleutian Islands (Heifetz et al., 2005). The fauna of the Octocorallia of the Aleutian Islands, seamounts, and guyots on the west coast of North America and the Hawaiian Chain is much better documented (see Table). Summarized data show the significant role of gorgonians in communities – the families Plexauridae and Primnoidae contain 28% of species recorded along the American coast and 46% recorded on the mountains of the Hawaiian Ridge (Cairns, Hourigan, 2017; Stone, Cairns, 2017). On the Emperor Chain, we also noted the predominance of gorgonians in terms of the number of genera, primarily fam. Primnoidae, which were found in a wide range of depths – from 330 to 2200 m (see Table). Based on the above findings, the Emperor Chain can be considered as a chain of oceanic risings, where a faunistic complex of tropical and subtropical species of deep-sea corals meets with a complex of boreal Pacific species. The biogeographic boundary between the coral fauna in the area of the Chain obviously runs between 37.5° N and 39° N (i.e., in the region of the Ojin guyot and Jingu seamount, Fig. 1). This observation fully coincides with the assumption about the position of the biogeographic boundary between the boreal and the West Pacific biogeographic regions in the Emperor Chain region, made by Sirenko and Smirnov (1989) based on the data on the echinoderm bathyal fauna (materials of the 33rd cruise of the TINRO RV *Odyssey*). The Far East seas and the Emperor Chain are a biogeographically important region of the Pacific Ocean, on the fauna of which so far there were only a few data of trawl catch (Cairns et al., 2018; Dautova, 2018, with an overview of studies in the region; Miyamoto et al., 2017). As a result of the use of the modern deep-sea TPA during the expedition, we significantly expanded the list of Pennatulacea genera of the chain, made unique and biogeographically important findings of the genera and species of Octocorallia.

