Title

Measures for co-existence between seals and coastal large-scale salmon set net fisheries: mitigation of catch damage by the use of rope grid

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Abstract

In recent decades, conflict between Kuril harbor seals (*Phoca vitulina stejnegeri*) and local fisheries have become a serious problem in Hokkaido, northern Japan. Catch damage in large-scale salmon set nets may be mitigated by attaching a rope grid to set net funnels. We investigated the effectiveness of different rope grids on catch damage caused by seals, and evaluated hidden impacts on catch caused by the seals using an underwater camera for observation of seal and salmon behavior coupled with on-board observations of catch and catch damage. The rate of seal prevention was highest for rope grid with 20 cm × 20 cm spacing (97.5%). The percentage of catch damage in the set net with this rope grid was significantly lower than that for the set net with other rope grid which was easy to enter for seals. We concluded that it is effective to attach an appropriate rope grid to set nets to prevent seals from entering fish bags and to ensure salmon catch amounts. The existence of "hidden damage" was quantitatively revealed via the underwater observation of seals removing salmon from the fish bag, and by comparing the number of salmon between underwater observation and on-board observation.

Key words

Kuril harbor seal, seal prevention, hidden impact, underwater observation, on-board observation

Main text

1. Introduction

In recent decades, conflicts between seals and fisheries in terms of both catch damage caused by seals and bycatch of seals have been reported on a global scale (e.g., Westerberg et al., 2006; Güçlüsoy, 2008; Lundström et al., 2010; Butler et al., 2011; Bruckmeier et al., 2013; Cronin et al., 2014; FAO, 2021). In Japan, the Kuril harbor seal (*Phoca vitulina stejnegeri*) and the local coastal fisheries have been in conflict, which has led stakeholders to seek out measures for co-existence. The Kuril harbor seal is distributed in the eastern Pacific coastal region in Hokkaido, in northern Japan (Kobayashi, 2015). The estimated seal population in this region in the 1940's was between 1,500 and 4,800 individuals. The population declined rapidly until the 1970's due to overhunting and habitat loss (Itoo and Shukunobe, 1986). The number of individuals has increased since the 1980's, when seal hunts became fewer. During the molting season of 2008, the number of counted individuals reached 1,089 (Kobayashi et al., 2014). The current status of the Kuril harbor seal in Japan is evaluated as Near Threatened (NT) on the Japanese Red List of threatened species (Ministry of the Environment, 2016b).

The population of the Kuril harbor seal has also been increasing since the 1980's around Cape Erimo in south eastern Hokkaido, where approximately 50% of the Japanese population exists (Matsuda et, al., 2015). The Cape Erimo population is genetically distinct from the eastern Hokkaido population (Nakagawa et al., 2010; Mizuno et al., 2018; Mizuno et al., 2020). In 2016, the population of the Cape Erimo seals was estimated to be approximately 1,000 individuals (Ministry of the Environment, 2016a).

With the recovery of the seal population, the amount of seal-induced catch damage in large-scale salmon set nets has increased. These salmon set nets target chum salmon (*Oncorhynchus keta*), pink salmon (*Oncorhynchus gorbuscha*), and cherry salmon (*Oncorhynchus masou*) in spring and chum salmon in autumn. At its highest, the catch damage accounts for 15% of the total catch per annum (Masubuchi et al., 2017). The reported economic loss due to catch damage was approximately 63 million yen (4.5 million euro) in 2014 (Ministry of the Environment, 2016b). Additionally, hidden damage must also be taken into consideration. Fjälling (2005) showed that the traditional method of assessing losses by counting the remains of fish underestimates losses by 46%, which increases the economic loss due to seals substantially.

To mitigate the economic losses and ensure the sustainability of the seal population, the Ministry of the Environment, which is responsible for wildlife management, developed a Kuril harbor seal management plan in 2014. Under this plan, the Kuril Harbor Seal Science Committee was created, which is composed of marine science experts. The plan also created the Kuril Harbor Seal Management Council, which is composed of local stakeholders. Together these groups were established to begin finding solutions for co-existence between the seals and local fisheries.

