

HOKKAIDO UNIVERSITY

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
Author(s)	Kuramoto, Yosuke; Fujimori, Yasuzumi; Ito, Ryohei; Kobayashi, Yumi; Sakurai, Yasunori
Citation	Fisheries research, 242, 106041 https://doi.org/10.1016/j.fishres.2021.106041
Issue Date	2021-10
Doc URL	http://hdl.handle.net/2115/90619
Rights	This manuscript version is made available under the CC-BY-NC-ND 4.0 license.
Rights(URL)	https://creativecommons.org/licenses/by/4.0/
Туре	article (author version)
File Information	seal-prevention-rope-grid.pdf



1	Title
2	Measures for co-existence between seals and coastal large-scale salmon set net fisheries:
3	mitigation of catch damage by the use of rope grid
4	
5	Authors: Yosuke Kuramoto ^{a,b} *, Yasuzumi Fujimori ^c , Ryohei Ito ^{a,1} , Yumi Kobayashi ^d ,
6	Yasunori Sakurai ^e
7	
8	^a Graduate School of Fisheries Sciences, Hokkaido University, Hakodate, Hokkaido
9	041-8611, Japan
10	
11	^b Ministry of the Environment, Government of Japan, Kasumigaseki 1-2-2, Chiyoda-Ku,
12	Tokyo 100-8975, Japan
13	
14	^c Faculty of Fisheries Sciences, Hokkaido University, Hakodate, Hokkaido 041-8611,
15	Japan
16	
17	^d Faculty of Agriculture, Hokkaido University, Sapporo, Hokkaido 060-8589, Japan
18	
19	^e Hakodate Cephalopod Research Center, Fisheries and Oceans Hakodate, Hakodate,
20	Hokkaido, 040-0051, Japan
21	
22	¹ Present address: NYK LINE, Marunouchi 2-3-2, Chiyoda-Ku, Tokyo 100-0005, Japan
23	
24	* Corresponding author
25	E-mail: ferreedelactee@yahoo.co.jp (Yosuke Kuramoto)

26 Phone and Fax number: +81-138-40-8829

27

- 28 List of e-mail addresses for co-authors
- 29 Yasuzumi Fujimori: fujimori@fish.hokudai.ac.jp
- 30 Ryohei Ito: ryouheiito0713@gmail.com

31 Yumi Kobayashi: kobayumi_kotomasu@hotmail.com

- 32 Yasunori Sakurai: sakurai@fish.hokudai.ac.jp
- 33
- 34

35 Abstract

36 In recent decades, conflict between Kuril harbor seals (*Phoca vitulina stejnegeri*) 37 and local fisheries have become a serious problem in Hokkaido, northern Japan. Catch 38 damage in large-scale salmon set nets may be mitigated by attaching a rope grid to set 39 net funnels. We investigated the effectiveness of different rope grids on catch damage 40 caused by seals, and evaluated hidden impacts on catch caused by the seals using an 41 underwater camera for observation of seal and salmon behavior coupled with on-board 42 observations of catch and catch damage. The rate of seal prevention was highest for 43 rope grid with 20 cm \times 20 cm spacing (97.5%). The percentage of catch damage in the 44 set net with this rope grid was significantly lower than that for the set net with other 45 rope grid which was easy to enter for seals. We concluded that it is effective to attach an 46 appropriate rope grid to set nets to prevent seals from entering fish bags and to ensure 47 salmon catch amounts. The existence of "hidden damage" was quantitatively revealed 48 via the underwater observation of seals removing salmon from the fish bag, and by 49 comparing the number of salmon between underwater observation and on-board 50 observation.