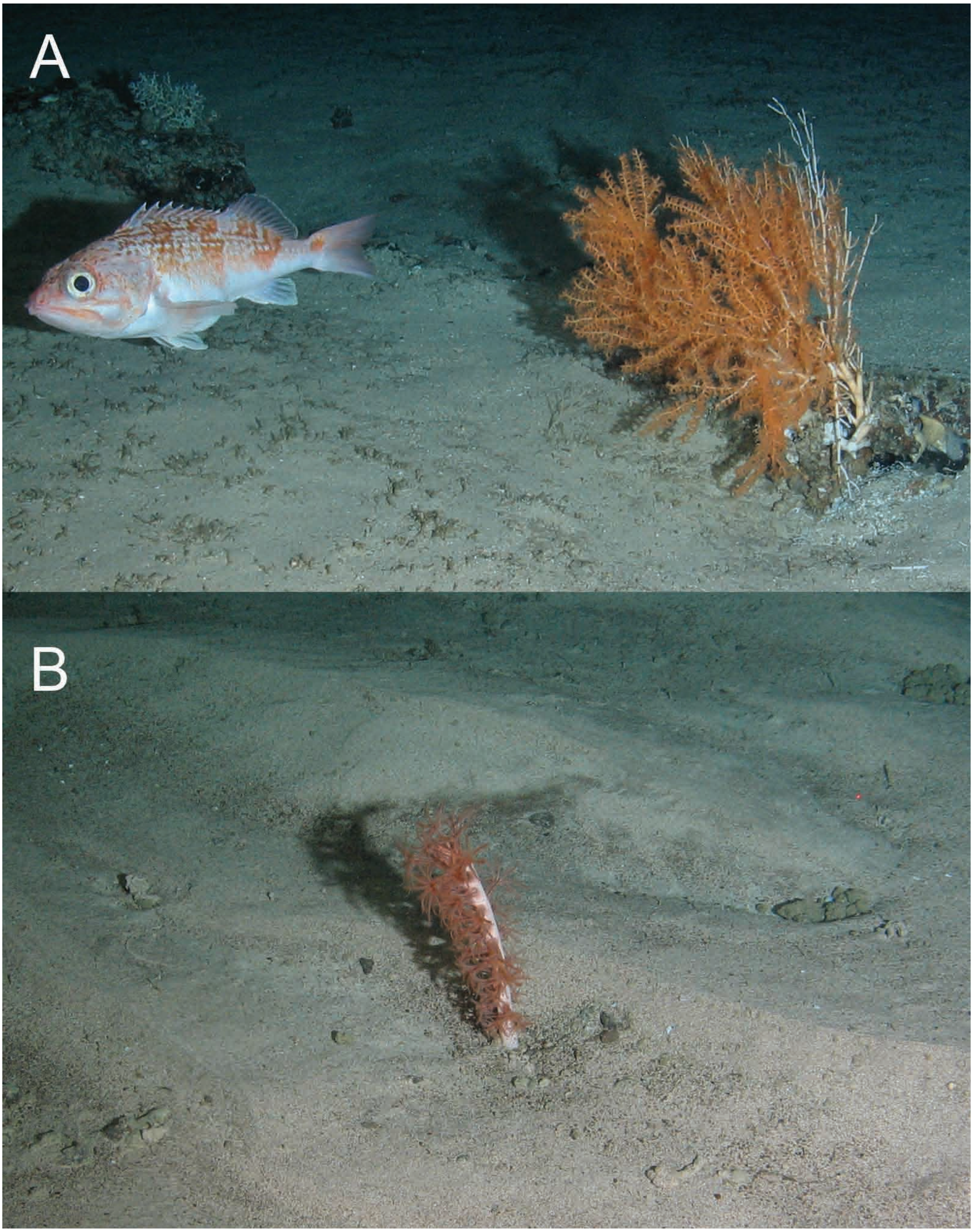

Fig. 2. Typical soft-bottom landscapes and inhabitants of the studied guyots. **A**. Bamboo coral (Octocorallia) and fish. Silty-sand bottom, Koko, 356 m depth. **B**. Sea pen (Pennatulacea) among the sandy dunes. These dunes show the influence of the strong currents. Koko, 1880 m.