To achieve co-existence on-the-ground, accurate damage states need to be determined, in order to create mitigation measures that are applicable to the local context. In the region around Cape Erimo, the seal-induced damage has been mostly reported as a form of catch damage in the fish bag, not as the gear damage. Likewise, minimal catch damage to the entrance of the set net has been reported. Thus, the fishing gear could be more effective if the seals were prevented from entering the fish bag, while mitigation methods aimed at stopping the salmon from entangling in net or improving the netting material are less likely to be beneficial, in contrast to what has been recommended for other regions (e.g., Lunneryd et al., 2003; Kauppinen et al., 2005). One successful method to prevent seals from entering the fish bag includes equipping a wire grid to the funnel; this method has been effective in reducing catch damage during earlier studies (Lehtonen and Suuronen, 2004; Suuronen et al., 2006). The set nets used around Cape Erimo are larger than the set nets used in these studies, making this wire grid method inapplicable to this region (i.e., the fish bag is approximately two times longer (30 m), 1.2–2 times wider (12 m), and 2–3 times deeper (12 m), and the entrance is approximately 2 times longer and wider (2 m)). It is not appropriate to install such a strong wire grid to the funnel, because it inevitably becomes heavy, which can lower catch efficiency in terms of both workability and salmon catch under the strong coastal currents and waves. A rope grid constructed from soft, light and strong material may be a better alternative to mitigate catch damage in this region (Fujimori et al., 2018), although attaining tension in a soft material may be difficult, and may consequently obstruct salmon from entering the fish bag.

In this study, we investigated the effectiveness of different types of rope grids as damage mitigation measures and also evaluated the hidden impacts on catch by seals via underwater camera observation of seal and salmon behavior coupled with on-board observation of catch and catch damage. Our goal was to develop measures for the co-existence between seals and coastal large-scale salmon set nets.

2. Materials and methods

All research was conducted on the salmon set nets closest to Cape Erimo (Figure 1). Figure 2A shows the basic structure of the set net. The set nets of this type are placed at inshore and offshore in a row in the permitted area shown in Figure 1.

Observations occurred during spring salmon fishing season (May–July) from 2015 to 2018. We tested six different types of rope grids made from white Dyneema (3 mm diameter), which we attached to the entrance (end of funnel) of the fish bag (Figure 3). Table 1 shows the experimental period for each rope grid. In 2015, rope grid type S1 (20 cm × 20 cm square-shaped grid) and type S2 (40 cm × 20 cm square-shaped gird) were tested as offshore nets. In 2016, type S1 was tested offshore, while type S2 and type S3 (25 cm × 25 cm square-shaped grid) were tested as inshore nets. In 2017, type S1 was tested offshore and type F1 was tested inshore (20 cm × 20 cm spacing with funnel structure net; i.e., a funnel structure net was attached in center of the rope grid; 4 × 4 meshes with 80 cm × 80 cm of spacing were cut as space for the entrance of this net, and the exit spacing was 25 cm × 25 cm). In 2018, type D (20 cm × 20 cm diamond-shaped grid) was tested offshore and type F2 was tested inshore (similar structure as type F1, but the entrance spacing of the funnel was 120 cm × 120 cm). While the objective of attaching F1 and F2 was mainly to capture seals in the fish bag for the purpose of mitigating catch damage by removing specialist seals per the seal management plan, we used the set net for the purpose of comparison, since the seals could easily enter it.

The appearance and behavior of seals and salmon were recorded by underwater observation. The underwater camera (GoPro Hero 3+, GoPro, Inc.) was hung at a depth of 3.5 m from the surface net, which allowed seal and salmon behavior around the funnel to be observed from inside the fish bag during the 2015 and 2016 test periods (Figure 2B). The camera was stored in waterproof housing (SVH-HERO3-100, NTF

Corporation) attached to an external battery to enable long-duration video recording from early morning immediately after the fish bag was lifted to sunset. The camera and battery were changed each time the fish bag was lifted. The frame rate of the video recording was 30 fps. In addition, the amount of salmon catch and catch damage were recorded by on-board observation. Each count was taken at the inshore and offshore nets by research staff during the 2016 to 2018 test periods. We counted three salmon species (chum salmon, pink salmon and cherry salmon) as “salmon” during observations, as it was difficult to classify them correctly.

In this study, we counted the number of seals that passed through the rope grid and the number of seals that turned back (including both seals that failed to pass through the rope grid and seals that did not try to enter the fish bag) via the underwater video. Since it was difficult to identify all the individual seals that appeared, to determine the effectiveness of the rope grid on the seals, the rate of seal prevention (P) was calculated by:

$$P(\%) = T_h/N_h \times 100 \tag{1}$$

where T_h is the number of events that seals turned back and N_h is number of events that seals appeared (the sum of the number of events that seals passed through the rope grid and the number of events that seals turned back).

