

## 論文内容要旨

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The ecology of fishes in areas of mining interest: results from ROV surveys and machine learning

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### 要 旨

The future of renewable energy and electronics manufacturing will require millions of tons of rare earth metals, and rising demand has increasingly turned attention to ocean resources. Mineral deposits in the ocean fall into three categories: polymetallic sulfides, polymetallic nodules, and manganese crusts. Polymetallic sulfides result from hydrothermal activity when seawater is superheated by magma. The minerals, including copper sulfides, gold, and silver, in the surrounding rock are leached out and expelled, where they precipitate back out of the seawater to form hydrothermal vent chimneys. Polymetallic nodules and manganese crusts are formed as metals, including manganese, cobalt, nickel, and rare earth metals, precipitating from seawater onto a substrate. Mining polymetallic sulfide deposits will release toxic metal sulfides into the water. Mining polymetallic nodules will release sediment plumes that spread for tens of kilometers to suffocate animals, lower light availability, interrupt bioluminescent signaling, and alter the water chemistry. Before large-scale deep-sea mining occurs, it is imperative to conduct environmental baseline surveys within potential mining areas so the effects of deep-sea mining can be properly assessed and managed. This work assesses the pre-disturbance fish fauna of two areas with mineral deposits: the Kurose Hole (Japan) and NORI-D (Clarion-Clipperton Zone). Because this is a pre-disturbance baseline assessment, non-destructive survey methods are essential. This survey uses Remotely Operated Vehicle (ROV) video to quantify the fishes living

The Kurose Hole is a semi-closed caldera located within the Izu-Bonin Island Arc, which possesses polymetallic sulfides at its base. The Kurose Hole has been surveyed three times: twice in September and October 2000 aboard the 'Natsushima' expedition and once in December 2020 aboard the 'Kaimei' expedition. During the 'Natsushima' expedition, the water temperature at the base of the caldera was 11.4°C while the temperature outside of the caldera was 4°C, and few fishes were observed. During the 'Kaimei' expedition, the water temperature at the base of the caldera was 17.9°C at 790 m depth, and the caldera was dominated by thousands of usually-solitary viperfishes (genus *Chauliodus*). This caldera possesses the highest density of viperfishes in the world with 6.7 viperfish observed per 100m<sup>3</sup> within the benthic boundary layer; previous trawl surveys in the Boso Peninsula only reported 0.001 viperfish per 100m<sup>3</sup>. All viperfish and dragonfish captured during the 'Kaimei' expedition were juveniles. One *Chauliodus sloani* was captured within the ROV suction sampler which possessed a combination of morphological characteristics that are distinct, but most closely match other *Chauliodus sloani* observed in the Indo-Pacific. A juvenile rover in the genus *Emmelichthys* was also captured in the ROV suction sampler which possessed distinct morphological characteristics that do not match any other described species. The semi-closed rim likely caused this localized aggregations by trapping the fishes inside as they transformed from larvae into juveniles. The 'Natsushima' expedition reported a gravid population of the hydromedusa *Earleria brunii* as the dominant midwater taxon; these highly localized aggregations within the Kurose Hole should be further studied to determine how mining could affect them in the future.

NORI-D is a mining license area within the eastern Clarion-Clipperton Zone which contains the

largest nickel deposit in the world in the form of polymetallic nodules. Mining polymetallic nodules would release a sediment plume on the seafloor and one in the midwater at 1,500 m depth. Despite the release of a sediment plume within the midwater, no midwater baseline surveys have ever been conducted within the CCZ. During the pilot mining collector test, there was also an incident where surface wastewater discharge went overboard from the mining vessel, further underscoring the need for subsurface and midwater baseline surveys. In two ROV surveys in 2021, one in spring and one in winter which surveyed the proposed mining site (CTA) and a nearby reserved site (PRZ), I found that commercially important fishes, including tuna, are present and reproducing in NORI-D, which could affect our food supply and increase metal concentrations in our food. Midwater fish distribution was heavily dependent on dissolved oxygen concentration; the oxygen minimum zone (OMZ) within NORI-D ranges between 300-800 m depth depending on location and season, with oxygen concentrations less than 0.05 ml/L. Many midwater species were observed within the lower oxycline, but almost none (only the unidentified barracudina in the family Parapidae, Melamphaidae morphospecies 'white', hatchetfishes in the family Sternoptychinae, and the lightfish *Vinciguerria* spp.) were observed within the OMZ. NORI-D is known to have anticyclonic eddies originating in Central America, with one passing through during the spring survey. This anticyclonic eddy made it difficult to determine the seasonal changes between spring and winter, however it also highlighted an additional risk and could disperse mining wastewater and sediment further from its origin. The most speciose group of fishes within NORI-D were benthic cusk eels (family Ophidiidae) with five unknown, possibly novel, morphospecies observed. Before mining commences, these morphospecies should be identified or described to fully understand the effect of mining on benthic species. The diversity of the benthic fish community was higher in the reserved PRZ compared to the mining area CTA, indicating that the PRZ is a good reserved site for fishes from polymetallic nodule mining.