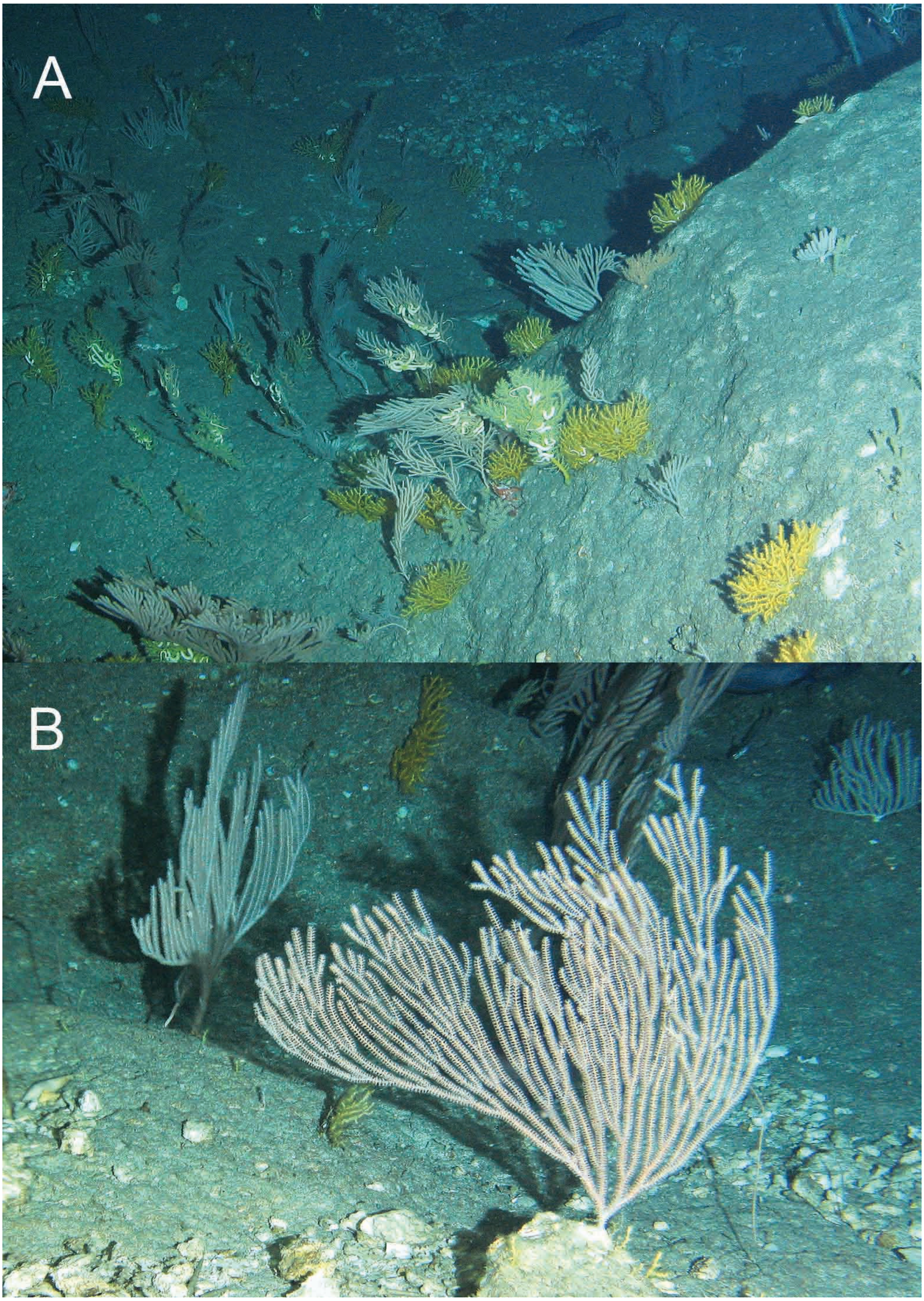

Fig. 3. Hard-substrata landscapes. **A**. Coral (Octocorallia) gardens on the hard substrata. Koko, 380 m depth. **B**. Gorgonian *Narella* on small stones. Koko, 378 m depth.

