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The estimation of hidden seal-inflicted losses in the Baltic Sea set-trap salmon fisheries

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A database has been constructed using detailed information on catches and seal-disturbance from contracted commercial fishers in the northern Baltic Sea. A model was developed for the calculation of seal-induced losses in set traps for salmon. The model compared catches on consecutive days or day-pairs. It was found that the total losses in set traps were high: 61% of the potential catch in a trend-adjusted sample of paired data. A significant part of these losses, such as fish wholly removed from gear was hidden. The traditional method of assessing losses by counting the remains of fish underestimated losses by 46%. The scaring effect of seal visits was not included. The model was also used for an analysis of the damage process. There were significant negative after-effects of seal visits on catch levels. It was also found that seal visits co-occur with salmon runs. It seems that seals prefer smaller to larger salmon when raiding traps. It is suggested that the traditional method of estimating losses by counting fish remains should be calibrated when used and that the new model with day-pairs should be tried in analyses of seal interference in other fishing operations.

Keywords: conflict, damage, fishery, grey seal, hidden loss, predation, salmon.

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Introduction

In several reports on the "seals versus fisheries" conflict, the percentage of damaged fish found in the catch is given as a measure of loss (see Wickens, 1995). Such figures may be used to derive estimates of the overall impact on large-scale fisheries, as in David (1987) and Wickens *et al.* (1992). In some European salmon fisheries, e.g. Finland, Great Britain, and Ireland, and previously in Sweden as well, the individual weights of fish loss are sometimes back-calculated from the remains found. In addition to those observed, there may be non-evident losses if fish are removed without leaving any traces, as suggested by Mountford and Smith (1963), Greenwood (1981), Wickens (1993), and reported in Wickens (1995). For example, small fish may be eaten whole by seals while fish remains may simply fall off the gear or be taken by other predators like seagulls. In one example (Lunneryd *et al.*, 2003) where a set trap for salmon was carefully studied, 188 holes were noted, each probably representing a fish taken by a seal, but only 38 remains of fish were found. It is also likely that live fish contained in the fish chamber of a trap may escape through holes torn in the net. Some fish may also be prevented from entering gear or be taken before entering by a "goal-keeper" seal. At yet another level, the net being tangled may reduce the catch. Attempts to estimate parts of these hidden effects were made by Potter and Swain (1979), referred to in Harwood and Greenwood (1985), Westerberg *et al.* (2000), and Anon. (2001). However, no dedicated attempt had been made to determine the significance of these effects and to explore their details. The basic question to be tested in the present investigations was: "Are there significant hidden seal-induced catch losses in the set-trap salmon fisheries?" If the answer is no, then, for a certain day with seal visits to the gear, the catch plus the observed number of damaged fish should equal that of the expected catch for that day, had there been no seal visits. This question was explored by analysing data from set-trap fisheries for salmonids in the Baltic Sea, which experience severe, and even extreme, levels of attack from grey seals (Anon., 1998; Westerberg, 2000; Westerberg *et al.*, 2000; Lunneryd, 2001). Harbour seals and harbour porpoises very rarely enter the areas concerned (Bothnian Sea and Bothnian Bay). Ringed seals are common in Bothnian Bay but are not known to interact with fisheries.

Material and methods

The source material for analysis was a database holding detailed catch data from contracted commercial fishers, about 20 during 2002, along the Swedish Baltic coast northwards from 60°N. Both fishing areas near salmon rivers and more remote areas are represented in the material. Each time, usually once per day, the traps or nets were checked and emptied, i.e. "a lifting event", and data were noted. The aspects covered were gear type, number, and position of gears (i.e. fishing operation), species, number, weight (i.e. catch), damage to gear (size and position of holes in net), and damage to catch (species and number of fish damaged by seals and by birds, respectively). The database holds about 12 000 entries for the years 1993–2001. Data quality was controlled by spot tests and by statistical means. The bulk of the data concerns set traps (mainly for salmonids and eel) and gillnets (mainly for salmonids, herring, cod, perch, and perch-pike). In all, 7920 lifting events, representing 7944 fishing days, relate to the three types of set traps for salmonids, traditional salmon trap, combi trap, and combiD trap, encompassing a total catch of 127 401 kg of salmon *Salmo salar* L., sea trout *Salmo trutta* L., and whitefish *Coregonus* spp. These traps are all designed like a Scottish salmon trap (von Brandt, 1984) (Figure 1). They differ from each other in mesh size and material. The traditional trap has a large mesh net, 100 mm stretched mesh, while the mesh of the two combi traps is smaller (70 mm stretched mesh in the larger part, 40 mm in the fish-court section) in order to catch whitefish as well as salmon and sea trout. The fish chamber of the combiD trap is partially made from a very strong material, Dynema (High Modulus Polyethylene).