We also counted the number of salmon that passed through the rope grid and the number of salmon that turned back. Since it was difficult to eliminate duplicate counts of the number of salmon due to multiple visits by the same school, to determine the effectiveness of the rope grid on the salmon, the rate of events that salmon that turned back (T) was calculated by:

$$T(\%) = T_s/N_s \times 100 \tag{2}$$

where T_{s} is the number of events that salmon turned back and N_{s} is the number of events that salmon appeared (the sum of the number of events that salmon passed through the rope grid and the events that salmon turned back).

All statistical analyses were performed with R version 4.0.0 (R Foundation).

3. Results

3.1. Behavior of seals and salmon observed by underwater camera

We obtained clear underwater images with our camera for 8 days at the offshore set net in 2015 and 6 days at the offshore and inshore set net in 2016 (Figure 4). The total recording time for each rope grid type (S1, S2 and S3) were 6,567 minutes, 4,215 minutes and 3,301 minutes, respectively. The reason for the limited number of successful recordings compared to the total days in the test period was a lack of clear images that captured the full view of the rope grid, which was due to high water turbidity caused by phytoplankton and high tide speeds. The total number of events that seals appeared during recording time for each rope grid type (S1, S2 and S3) were 569, 567 and 795, respectively. The total number of events that salmon appeared during recording time for each rope grid type (S1, S2 and S3) were 622, 155 and 74, respectively.

The highest seal prevention rate by rope grid was 97.5% for rope grid S1. The seal prevention rate of rope grids S2 and S3 were 10.6% and 46.7%, respectively. There was a significant difference in the seal prevention rate of each rope grid ($p < 0.05$, Fisher's exact test).

The highest rate of events that salmon turned back due to the rope grid was 68.3% for rope grid S1. The rate of events that salmon turned back for rope grids S2 and S3 were 52.9% and 39.2%, respectively. There was a significant difference in the rate of events that salmon turned back for each rope grid ($p < 0.05$, Fisher's exact test).

3.2. Share of catch and catch damage, and "hidden damage" by seals

During the 2016 to 2018 test periods, we compared the percentage of catch damage to the sum of total catch and total catch damage during each test period among the different types of rope grids. There was no significant difference found in the percentage of catch damage between the offshore set net with rope grid S1 (4%) and the inshore set nets with rope grids S2 (3%) and S3 (5%) in 2016. The percentage of catch damage in the offshore set net with rope grid S1 (4%) was significantly lower than the inshore set net with rope grid F1 (30%) in 2017. The percentage of catch damage in the offshore set net with rope grid D (4%) was significantly lower than the inshore set net with rope grid F2 (22%) in 2018 (Table 2; $p < 0.05$, Fisher's exact test).

In 2016, we compared the number of salmon that passed through the rope grid with the number of salmon (sum of the salmon catch and damage) at the same set net on the following day to evaluate impacts on salmon catch as "hidden damage" by seals (Table 3). The sum of the salmon catch and catch damage for the inshore rope grids S2 and S3 (in total; S2: 5, S3: 13) were much less than the number of salmon that passed through the rope grid (in total; S2: 391, S3: 195). The percentage of salmon catch and catch damage to the number of salmon that passed through the rope grid were significantly different among the rope grids (62.0% for rope grid S1; 1.3% for rope grid S2; and 6.7% for rope grid S3) ($p < 0.05$, Fisher's exact test). The maximum number of salmon that seals caught from the fish bag per day for each rope grid type (S1, S2 and S3) recorded by the underwater camera were 0, 23, 36 respectively. Salmon behavior during exit from the fish bag was not observed.

4. Discussion

We showed that the rope grids that prevent seals from entering the fish bag can reduce the percentage of the catch damage. The rope grids S1 and D (20 cm spacing) which can prevent seals reduced the percentage of catch damage compare to the rope grids F1 and F2 which were easy to enter for seals. It was determined that rope grid S1 successfully prevented seals from entering the fish bag. In fact, almost all (97.5%) seals were prevented from entering the fish bag when rope grid S1 was used; however, there was still catch damage in the set net when rope grid S1 was attached, which means that small size seals were still able to enter the fish bag. On the other hand, the rate of events that salmon turned back was 68.9% for rope grid S1, which was higher than for the other rope grids.