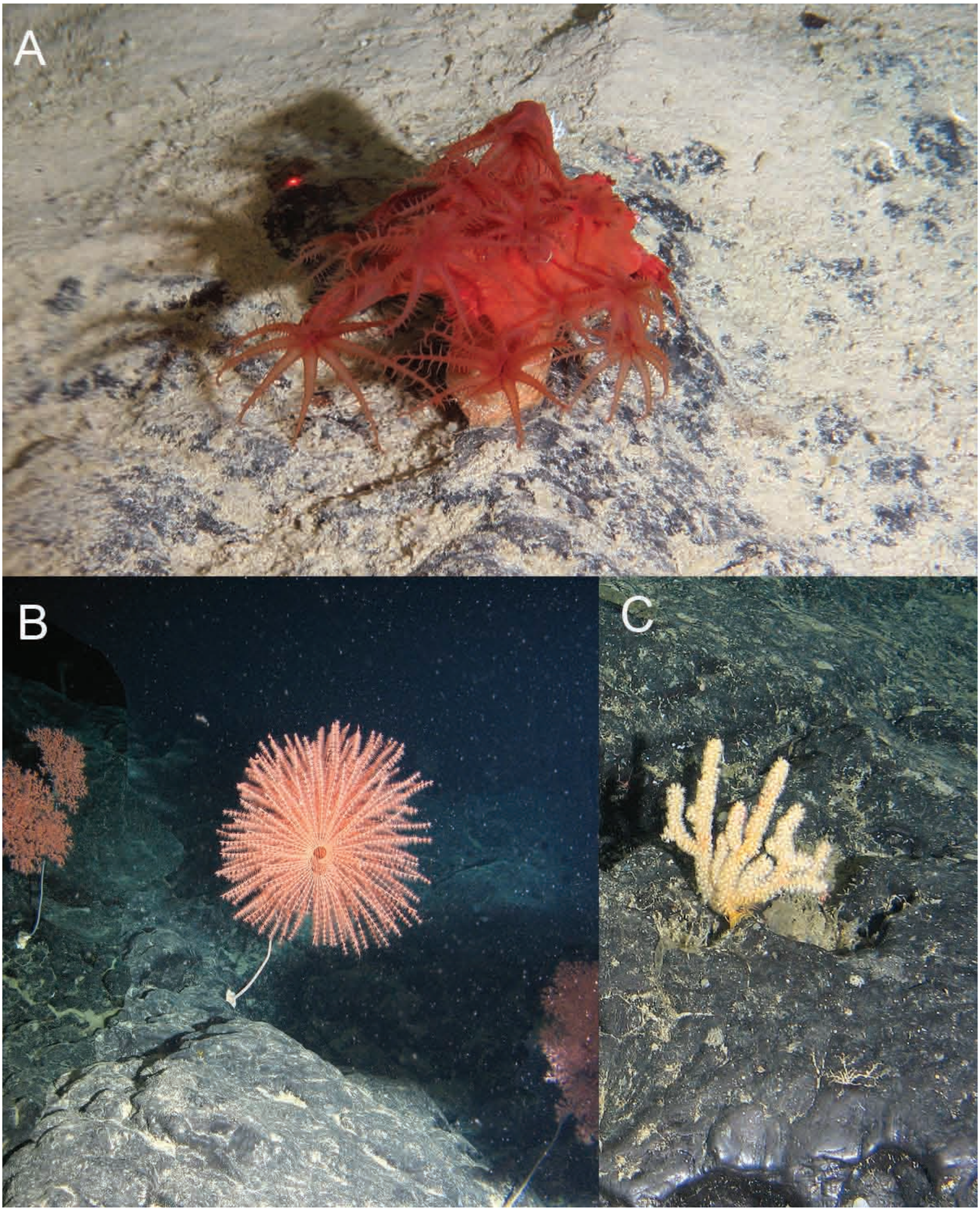

Fig. 4. Rocky landscapes. **A**. Soft coral *Anthomastus* settled on the old lava flow (covered by thin layer of fine sand). Koko, 2100 m depth. **B**. Settlements of the chrysogorgiid gorgonians (Octocorallia) – *Iridogorgia* sp. and *Metallogorgia* sp. on rocky substrata. Koko, 1431 m depth. **C**. *Acanthogorgia* on the old lava flow covered by manganese crust. Jingu, 1267 m depth.

Anthropogenic threats – loss of coral communities from heavy fishing?

Traces of trawls and anthropogenic trash were found in a number of areas on the top part of the Koko. These are clearly visible on calcareous outcrops in the shallow areas of Koko (350–550 m) which are more easily accessible for trawl fishing (Fig. 5C).

There is practically no bottom population. These subjects of anthropogenic origin includes not only plastic and metal dishes, but also scraps of fishing gear (Fig. 6).

In deeper areas (1000–2000 m) on the Koko slopes, no such traces of trawls were noted. In the shallow areas, Koko has a unique faunal coral complex as shown above. Therefore, damage or destruction of coral settlements here may be irreversible. Since there may be no similar settlements at great depths on this guyot and, therefore, there may not be a source for restoration of populations through larval settlement.

There are many studies of fishing impacts in shallow continental shelf environments demonstrated that recovery (of species richness, abundance, population biomass and production) can take several years and is dependent on both the type and extent of impact and the natural levels of disturbance that characterize a community (Collie et al., 2000, with a review). In contrast, only a few studies have examined impacts of fishing on the benthic communities of seamounts. In all these cases, the loss of coral populations and other microbenthic communities has been documented from heavily fished seamounts. Abundant scrape marks were visible, and the seamount rock surface was bare. For example, Clark and Koslow (2007) noted these facts in Tasmania; Clark and O'Driscoll (2003) noted out that effect of trawling by comparing areas subject to different intensities of fishing in New Zealand, while Watling et al. (2007) recorded the same situation in the North Atlantic.