52 Key words

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

55

56 Main text

57 **1. Introduction**

58 In recent decades, conflicts between seals and fisheries in terms of both catch 59 damage caused by seals and bycatch of seals have been reported on a global scale (e.g., 60 Westerberg et al., 2006; Güçlüsoy, 2008; Lundström et al., 2010; Butler et al., 2011; 61 Bruckmeier et al., 2013; Cronin et al., 2014; FAO, 2021). In Japan, the Kuril harbor seal 62 (*Phoca vitulina stejnegeri*) and the local coastal fisheries have been in conflict, which 63 has led stakeholders to seek out measures for co-existence. The Kuril harbor seal is 64 distributed in the eastern Pacific coastal region in Hokkaido, in northern Japan 65 (Kobayashi, 2015). The estimated seal population in this region in the 1940's was 66 between 1,500 and 4,800 individuals. The population declined rapidly until the 1970's 67 due to overhunting and habitat loss (Itoo and Shukunobe, 1986). The number of 68 individuals has increased since the 1980's, when seal hunts became fewer. During the 69 molting season of 2008, the number of counted individuals reached 1,089 (Kobayashi et 70 al., 2014). The current status of the Kuril harbor seal in Japan is evaluated as Near 71 Threatened (NT) on the Japanese Red List of threatened species (Ministry of the 72 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

76 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).

80 With the recovery of the seal population, the amount of seal-induced catch damage 81 in large-scale salmon set nets has increased. These salmon set nets target chum salmon 82 (Oncorhynchus keta), pink salmon (Oncorhynchus gorbuscha), and cherry salmon 83 (Oncorhynchus masou) in spring and chum salmon in autumn. At its highest, the catch 84 damage accounts for 15% of the total catch per annum (Masubuchi et al., 2017). The 85 reported economic loss due to catch damage was approximately 63 million yen (4.5 86 million euro) in 2014 (Ministry of the Environment, 2016b). Additionally, hidden 87 damage must also be taken into consideration. Fjälling (2005) showed that the 88 traditional method of assessing losses by counting the remains of fish underestimates 89 losses by 46%, which increases the economic loss due to seals substantially. 90 To mitigate the economic losses and ensure the sustainability of the seal population, 91 the Ministry of the Environment, which is responsible for wildlife management, 92 developed a Kuril harbor seal management plan in 2014. Under this plan, the Kuril 93 Harbor Seal Science Committee was created, which is composed of marine science 94 experts. The plan also created the Kuril Harbor Seal Management Council, which is 95 composed of local stakeholders. Together these groups were established to begin finding 96 solutions for co-existence between the seals and local fisheries. 97 To achieve co-existence on-the-ground, accurate damage states need to be 98 determined, in order to create mitigation measures that are applicable to the local

99 context. In the region around Cape Erimo, the seal-induced damage has been mostly

100 reported as a form of catch damage in the fish bag, not as the gear damage. Likewise,

101 minimal catch damage to the entrance of the set net has been reported. Thus, the fishing 102 gear could be more effective if the seals were prevented from entering the fish bag, 103 while mitigation methods aimed at stopping the salmon from entangling in net or 104 improving the netting material are less likely to be beneficial, in contrast to what has 105 been recommended for other regions (e.g., Lunneryd et al., 2003; Kauppinen et al., 106 2005). One successful method to prevent seals from entering the fish bag includes 107 equipping a wire grid to the funnel; this method has been effective in reducing catch 108 damage during earlier studies (Lehtonen and Suuronen, 2004; Suuronen et al., 2006). 109 The set nets used around Cape Erimo are larger than the set nets used in these studies, 110 making this wire grid method inapplicable to this region (i.e., the fish bag is 111 approximately two times longer (30 m), 1.2–2 times wider (12 m), and 2–3 times deeper 112 (12 m), and the entrance is approximately 2 times longer and wider (2 m)). It is not 113 appropriate to install such a strong wire grid to the funnel, because it inevitably 114 becomes heavy, which can lower catch efficiency in terms of both workability and 115 salmon catch under the strong coastal currents and waves. A rope grid constructed from 116 soft, light and strong material may be a better alternative to mitigate catch damage in 117 this region (Fujimori et al., 2018), although attaining tension in a soft material may be 118 difficult, and may consequently obstruct salmon from entering the fish bag. 119 In this study, we investigated the effectiveness of different types of rope grids as 120 damage mitigation measures and also evaluated the hidden impacts on catch by seals 121 via underwater camera observation of seal and salmon behavior coupled with on-board 122 observation of catch and catch damage. Our goal was to develop measures for the 123 co-existence between seals and coastal large-scale salmon set nets. 124

125 **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.