Using fish behavior to examine the effect of dissolved toxins has been proposed as an addition to wastewater discharge monitoring and ecotoxicological research. Exposure to heavy metals has been shown to affect the behavior of fishes even at concentrations far below the median lethal concentration. Because the behavior of many deep-sea fishes is unknown, I recorded the swimming and resting behavior of fishes within NORI-D. I found that the lightfish *Vinciguerria* sp. is positively phototactic and will be attracted to the lights of the mining vessel and may be disproportionately affected by surface discharge. Dissolved oxygen concentrations affected the overall activity level of ridgeheads (family Melamphaidae), with more fish swimming in higher oxygen concentrations. Moreover, depth and dissolved oxygen concentrations had an effect on the direction of swimming, with the average depth for fishes swimming down (average= 444 m) and the average oxygen concentration (average=0.20 ml/L) for fishes swimming down being shallower and lower when compared to fishes swimming up or horizontally. This behavior likely relates to the OMZ, with fishes within the OMZ swimming downward into higher dissolved oxygen. Midwater fishes typically rest with the eyes facing upward to hunt, looking for the shadow of their prey against downwelling light. This survey identified several species (the blackchin *Scopelengys tristis* and ridgeheads in the family Melamphaidae) which prefer to rest with the head facing downward, while others (including sawtooth eels in the family Serrivomeridae and snipe eels in the family Nemichthyidae) were observed resting head upward and head downward. By facing head downward rather than head upward, prey looking upward may not recognize the diminished shadow as a potential predator hunting from above. Moreover, bioluminescent signals released by their prey are easier to see against a darker background when the fish is facing downward. I also propose that fish behavior can be used for *in-situ* identification. Ridgeheads are the only midwater fish which use labriform swimming, and the rigid vertical behavior of sawtooth eels helps differentiate them from snipe eels.

The volume of data generated from ROV surveys can overwhelm researchers. This work alone analyzed over four hundred and fifty hours of video data. Deep-learning models can decrease video processing time and increase data processing efficiency, with some models having over 90% accuracy. I used two types of deep-learning models on data collected from the Kurose Hole and NORI: image classification models, which differentiate between cropped images of fish, and image segmentation, which identify and count the fish in an uncropped image. I used and compared the image classification models ResNet50v2, ResNet152v2, InceptionV3, and Inception-ResNet. These four models were pretrained on the standard image dataset ImageNet, and I also used an InceptionV3

model trained on data from the popular app iNaturalist. I used the image segmentation model YOLOv5, which was also pretrained on ImageNet. Image datasets created from the Kurose Hole included uncropped and cropped images of the most abundant species (including *Chauliodus*, the black dragonfish Melanostomiinae, and shrimp in the family Pasiphaeidae), and eleven other commonly observed fishes (including the alfonsino *Beryx decadactylus*, the slimehead *Hoplostethus crassispinus*, snipe eels in the family Nemichthyidae, the Japanese armorhead *Pentaceros japonicus*, the oilfish *Ruvettus pretiosus*, spiny dogfish in the genus *Squalus*, cutthroat eels in the family Synphobranchidae, the trapezoid torpedo ray *Tetronarce tokionis*, the snake mackerel *Thyrsooides marleyi*, the Japanese horse mackerel *Trachurus japonicus*, and cutlassfishes in Trichiuridae). For NORI-D, I included uncropped and cropped images of nineteen bathypelagic species including gelatinous animals (the rhopalonematid jellyfish *Arctapodema*, the narcomedusa *Bathychorus*, and larvacen tunicates in the family Oikopleuridae), polychaete worms (the flabelligerid *Flota*, scale worms in the family Polynoidae, and the bomber worm *Swima*), other invertebrate predator/scavengers (shrimp in the family Aristeidae and the cirrate octopus *Grimpoteuthis*) and the fishes (the cusk eels *Barathrites iris*, *Bassozetus nasus*, *Bassozetus* sp. B, *Bathyonus caudalis*, *Leucicorus*, Ophidiidae cf *Holcomycteronus*, Ophidiidae morphospecies 1, and Ophidiidae morphospecies 3, the highfin lizardfish *Bathysaurus mollis*, the grenadier *Coryphaenoides*, and the grideye *Ipynops meadi*). Image classification and image segmentation datasets were trained on the same annotations. Across all cropped image datasets, ResNet50 and ResNet152 consistently outperformed InceptionV3, the inceptionV3 trained on iNaturalist data, and Inception-ResNet. All models were able to learn and differentiate between the eleven fishes in Kaimei and the nineteen bathypelagic species in NORI-D. Neither the image segmentation or image classification models could identify and differentiate between *Chauliodus*, Melanostomiinae, and Pasiphaeidae. In the future, the performance of these models can be improved upon by using models pre-trained on in-situ data and by subtracting the background. Environmental monitoring surveys conducted during mining using Autonomous Underwater Vehicles (AUVs) can use these models to identify species impacted by mining in addition to monitoring sedimentation and dissolved metal concentrations.