Conclusions – trends and future research directions

The role of the Emperor Chain of seamounts and guyots (as part of the Emperor-Hawaiian Chain) in the distribution of corals in the northern Pacific Ocean can be very significant due to its extended length to the north in the meridional direction. Individual seamounts are believed to form biogeographic patterns and gradients of biodiversity, acting as "stepping stones" for settling species, like refugia or deep-sea speciation centers (O'Hara, Tittensor, 2010). However, it is still unclear how significant the connection between the neighboring mountains is. Genetic studies of fish fauna and free-living macrobenthos of seamounts have shown insignificant isolation (and even its complete absence) between neighboring mountains. However, for sedentary bottom organisms, both a high degree of isolation in some species and a high degree of genetic similarity in other representatives of benthos were revealed (Samadi et al., 2007; Cho, Shank, 2010; Tunnicliffe et al., 2010). The degree of interconnection between the faunas of neighboring mountains ultimately turns out to be specific species-specific and significantly depends on oceanographic conditions – especially currents that determine the range and distribution paths (Cho, Shank, 2010; Tunnicliffe et al., 2010). The use of ROV not only provides the opportunity for gentle non-contact monitoring of bottom communities, but also increases the possibility of targeted collection of bottom organisms. Conducting comprehensive hydrobiological studies of VMEs (along with hydrophysical, geological, and other works) in the area of the chain is urgently needed as soon as possible for study and conservation measures. It is extremely important to expand the data we obtained on the coral biodiversity of this region and compare them with the data on the current system that exists here. This possess new data on