129 Observations occurred during spring salmon fishing season (May-July) from 2015 130 to 2018. We tested six different types of rope grids made from white Dyneema (3 mm 131 diameter), which we attached to the entrance (end of funnel) of the fish bag (Figure 3). 132 Table 1 shows the experimental period for each rope grid. In 2015, rope grid type S1 133 $(20 \text{ cm} \times 20 \text{ cm} \text{ square-shaped grid})$ and type S2 $(40 \text{ cm} \times 20 \text{ cm} \text{ square-shaped gird})$ 134 were tested as offshore nets. In 2016, type S1 was tested offshore, while type S2 and 135 type S3 (25 cm \times 25 cm square-shaped grid) were tested as inshore nets. In 2017, type 136 S1 was tested offshore and type F1 was tested inshore (20 cm \times 20 cm spacing with 137 funnel structure net; i.e., a funnel structure net was attached in center of the rope grid; 138 4×4 meshes with 80 cm \times 80 cm of spacing were cut as space for the entrance of this 139 net, and the exit spacing was 25 cm \times 25 cm). In 2018, type D (20 cm \times 20 cm 140 diamond-shaped grid) was tested offshore and type F2 was tested inshore (similar 141 structure as type F1, but the entrance spacing of the funnel was $120 \text{ cm} \times 120 \text{ cm}$). 142 While the objective of attaching F1 and F2 was mainly to capture seals in the fish bag 143 for the purpose of mitigating catch damage by removing specialist seals per the seal 144 management plan, we used the set net for the purpose of comparison, since the seals 145 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

151 Corporation) attached to an external battery to enable long-duration video recording 152 from early morning immediately after the fish bag was lifted to sunset. The camera and 153 battery were changed each time the fish bag was lifted. The frame rate of the video 154 recording was 30 fps. In addition, the amount of salmon catch and catch damage were 155 recorded by on-board observation. Each count was taken at the inshore and offshore 156 nets by research staff during the 2016 to 2018 test periods. We counted three salmon 157 species (chum salmon, pink salmon and cherry salmon) as "salmon" during 158 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:

165
$$P(\%) = T_h / N_h \times 100$$
 (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:

174
$$T(\%) = T_s/N_s \times 100$$
 (2)

175 where T_s is the number of events that salmon turned back and N_s is the number of events

176 that salmon appeared (the sum of the number of events that salmon passed through the

177 rope grid and the events that salmon turned back).

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

179

180 **3. Results**

181 **3.1. Behavior of seals and salmon observed by underwater camera**

182 We obtained clear underwater images with our camera for 8 days at the offshore set 183 net in 2015 and 6 days at the offshore and inshore set net in 2016 (Figure 4). The total 184 recording time for each rope grid type (S1, S2 and S3) were 6,567 minutes, 4,215 185 minutes and 3,301 minutes, respectively. The reason for the limited number of 186 successful recordings compared to the total days in the test period was a lack of clear 187 images that captured the full view of the rope grid, which was due to high water 188 turbidity caused by phytoplankton and high tide speeds. The total number of events that 189 seals appeared during recording time for each rope grid type (S1, S2 and S3) were 569, 190 567 and 795, respectively. The total number of events that salmon appeared during 191 recording time for each rope grid type (S1, S2 and S3) were 622, 155 and 74, 192 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).