In the comparison of catches between days in day-pairs, data from a single day may have been used more than once, i.e. the first time as second in a pair, and then as the first day in another pair. The estimated total losses were calculated by deducting catches for seal-disturbed days in day-pairs from those for non-disturbed days. The observed losses were calculated from the number of fish remains found per species multiplied by the average weights. A seal visit was deemed to have occurred when, at lifting of the gear, either fish with seal bites, fish remains, or new holes in the net were found. For comparisons between catches in day-pairs and in mean weights the z-test was used.

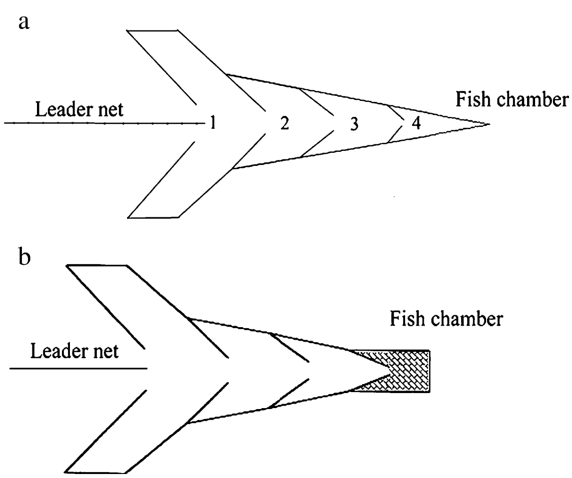

Figure 1. Basic design for set traps for salmonids; (a) salmon trap, (b) combi trap, and combiD trap.

Results and discussion

Summed over the season, catches were considerably lower on days with seal visits than on days without such visits (Table 1). Catches do, however, generally peak during a short period in the early summer, whereas seal-inflicted damages increase in extent and intensity towards the autumn. For this reason, it is unclear to what extent these figures reflect the results of seal visits or seasonal variations; a more stable measure was required to test the basic hypothesis.

Catches vary with biological factors over a time scale of months, and with weather, wind, and currents on a shorter time scale (weeks or days). However, if catches vary less over a short time scale than over a long one, it should be possible to estimate the expected catch for a certain day from that on a preceding day at the same site. To test this, all day-pairs were selected where seals did not visit the trap on either of the two consecutive days and where fish were caught on at least one of the two days (Table 2). The mean catch, all species unless otherwise specified, for the two days did not differ. The mean weights of the main catch species, salmon, did differ, but only slightly. This reflects the biology of the salmon; large salmon migrate towards the spawning grounds earlier than small ones: the mean weight of salmon was 8.4 kg for week 23 and 3.7 kg for week 33. It was therefore concluded that in the absence of seals, the catch could as a rule be expected to be the same on adjacent days. The mean weights of sea trout did not differ significantly. For whitefish no calculations of mean weights were made since fishers often estimate the numbers from the landed weights.

As a next step, the catch for days with seal visits was compared with the expected catch had there been no seal visits. This was done by selecting all the day-pairs, where one day without a seal visit was followed by one with such

Table 1. Catches of salmon, sea trout and whitefish in set-trap fisheries for days with and without seal visits.

	Lifting occasions	Fishing effort (trap days)	Catch (kg) per effort	% of 22.1
Liftings without signs of seal visits	3 849	3 748.2	22.1	
Liftings with signs of seal visits	4 071	4 196.0	10.4	47

Table 2. Catch (all species), fishing effort and mean lengths for salmon and sea trout for selected day-pairs and day-trios in set-trap fisheries in the Baltic Sea.