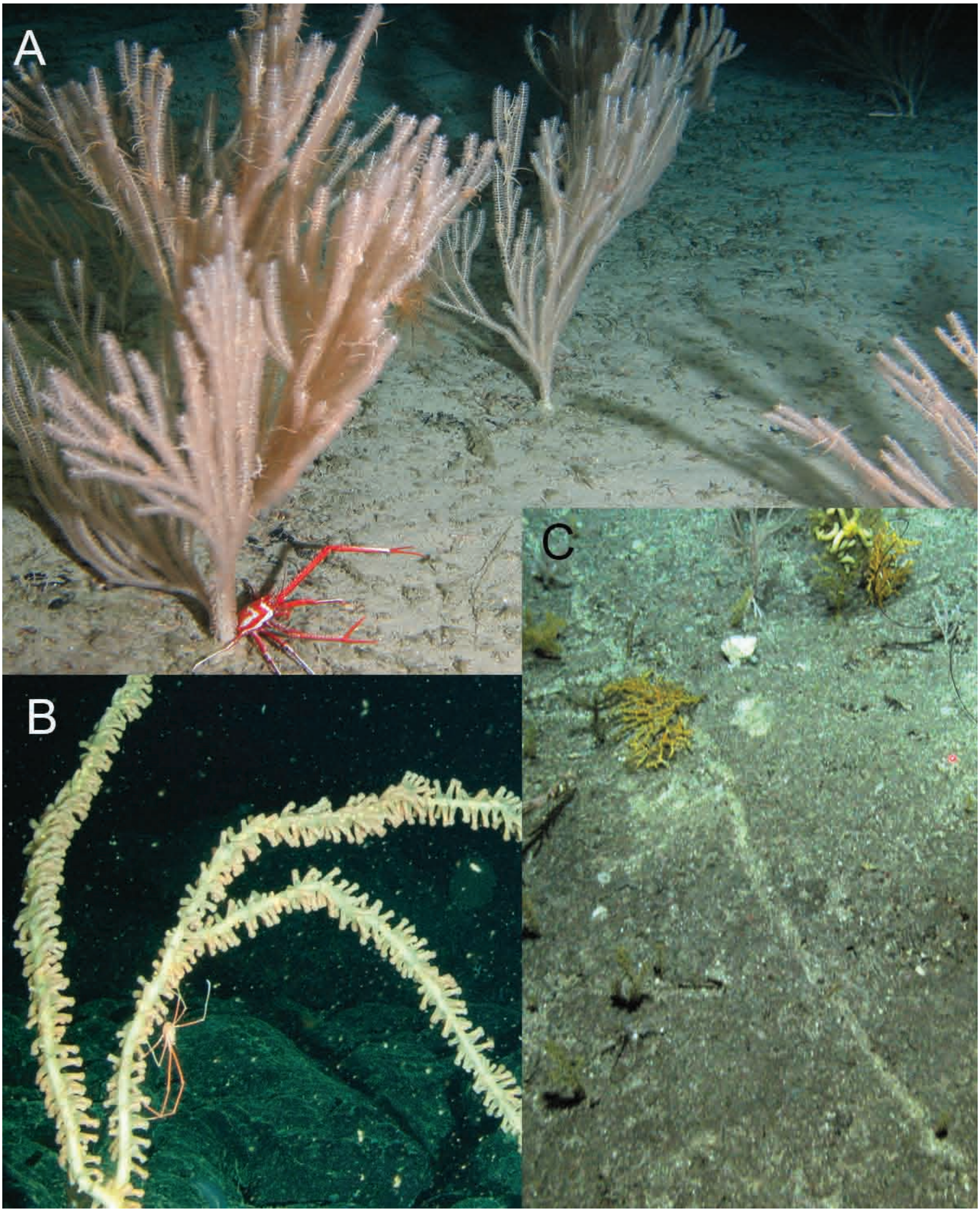

Fig. 5. Protecting role of Octocorallia. **A**. Crab among the *Narella* gorgonians, Koko, 380 me depth. **B**. Crab on the bamboo coral. Koko, 1431 m depth. **C**. Traces of trawls on calcareous hard substrata. One gorgonian *Isidella* is broken.