The existence of hidden damage was quantitatively revealed via the underwater observation of seals removing salmon from the fish bag, and by comparing the number of salmon between underwater observation and on-board observation. This clearly shows that the reported amount of catch damage is underestimated. The percentage of caught salmon per number of observed salmon that passed through the rope grid was higher in the fish bag with rope grid S1 than in those with rope grid S2 and S3. This difference is thought to be caused by events occurred during the night that could not be observed in this study. During the nighttime, S1 may have prevented seals from taking salmon away from the fish bag, or may have hindered salmon from leaving the fish bag, or both. Based on the findings from the previous study that revealed seals appeared in the fish bag frequently from evening to night by the acoustic camera observation (Fujimori et al., 2018), it is possible that the damage by seals in the fish bag with rope grid S2 and S3 were extremely high during nighttime. Based on these results, we determined that rope grid S1 can mitigate hidden damage. To reduce the amount of hidden damage, seals could be allowed to learn that they cannot enter the fish bag when a rope grid is attached. Further research for quantifying hidden damage is required, since seal and salmon behavior in the fish bag at night was not recorded by the underwater camera, and because the impact of the existence of seals on the salmon around the set net was not evaluated.

The use of a rope grid with the fish bag is one of the most important measures for the co-existence between seals and local salmon set net fisheries, because this measure simultaneously ensures the viability of the seal population and the sustainability of the local fisheries. Co-existence is particularly important since the Kuril harbor seals are listed as NT on the Japanese Red List of threatened species (Ministry of the Environment, 2016b), and because the Erimo seals are genetically distinct from the eastern Hokkaido seals (Nakagawa et al., 2010; Mizuno et al., 2018; Mizuno et al., 2020). This measure also mitigates the impacts of set net on the seal population, given the fact harbor seal by-catch in the salmon set nets in eastern Hokkaido have been reported (Haneda et al., 2017).

The rope grid that prevented seals from entering the fish bag, also became an obstacle for the salmon. One method to combat this issue could be the use of a colored rope that is less visible to salmon, which should increase the rate of salmon that successfully pass through the rope grid. It has been previously reported that the grid’s color and contrast may play a marked role in capture efficiency (Suuronen et al., 2006).

Masubuchi et al. (2019) showed that many yearling seals, not just adult seals, were visiting and staying at the set nets around Cape Erimo. Fujimori et al. (2018) suggested that a grid size of 15 × 15 cm would prevent seal invasions into the set net based on observations made by acoustic camera of seal size in the area. Suuronen et al. (2006) suggested that wire-grid spacing would need to be less than 18 cm to prevent young grey seals, and that it is not possible to completely prevent the passage of the smallest grey seals (typically pups) through the wire-grid, unless the wire-spacing would be perhaps less than 15 cm. Such a narrow grid spacing should only be tested on set nets with extremely high catch damage, since it could greatly reduce the rate of salmons that pass through the rope grid.

When considering the co-existence between seals and local fisheries in this region, it is important to apply multiple seal prevention measures, such as rope grids and acoustic deterrent devices (Fjälling et al., 2006; Graham et al., 2009; Harris et al., 2014; Götz and Janik, 2016). It would also be beneficial to capture specialist seal individuals (Lehtonen and Suuronen, 2010; Königson et al., 2013), since these seals are likely to shift their target set net when they can no longer gain access to a certain set net, and would consequently expand the area where damage occurs. Varjopuro (2011) suggested that the role of technology is critical in the seal-fishery controversy, and also suggested that fisheries must adapt to the new environment. It is expected that technological measures will improve and local fisheries will adapt to co-existence by building consensus among stakeholders by utilizing the Kuril Harbor Seal Science Committee and the Kuril Harbor Seal Management Council.

CRediT authorship contribution statement

Yosuke Kuramoto: Conceptualization, Formal analysis, Investigation, Writing - Original Draft. **Yasuzumi Fujimori**: Conceptualization, Writing - Review & Editing, Supervision, Project administration. **Ryohei Ito**: Formal analysis, Investigation. **Yumi Kobayashi**: Investigation, Writing - Review & Editing. **Yasunori Sakurai**: Conceptualization, Writing - Review & Editing, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Figure captions

Figure 1. Location of the experimental salmon set net in this study. In the right panel, the grey squares indicate the permitted areas of the nets owned by different entities, and the set nets are placed inshore and offshore within each of these areas.