197 The highest rate of events that salmon turned back due to the rope grid was 68.3% for 198 rope grid S1. The rate of events that salmon turned back for rope grids S2 and S3 were 199 52.9% and 39.2%, respectively. There was a significant difference in the rate of events 200 that salmon turned back for each rope grid (p < 0.05, Fisher's exact test).

202 **3.2.** Share of catch and catch damage, and "hidden damage" by seals

203 During the 2016 to 2018 test periods, we compared the percentage of catch damage 204 to the sum of total catch and total catch damage during each test period among the 205 different types of rope grids. There was no significant difference found in the percentage 206 of catch damage between the offshore set net with rope grid S1 (4%) and the inshore set 207 nets with rope grids S2 (3%) and S3 (5%) in 2016. The percentage of catch damage in 208 the offshore set net with rope grid S1 (4%) was significantly lower than the inshore set 209 net with rope grid F1 (30%) in 2017. The percentage of catch damage in the offshore set 210 net with rope grid D (4%) was significantly lower than the inshore set net with rope grid 211 F2 (22%) in 2018 (Table 2; p < 0.05, Fisher's exact test).

212 In 2016, we compared the number of salmon that passed through the rope grid with 213 the number of salmon (sum of the salmon catch and damage) at the same set net on the 214 following day to evaluate impacts on salmon catch as "hidden damage" by seals (Table 215 3). The sum of the salmon catch and catch damage for the inshore rope grids S2 and S3 216 (in total; S2: 5, S3: 13) were much less than the number of salmon that passed through 217 the rope grid (in total; S2: 391, S3: 195). The percentage of salmon catch and catch 218 damage to the number of salmon that passed through the rope grid were significantly 219 different among the rope grids (62.0% for rope grid S1; 1.3% for rope grid S2; and 6.7% 220 for rope grid S3) (p < 0.05, Fisher's exact test). The maximum number of salmon that 221 seals caught from the fish bag per day for each rope grid type (S1, S2 and S3) recorded 222 by the underwater camera were 0, 23, 36 respectively. Salmon behavior during exit from 223 the fish bag was not observed.

224

225 **4. Discussion**

226 We showed that the rope grids that prevent seals from entering the fish bag can 227 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 228 229 grids F1 and F2 which were easy to enter for seals. It was determined that rope grid S1 230 successfully prevented seals from entering the fish bag. In fact, almost all (97.5%) seals 231 were prevented from entering the fish bag when rope grid S1 was used; however, there 232 was still catch damage in the set net when rope grid S1 was attached, which means that 233 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 234 235 other rope grids.

236 The existence of hidden damage was quantitatively revealed via the underwater 237 observation of seals removing salmon from the fish bag, and by comparing the number 238 of salmon between underwater observation and on-board observation. This clearly 239 shows that the reported amount of catch damage is underestimated. The percentage of 240 caught salmon per number of observed salmon that passed through the rope grid was 241 higher in the fish bag with rope grid S1 than in those with rope grid S2 and S3. This 242 difference is thought to be caused by events occurred during the night that could not be 243 observed in this study. During the nighttime, S1 may have prevented seals from taking 244 salmon away from the fish bag, or may have hindered salmon from leaving the fish bag, 245 or both. Based on the findings from the previous study that revealed seals appeared in 246 the fish bag frequently from evening to night by the acoustic camera observation 247 (Fujimori et al., 2018), it is possible that the damage by seals in the fish bag with rope 248 grid S2 and S3 were extremely high during nighttime. Based on these results, we 249 determined that rope grid S1 can mitigate hidden damage. To reduce the amount of 250 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.