Trap type	Selection	Day	Category	Lifting occasions	Effort (trap days)	Catch (kg/effort)	Diff.	95% CI	p	Obs. loss (kg/effort)	Salmon mean weight (kg)	95% CI	p	Sea-trout mean weight (kg)	95% CI	p
All traps	Day-pairs	First day	Without seal visit	3 504	3 024.9	18.1	–	–	–	0	6.52	±0.070	–	2.40	±0.049	
		Second day	Without seal visit	3 504	3 099.7	18.3	+0.2	±1.40	0.61	0	6.42	±0.068	0.047	2.45	±0.050	0.23
All traps	Day-pairs	First day	Without seal visit	1 054	1 101.5	24.9	–	–	–	0	5.94	±0.09	–	2.08	±0.07	
		Second day	With seal visit	1 054	1 111.9	10.8	−14.1	±2.19	<0.001	8.9	6.16	±0.12	0.005	2.01	±0.10	0.31
All traps	Day-trios	First day	Without seal visit	683	626.1	20.1	–	–	–	0	6.02	±0.13	–	2.24	±0.09	–
		Second day	Without seal visit	683	657.0	22.1	+2.0	±2.60	0.10	0	6.14	±0.13	0.19	2.24	±0.11	0.49
		Third day	With seal visit	683	667.5	9.9	−12.2	±2.77	<0.001	8.8	6.33	±0.16	0.041	2.15	±0.11	0.23
Salmon trap	Day-trios	First day	Without seal visit	176	141.3	23.6	–	–	–	0	6.36	±0.26	–	3.12	±0.30	–
		Second day	With seal visit	176	144.3	10.3	−13.3	±4.48	<0.001	9.3	7.37	±0.40	<0.001	2.08	±0.26	<0.001
		Third day	Without seal visit	176	142.1	15.5	−8.1*	±5.68*	0.016*	0	6.25	±0.26	–	3.22	±0.40	–
combi trap	Day-trios	First day	Without seal visit	168	170.3	25.4	–	–	–	0	6.24	±0.27	–	1.76	±0.26	–
		Second day	With seal visit	168	175.3	8.3	−17.1	±5.92	<0.001	9.5	6.48	±0.38	0.15	2.75	±1.05	0.06
		Third day	Without seal visit	168	163.6	15.9	−9.5*	±4.32*	0.001*	0	6.20	±0.34	–	1.93	±0.44	–
combiD trap	Day-trios	First day	Without seal visit	203	212.1	26.8	–	–	–	0	5.49	±0.19	–	1.82	±0.07	–
		Second day	With seal visit	203	220.8	12.6	−14.2	±4.86	<0.001	8.6	5.27	±0.22	0.08	1.83	±0.10	0.89
		Third day	Without seal visit	203	215.7	25.0	−1.8*	±5.72*	0.25*	0	5.74	±0.17	–	1.76	±0.08	–
All traps	Day-trios	First day	Without seal visit	547	523.7	25.4	–	–	–	0	5.95	±0.13	–	2.08	±0.10	–
		Second day	With seal visit	547	540.5	10.6	−14.8	±2.93	<0.001	8.9	6.08	±0.19	0.11	2.04	±0.19	0.72
		Third day	Without seal visit	547	521.4	19.6	+5.8*	±3.09*	0.001*	0	5.97	±0.13	0.86*	2.07	±0.13	0.98*

*Comparison with corresponding figure for the first day in that day-trio.

a visit (Table 2). The mean catch for the second day (with a seal visit) was significantly lower than expected, i.e. than the catch for the first day. The difference, the estimated total catch losses, was significantly larger than the observed mean losses estimated from counted fish remains ($p < 0.01$). The conclusion is that there was indeed hidden seal-induced catch losses amounting to 5.2 kg/effort, i.e. the estimated total catch losses minus the observed losses. The traditional method, only taking observed losses into consideration, underestimated losses by at least 37%. The mean weights of salmon were higher for days with seal visits, indicating that seals more often take small salmon than large ones from traps. Alternatively, this may be a result of small fish more readily escaping through broken meshes than large fish.