Figure 2. (A) Outline of the large-scale salmon set net used in this study. (B) Schematic view of the underwater camera hung from the surface net of the fish bag.

Figure 3. Schematics of the rope grid used in the experiment. S1–S3 are square-shaped grids with different opening sizes, and D is a diamond-shaped grid. F1 and F2 have a funnel on S1 for capturing seals.

Figure 4. Example image of a seal prevented from entering the fish bag by a rope grid attached to the end of the funnel.

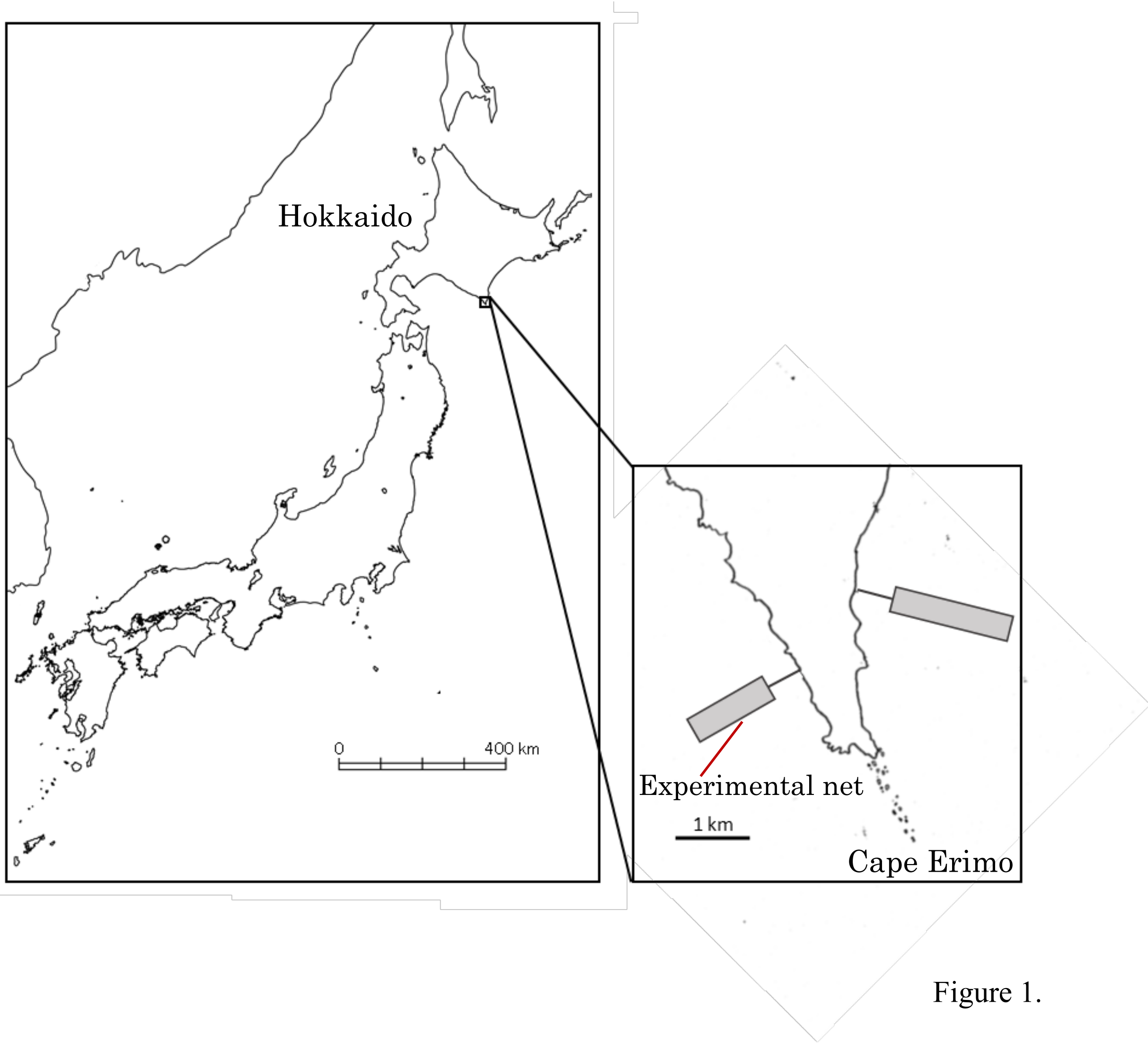

Figure 1.