255 The use of a rope grid with the fish bag is one of the most important measures for the 256 co-existence between seals and local salmon set net fisheries, because this measure 257 simultaneously ensures the viability of the seal population and the sustainability of the 258 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 259 260 Environment, 2016b), and because the Erimo seals are genetically distinct from the 261 eastern Hokkaido seals (Nakagawa et al., 2010; Mizuno et al., 2018; Mizuno et al., 262 2020). This measure also mitigates the impacts of set net on the seal population, given 263 the fact harbor seal by-catch in the salmon set nets in eastern Hokkaido have been 264 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 276 grey seals (typically pups) through the wire-grid, unless the wire-spacing would be 277 perhaps less than 15 cm. Such a narrow grid spacing should only be tested on set nets 278 with extremely high catch damage, since it could greatly reduce the rate of salmons that 279 pass through the rope grid.

280 When considering the co-existence between seals and local fisheries in this region, it 281 is important to apply multiple seal prevention measures, such as rope grids and acoustic 282 deterrent devices (Fjälling et al., 2006; Graham et al., 2009; Harris et al., 2014; Götz 283 and Janik, 2016). It would also be beneficial to capture specialist seal individuals 284 (Lehtonen and Suuronen, 2010; Königson et al., 2013), since these seals are likely to 285 shift their target set net when they can no longer gain access to a certain set net, and 286 would consequently expand the area where damage occurs. Varjopuro (2011) suggested 287 that the role of technology is critical in the seal-fishery controversy, and also suggested 288 that fisheries must adapt to the new environment. It is expected that technological 289 measures will improve and local fisheries will adapt to co-existence by building 290 consensus among stakeholders by utilizing the Kuril Harbor Seal Science Committee 291 and the Kuril Harbor Seal Management Council.

292

293 CRediT authorship contribution statement

294 Yosuke Kuramoto: Conceptualization, Formal analysis, Investigation, Writing -

295 Original Draft. Yasuzumi Fujimori: Conceptualization, Writing - Review & Editing,

296 Supervision, Project administration. Ryohei Ito: Formal analysis, Investigation. Yumi

297 Kobayashi: Investigation, Writing - Review & Editing. Yasunori Sakurai:

298 Conceptualization, Writing - Review & Editing, Project administration.

299

300 Declaration of Competing Interest

301 The authors declare that they have no known competing financial interests or 302 personal relationships that could have appeared to influence the work reported in this 303 paper.

304

305 Acknowledgments

306 We are grateful to the fisheries cooperative of Erimo, Marukyo-Toyo and Erimo

307 Ranger office for their cooperation to the study and provision of the count data of

308 salmon catch and damage. We also thank to Dr. M. Kobayashi, Dr. Y. Mitani and

309 members of researchers from Tokyo University of Agriculture and Hokkaido University

310 for their assistance in the field sampling. Part of this research was supported by the

311 Environment Research and Technology Development Fund (4-1301) of the

312 Environmental Restoration and Conservation Agency of Japan.

313

314 **References**

315 Bruckmeier K., Westerberg H., and Varjopuro R. 2013. Baltic Seal Reconciliation in

316 Practice. In Human - Wildlife Conflicts in Europe. Environmental Science and

317 Engineering (Environmental Engineering), pp15–48. Ed. by Klenke R., Ring I.,

318 Kranz A., Jepsen N., Rauschmayer F., and Henle, K. Springer, Berlin, Heidelberg.

319 https://doi.org/10.1007/978-3-540-34789-7_3.

320 Butler, J. R. A., Middlemas, S. J., Graham, I. M., and Harris, R. N. 2011. Perceptions

321 and costs of seal impacts on Atlantic salmon fisheries in the Moray Firth, Scotland:

322 Implications for the adaptive co-management of seal-fishery conflict. Marine Policy,

323 35: 317–323. https://doi.org/10.1016/j.marpol.2010.10.011.