A common statement by fishers is: "When a salmon run begins, seals show up". If indeed seal attacks are correlated with a rising trend in catch figures, there remains a risk of underestimating the extent of losses when using day-pairs. To test this, day-trios were selected where a day with seal damage was preceded by two consecutive days without damage (Table 2). There was indeed a positive trend in catch levels just prior to seal visits. If the expected catches for the days with seal visits in the example above were adjusted upwards accordingly, the total losses would have been even larger and the hidden part of the losses 7.7 kg/effort. This means that the traditional method would have underestimated actual losses by no less than 46%. Corrections for this factor are not, however, applied in Table 3 in order to keep the different issues separate.

The observed and hidden catch losses varied over time, but increased at the end of the season. Large incidental catches of whitefish in autumn complicate the picture. For catches of salmon and sea trout only, and averaged over two-week periods, the picture was clearer (Figure 2). The occasional negative figures for hidden losses were artefacts attributable to sharp-weather shifts inducing high catches on days with seal visits, in combination with insufficient data.

It was then considered whether there were any negative after-effects of seal visits, as fishers sometimes claim. This has been attributed to the scent of seals by Bonner (1982), with some support in Alderice *et al.* (1954). If there were no such effects, the catch on an undisturbed day after a seal visit should be the same as the day before the seal visit or slightly higher because of the rising trend factor. To test this hypothesis, day-trios were selected where an undisturbed day was followed by a day with a seal visit and then again by an undisturbed day (Table 2). The catches for the next undisturbed days after a seal visit were, on average for all traps, significantly lower than expected: there were indeed negative after-effects of seal visits. The reason for this effect was then considered. If the smell of seals on traps was responsible, the effect should be the same for all three trap sub-types. On a closer look, however, only the traditional salmon trap and the combi trap actually fitted this pattern, whereas the combiD trap did not; the catches in the latter were not lower than expected. The traps differ only in that the central part, mainly the fish chamber, of the combiD trap is made of Dynema, a material of great strength. The most obvious interpretation is therefore that the negative after-effects observed were mainly a result of unrepaired structural damage, such as holes in net panels. This conclusion was supported by the rate of damage to nets, highest (0.68/effort) for the most vulnerable one, the standard salmon trap, intermediate (0.55) for the combi trap, and lowest (0.52) for the strong combiD trap. Furthermore, the severity of damage as judged by the size of holes and their position differed; damage to traditional traps and combi traps was often extensive, whereas for the combiD trap, as a rule it was small. Hence, the after-effects can be expected to vary over time, since a few days after a seal attack most fishers are likely to have made the necessary repairs, though others do not care to do so or are less proficient in this work. Holes in the bottom sections of a trap often go undetected until the gear is lifted.

Table 3. Observed and estimated losses per trap type and fish species, and loss factor (calibration factor).

		Observed losses			Estimated losses (from day-pair model)			Loss factor		
		Number of counted remains per effort			Number of fish per effort			Number of fish per remains found		
	Number (no.) of day-pairs	Salmon	Sea trout	Whitefish	Salmon	Sea trout	Whitefish	Salmon	Sea trout	Whitefish
combi trap	293	1.2	0.5	3.0	1.5	0.6	15.6	1.3	1.2	5.3
combiD trap	416	1.3	0.6	2.2	1.5	1.0	11.2	1.2	1.5	5.2
Traditional trap	345	1.1	0.1	–	1.7	0.4	–	1.6	4.1	–
All traps	1 054	1.2	0.5	2.4*	1.6	0.7	12.9*	1.3	1.5	5.1*

*There was no catch of whitefish in the traditional salmon traps, this was expected as this gear has large meshes which whitefish normally pass through, average figures were thus calculated for combi and combiD traps only.

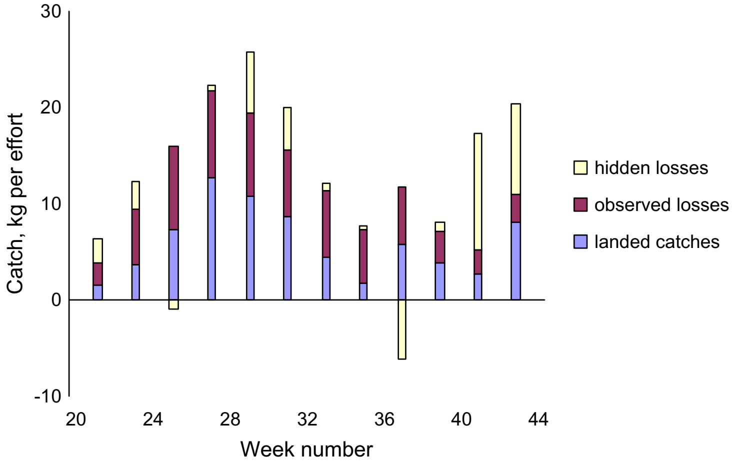

Figure 2. Potential catches (total height), landed catches, observed losses, and hidden losses (salmon and sea trout) per two-week period.