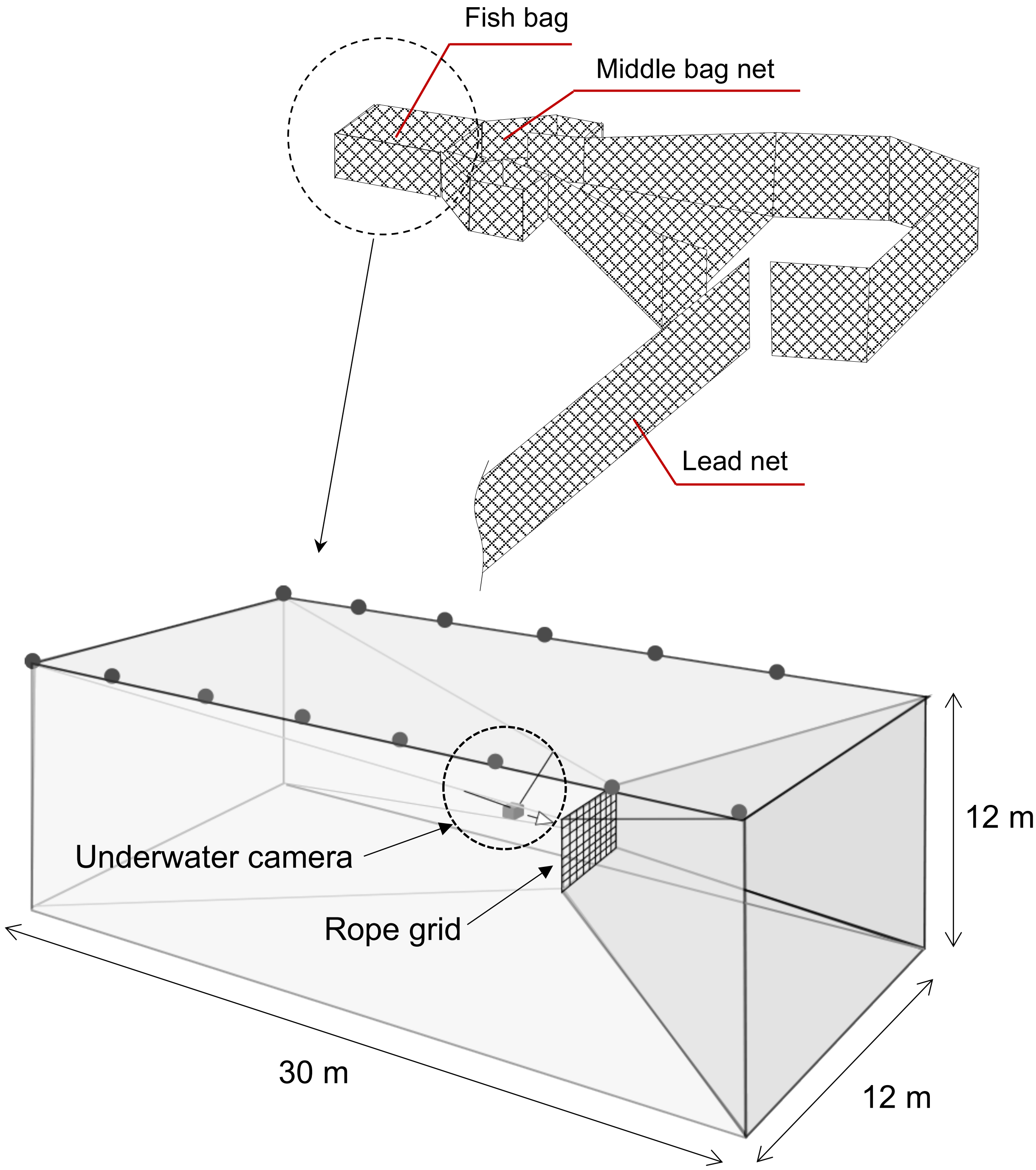
Fish bag
Middle bag net
Lead net
Underwater camera
Rope grid
12 m
30 m
12 m

Figure 2. (A), (B)