- 324 Cronin, M., Jessopp, M., Houle, J., and Reid, D. 2014. Fishery-seal interactions in Irish
- 325 waters: Current perspectives and future research priorities. Marine Policy, 44: 120–

- 326 130. https://doi.org/10.1016/j.marpol.2013.08.015.
- FAO. 2021. Fishing operations. Guidelines to prevent and reduce bycatch of marine
 mammals in capture fisheries. FAO Technical Guidelines for Responsible Fisheries
 No.1, Suppl. 4. Rome. https://doi.org/10.4060/cb2887en.
- Fjälling, A. 2005. The estimation of hidden seal-inflicted losses in the Baltic Sea
 set-trap salmon fisheries. ICES Journal of Marine Science, 62: 1630–1635.
 https://doi.org/10.1016/j.icesjms.2005.02.015.
- Fjälling, A., Wahlberg, M., and Westerberg, H. 2006. Acoustic harassment devices
 reduce seal interaction in the Baltic salmon-trap, net fishery. ICES Journal of Marine
 Science, 63: 1751–1758. https://doi.org/10.1016/j.icesjms.2006.06.015.
- 336 Fujimori, Y., Ochi, Y., Yamasaki, S., Ito, R., Kobayashi, Y., Yamamoto, J., Tamaru, O.,
- 337 Kuramoto, Y., and Sakurai, Y. 2018. Optical and acoustic camera observations of the
- behavior of the Kuril harbor seal *Phoca vitulina stejnegeri* after invading a salmon
- 339 setnet. Fisheries science, 84: 953–961. https://doi.org/10.1007/s12562-018-1236-z.
- Götz, T. and Janik, V. M. 2016. Non-lethal management of carnivore predation:
 long-term tests with a startle reflex-based deterrence system on a fish farm. Animal
- 342 Conservation 19: 212–221. https://doi.org/10.1111/acv.12248.
- Graham, I. M., Harris, R. N., Denny, B. Fowden, D., and Pullan, D. 2009. Testing the
 effectiveness of an acoustic deterrent device for excluding seals from Atlantic
 salmon rivers in Scotland. ICES Journal of Marine Science, 66: 860–864.
 https://doi.org/10.1093/icesjms/fsp111.
- Güçlüsoy, H. 2008. Damage by monk seals to gear of the artisanal fishery in the Foça
 Monk Seal Pilot Conservation Area, Turkey. Fisheries Research 90: 70–77.
 https://doi.org/10.1016/j.fishres.2007.09.012.
- 350 Haneda, T., Morohoshi, A., Kobayashi, M. 2017. By-catch records of pinnipeds by

- 351 salmon set-nets in the Pacific Ocean of the eastern Hokkaido from 2012 to 2014.
 352 Wildlife and Human Society, 4: 1–10. https://doi.org/10.20798/awhswhs.4.2_1. (in
 353 Japanese with English abstract).
- Harris, R. N., Harris, C. M., Duck, C. D., and Boyd, I. L. 2014. The effectiveness of a
 seal scarer at a wild salmon net fishery. ICES Journal of Marine Science, 71: 1913–
 1920. https://doi.org/10.1093/icesjms/fst216.
- Itoo, T., and Shukunobe T. 1986. Number and present status of the Kuril seal. *In*Ecology and protection of Kuril seal, pp18–58. Ed. by Wada, K., Itoo, T., Niizuma,
 A., Hayama, S., and Suzuki, M. Tokai University Press, Tokyo. (in Japanese with
 English abstract).
- Kauppinen, T., Siira, A., and Suuronen, P. 2005. Temporal and regional patterns in
 seal-induced catch and gear damage in the coastal trap-net fishery in the northern
 Baltic Sea: effect of netting material on damage. Fisheries Research, 73: 99–109.
 https://doi.org/10.1016/j.fishres.2005.01.003.
- 365 Kobayashi, M. 2015. Phoca vitulina Linnaeus, 1758. In The Wild Mammals of Japan