The traditional measure of losses, i.e. counting the number of fish remains, is simple and straightforward and thus is useful in practical day-to-day fisheries management. It needs, however, to be calibrated for hidden losses, and figures were therefore calculated for the number of fish lost per remains found for all three types of set traps discussed (Table 3). The data indicate a loss of 1.1−1.3 salmon per effort using the observed loss method and 1.5−1.7 for the new method. It was then possible to calculate a loss factor, which can be used for an improved estimation of losses based on the counted number of fish remains. For salmon, this factor would be 1.2−1.6 salmon per fish remains (salmon) found depending on trap sub-type, or 1.3 as an average over all traps not taking into account any adjustment for the rising catch trend. For sea trout and whitefish, the loss rates were higher. The remains of fish often fall out through meshes or holes in the net, so the overall loss rate is inverse to mesh size, strength of the net material, and the body size of the fish species concerned. Salmon caught in a combiD trap (small mesh, strong material) had a low loss rate, whereas the loss rate was higher in the combi trap (small mesh, weak material), and highest in a traditional salmon trap (large mesh, weak material). For sea trout and whitefish, the general picture was the same. Whitefish are known to escape promptly through even minute holes in the net and have the highest loss rate.

In addition to counting fish remains, the new method estimates non-evident loss of fish (i.e. fish escaped through holes, fish eaten whole, and fish remains fallen out of gear). The new method could be further improved by documenting the observations of seals in the vicinity of fishing gear. The diversion effects of the presence of seals near the gear could then be evaluated by comparing catches for days with observations of seals with days without observations of seals, assuming that there were no signs of physical damage to gear or catch on either day.

The estimates of the negative effects of seal visits using day-pairs probably constitute minimum figures, since some days that were classified as "seal-free" through lack of positive observations would in fact have had seal visits. Such occasions will tend to reduce the estimates for expected catches. An indication of this was noted during a technical trial with an AHD (Acoustic Harassment Device) in a supposedly seal-free environment. Catches unexpectedly turned out to be somewhat higher when the AHD was switched on than when it was not. Since salmonids are not capable of hearing the frequency used (17 kHz) and porpoises do not frequent the area (the Bothnian Sea and the Bothnian Bay), this was interpreted as an effect of seals that were present but undetected being deterred.

It should be noted that this approach is sensitive to changes in the overall situation. The figures need to be kept updated and used with discretion. This is particularly true for the Baltic Sea, where the grey seal population is now increasing rapidly, and where the high seal activity brings about dramatic changes in the types of fishing gear being used.

A prerequisite for using the day-pairs model is that days without seal visits should occur regularly. Granted this and that the general day-to-day variation in catches is not too high, it should be possible to perform a comparison of catches for day-pairs in several other fisheries, using both passive and active gear. The proposed method may allow for a deeper analysis of the damage process, in that the preferences of seals in regard to fish species, sex, size, condition factor, etc., could be determined by establishing which fish are missing in the landed catch on the day of a seal attack.

Conclusions

(i) There were significant hidden negative effects on catches attributable to seal visits.
(ii) The traditional method of assessing seal-induced losses by counting fish remains underestimates losses and should be calibrated, using the type of calculations presented in this paper.

(iii) There is a correlation between rising catch sizes attributable to the arrival of migrating salmon and losses to seals.
(iv) There were negative after-effects of seal visits to salmon traps, probably as a result of structural damage to gear.
(v) The new method described in this paper of using day-pairs may possibly be used for determining hidden losses in other types of fishing gear and for a deeper analysis of the damage process.
(vi) The calculations presented here confirm that the seal-induced effects on the Swedish set-trap fisheries for salmonids are substantial.

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