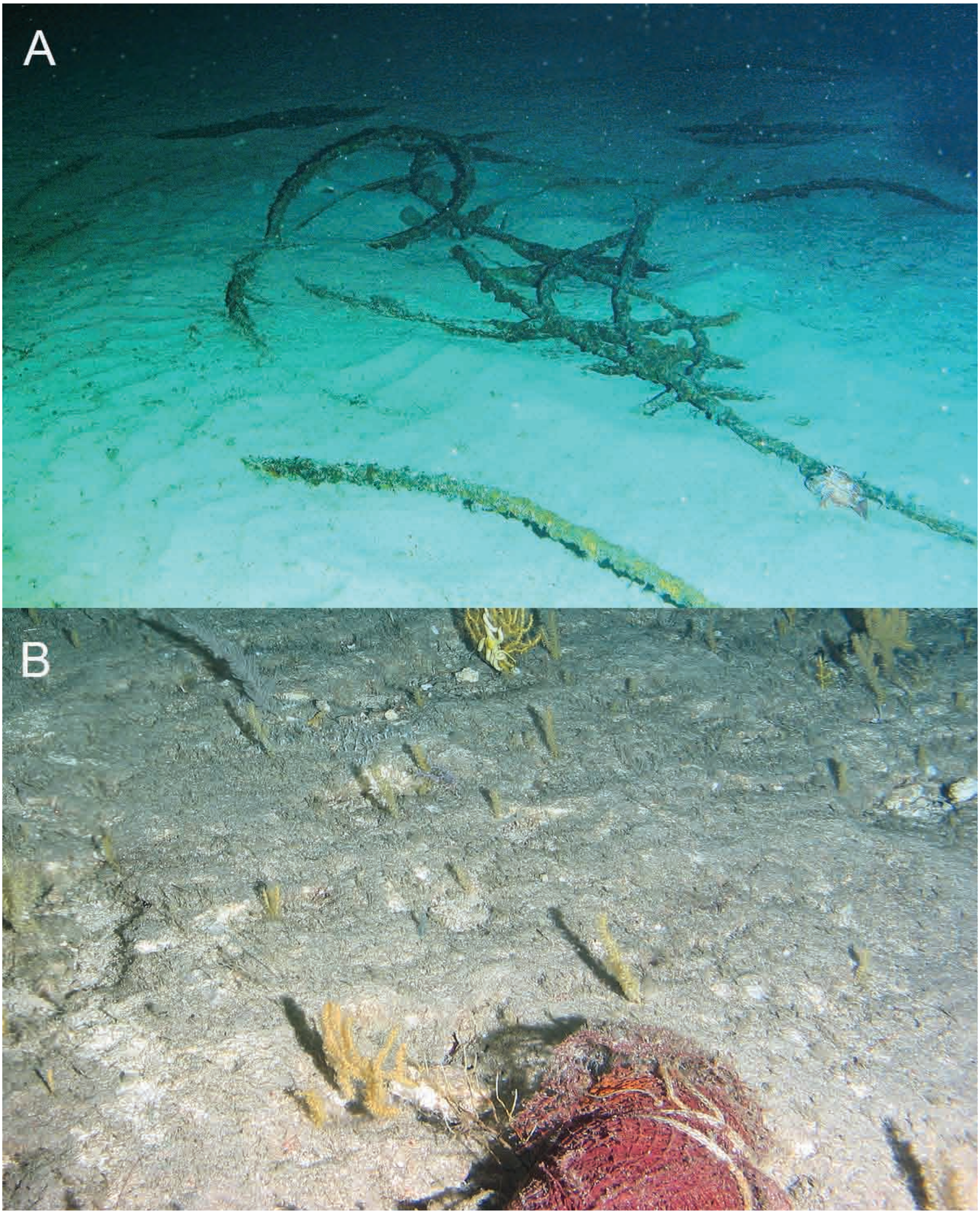

Fig. 6. Consequences of anthropogenic (fishery) activities noted at the Emperor Chain during the expedition (July–August 2019, RV *Akademik M.A. Lavrentiev*). Anthropogenic garbage. **A**. Metal cable, Koko, 760 m depth. **B**. Old fishery net, Koko, 380 m depth.

the biodiversity of the bathyal communities in the high seas of the North Pacific. It makes a significant contribution both to the work of the NPFC and to international scientific cooperation, and to the solution of food problems in the region.

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A large-scale multidisciplinary expedition organized to the Emperor Chain (Nothwestern Pacific) by the A.V. Zhirmunsky National Scientific Center of Marine Biology FEB RAS (Vladivostok, Russia) was held in July–August 2019. The expedition, financially supported by the Ministry of Science and Higher Education of the Russian Federation, was carried out with the participation of a number of institutes of the RAS and Far East Federal University. The main goals were planned in order to comprehensively study the vulnerable marine ecosystems (VMEs) of the Chain – their biodiversity, communities, geological, hydrological and geochemical characteristics in a wide geographical range. Research methods included collecting and video filming using the remotely operated vehicle Comanche 18. The deep-water corals Octocorallia, recognized in the area as the indicator benthic taxa of VMEs, showed differences in their diversity and distribution between the southern part of the Chain (guyot Koko, with tropical and subtropical deep-water corals) and the northern guyots. The intermediate position of the guyots Ojin and Jingu (with their mixed northern/tropical Octocorallia fauna, 37.5° N to 39° N) encourages implying a biogeographic boundary between the boreal and the West Pacific biogeographic areas. Traces of trawls and anthropogenic trash found in a number of areas should stimulate further studies of the chain' VMEs for the rational fishery and conservation measures.

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