366 Second edition, pp280–281. Ed. by Ohdachi, S.D., Ishibashi, Y. Iwasa, M.A. Fukui,

- 367 D., and Saitoh, T. Shoukadoh Book Sellers and the Mammal Society of Japan,368 Kyoto.
- 369 Kobayashi, Y., Kariya, T., Chishima, J., Fujii, K., Wada, K., Baba, S., Itoo, T.et al. 2014.
- 370 Population trends of the Kuril harbour seal *Phoca vitulina stejnegeri* from 1974 to
- 371 2010 in southeastern Hokkaido, Japan. Endangered Species Research, 24: 61–72.
- 372 https://doi.org/10.3354/esr00553.
- Königson, S., Fjälling, A., Berglind, M., and Lunneryd, S. G. 2013. Male gray seals
 specialize in raiding salmon traps. Fisheries Research 148: 117–123.
 https://doi.org/10.1016/j.fishres.2013.07.014.

- Lehtonen, E. and Suuronen, P., 2004. Mitigation of seal-induced damage in salmon and
 whitefish trapnet fisheries by modification of the fish bag. ICES Journal of Marine
 Science, 61: 1195–1200. https://doi.org/10.1016/j.icesjms.2004.06.012.
- Lehtonen, E. and Suuronen, P. 2010. Live-capture of grey seals in a modified salmon
 trap. Fisheries Research, 102: 214–216.
 https://doi.org/10.1016/j.fishres.2009.10.007.
- Lundström, K., Lunneryd, S. G., Königson, S., and Hemmingsson, M. 2010.
 Interactions between harbour seals (*Phoca vitulina*) and coastal fisheries along the
 Swedish west coast: an overview. NAMMCO Scientific Publications, 8: 329-340.
 https://doi.org/10.7557/3.2697.
- Lunneryd, S. G., Fjälling, A., and Westerberg, H. 2003. A large-mesh salmon trap: a
 way of mitigating seal impact on a coastal fishery. ICES Journal of Marine Science,
 60: 1194–1199. https://doi.org/10.1016/S1054-3139(03)00145-0.
- Masubuchi, T., Kobayashi, M., Ohno, K., Ishikawa, A., and Kuramoto, Y. 2019.
 Dependency of Japanese harbor seals (*Phoca vitulina*) on salmon set nets at Cape
 Erimo, Hokkaido, Japan. Marine Mammal Science, 35: 58–71.
 https://doi.org/10.1111/mms.12514.
- Masubuchi, T., Ohyama, N., Aizaki, S., Okada, K., Ohno, K., Ishikawa, A., Echigo, H.
 et al. 2017. Evaluation of the damage to the salmon set trap fishery for salmon by
 Kuril harbor seals in Cape Erimo, Hokkaido, Japan–first study using both seals
 behavior and the number of damage–Wildlife and Human Society, 4: 19–27.
 https://doi.org/10.20798/awhswhs.4.2_19. (in Japanese with English abstract).
- 398 Matsuda, H., Yamamura, O., Kitakado, T., Kobayashi, Y., Kobayashi, M., Hattori, K.,
- and Kato, H. 2015. Beyond dichotomy in the protection and management of marine
- 400 mammals in Japan. Therya, 6: 283–296. https://doi.org/10.12933/therya-15-235.