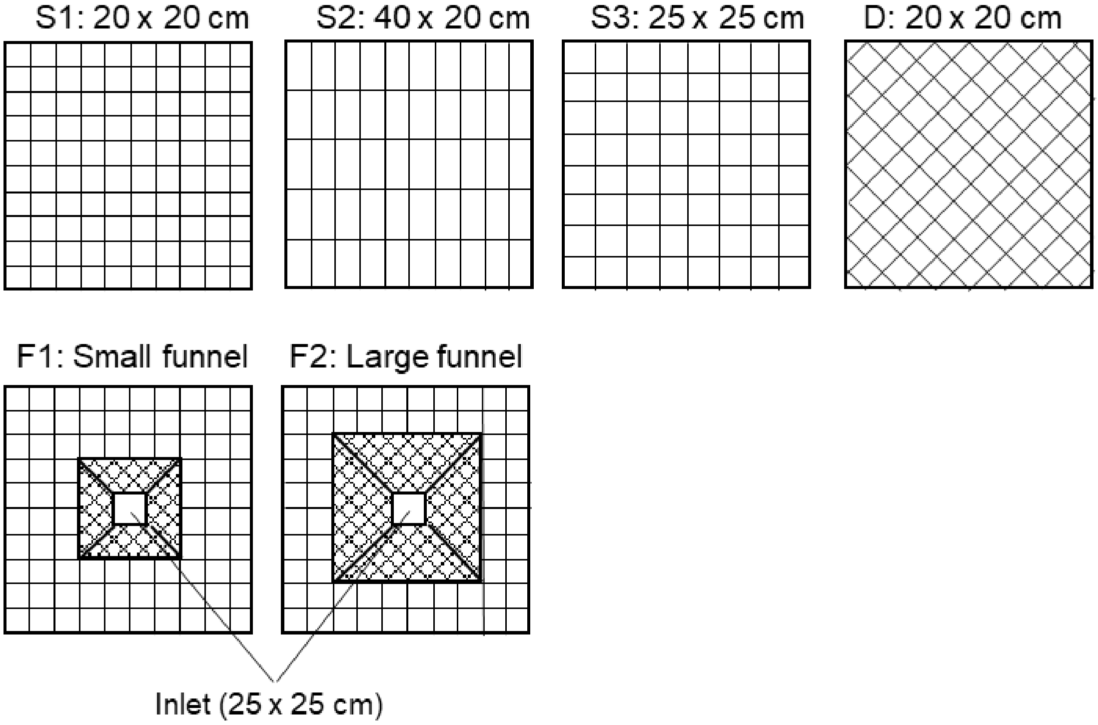
S1: 20 x 20 cm
S2: 40 x 20 cm
S3: 25 x 25 cm
D: 20 x 20 cm
F1: Small funnel
F2: Large funnel
Inlet (25 x 25 cm)

Figure 3.

Figure 4.

Table 1. Experimental period for each rope grid at the offshore and inshore fish bag during 2015-2018.

Time period		Rope grid offshore	Rope grid inshore
2015	5/26–6/26	S1 (5/29–6/8)	
		S2 (5/26–5/28, 6/9–6/26)	
2016	5/19–6/27	S1	S2 (5/19–6/2)
			S3 (6/3–6/27)
2017	5/22–7/1	S1	F1
2018	5/8–6/27	D	F2

Table 2. Total salmon catch, catch damage and share of catch damage in the fish bags with different types of rope grid.

Year	Rope grid type	Lifts	Salmon catch	Catch damage	Catch damage (%)
2016	S1 (offshore)	40	2898	109	4
	S2 (inshore)	17	359	12	3
	S3 (inshore)	23	179	10	5
2017	S1 (offshore)	29	750	33	4
	F1 (inshore)	29	178	76	30
2018	D (offshore)	32	1119	52	4
	F2 (inshore)	32	468	130	22

Table 3. Total number of salmon passed through the rope grid observed by the underwater camera, and total number of salmon in the fish bag (sum of the salmon catch and damage) recorded by on-board observation on the following day. The number of salmon taken away by seals and the number of events that seals appeared were also observed. Recording time shows the length of video data captured.

Net site	Rope grid type	Day	Salmon passed through the rope grid	Salmon in the fish bag on the following day	Salmon taken away by seals	Events that seals appeared	Recording time (minutes)
Offshore	S1	5/30, 31, 6/4, 6, 7, 8	1027	637	0	466	4774
Inshore	S2	5/30, 31	391	5	23	314	1611
	S3	6/4, 6, 7, 8	195	13	70	793	3301