- 401 Ministry of the Environment. 2016a. Ministry of the Environment Erimo Area Kuril 402 Harbor Project Plan, FY Seal Management Implementation 2016: 403 http://hokkaido.env.go.jp/wildlife/mat/H28zenigataazarashizishikeikaku2 Eng.pdf 404 (last accessed February 15, 2021). 405 Ministry of the Environment. 2016b. Erimo Area Kuril Harbor Seal Specified Rare 406 Wildlife Management Plan: 407 http://hokkaido.env.go.jp/wildlife/mat/H28zenigataazarashizishikeikaku2 Eng.pdf 408 (last accessed February 15, 2021). 409 Mizuno, M., Sasaki, T., Kobayashi, M. Haneda, T., and Masubuchi, T. 2018. 410 Mitochondrial DNA reveals secondary contact in Japanese harbour seals, the 411 southernmost population in the western Pacific. PLoS ONE, 13: e0191329. 412 https://doi.org/10.1371/journal.pone.0191329. 413 Mizuno, M., Kobayashi, M., Sasaki, T., Haneda, T., and Masubuchi T. 2020. Current
- 413 Mizuno, M., Kobayashi, M., Sasaki, T., Haneda, T., and Masubuchi T. 2020. Current
 414 population genetics of Japanese harbor seals: Two distinct populations found within
 415 a small area. Marine Mammal Science, 36: 915–924.
 416 https://doi.org/10.1111/mms.12697.
- 417 Nakagawa, E., Kobayashi, M., Suzuki M., and Tsubota, T. 2010. Genetic variation in the
 418 Harbor Seal (*Phoca vitulina*) and Spotted Seal (*Phoca largha*) around Hokkaido,
 419 Japan, based on mitochondrial cytochrome b sequences. Zoological Science, 27:
 420 263–268. https://doi.org/10.2108/zsj.27.263.
- 421 Suuronen, P., Siira, A., Kauppinen, T., Riikonen, R., Lehtonen, E., and Harjunpää, H.
- 422 2006. Reduction of seal-induced catch and gear damage by modification of trap-net
- 423 design: Design principles for a seal-safe trap-net. Fisheries Research, 79: 129–138.
- 424 https://doi.org/10.1016/j.fishres.2006.02.014.
- 425 Varjopuro, R. 2011. Co-existence of seals and fisheries? Adaptation of a coastal fishery
 - 17

- 426 for recovery of the Baltic grey seal. Marine Policy, 35: 317–323.
- 427 https://doi.org/10.1016/j.marpol.2010.10.023.
- 428 Westerberg, H., Lunneryd, S. G., Wahlberg, M., and Fjälling, A. 2006. Reconciling
- 429 fisheries activities with the conservation of seals throughout the development of new
- 430 fishing gear: A case study from the Baltic fishery–gray seal conflict. American
- 431 Fisheries Society Symposium. 587-597.

434	Figure	cantions
-77-	Inguit	captions

435	Figure 1. Location of the experimental salmon set net in this study. In the right panel,
436	the grey squares indicate the permitted areas of the nets owned by different entities, and
437	the set nets are placed inshore and offshore within each of these areas.
438	
439	Figure 2. (A) Outline of the large-scale salmon set net used in this study. (B) Schematic
440	view of the underwater camera hung from the surface net of the fish bag.
441	
442	Figure 3. Schematics of the rope grid used in the experiment. S1–S3 are square-shaped
443	grids with different opening sizes, and D is a diamond-shaped grid. F1 and F2 have a
444	funnel on S1 for capturing seals.
445	
446	Figure 4. Example image of a seal prevented from entering the fish bag by a rope grid
447	attached to the end of the funnel.
448	





S1: 20 x 20 cm

S2: 40 x 20 cm								

S3: 25 x 25 cm								



F1: Small funnel

F2: Large funnel



Inlet (25 x 25 cm)

Figure 3.

	A DAY
	T
511	
512	
513	
514	
515	
516	
517	
518	
510	
520	
520	
521	
522	
523	
524	Figure 4.
525	2

-	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

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

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

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

532 Table 3. Total number of salmon passed through the rope grid observed by the underwater camera, and total number of salmon in the fish

- 533 bag (sum of the salmon catch and damage) recorded by on-board observation on the following day. The number of salmon taken away by
- 534 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	Day	Salmon passed	Salmon in the fish bag	Salmon taken away	Events that seals	Recording time
	type		through the rope	on the following day	by seals	appeared	(minutes)
			grid				
Offshore	S1	5/30, 31,	1027	637	0	466	4774
		6/4, 6, 7, 8					
Inshore	S2	5/30, 31	391	5	23	314	1611
	S3	6/4, 6, 7, 8	195	13	70	793	3301