Foraging behaviour of cormorants Phalacrocorax carbo in pound nets in Denmark: the use of barrel nets to reduce predation

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ORIGINAL ARTICLES

Foraging behaviour of cormorants *Phalacrocorax carbo* in pound nets in Denmark: the use of barrel nets to reduce predation

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Yields in pound nets are in particular damaged or reduced by cormorant *Phalacrocorax carbo* predation. In this study we examined the effect on predation in pound nets by mounting barrel nets vertically under the water in the pot in order to obstruct cormorants during their hunt. To keep control of the content of fish we used an experimental pot with a closed throat. The pot was stocked repeatedly with rainbow trout *Oncorhyncus mykiss* and its content of fish was thereby maintained at between 10 and 100 individuals during all periods of data collection. Video recordings, both above and under water, were carried out during May - August 1995 under various experimental conditions. We tested five different barrel net arrangements including a control situation without barrel net. Two bird categories were defined *a posteriori*: those that caught one or more fish during their visit to the pot (successful birds) and those that failed to catch a fish (unsuccessful birds). Successful and unsuccessful birds differed in a number of ways. Successful cormorants stayed longer in the pot, performed more dives, and spent more time diving and shorter time on the surface. When barrel nets were present, fewer cormorants of both categories visited the pot. Furthermore, the barrel nets affected successful birds by increasing the number of dives required to catch their first fish, reduced the time that both successful and unsuccessful birds remained in the pot, and reduced the number of dives performed by unsuccessful birds. Therefore, it seems that barrel nets may have a potential as a predation reducing device in pound net fishery. Introducing the use of barrel nets in pound net fisheries may force cormorants to hunt in free waters, possibly with reduced foraging success. This may eventually lead to a reduction in the cormorant population which will make it better fit the natural carrying capacity of the environment.

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Fish predation by cormorants *Phalacrocorax carbo* has traditionally been considered a threat to commercial fishing and as a consequence of this view the species was formerly excessively hunted. It consequently became extinct as a breeding bird in Denmark about 100 years ago, but reappeared as a breeding bird in 1938 and has gradually increased in numbers since then (Bregnballe & Gregersen in press).

During the last decade a reduction in catches of commercially relevant fish species has been reported with an increasing frequency by Danish pound net fishermen. A pound net is a stationary net, i.e. a fish trap consisting of a netting arranged into a directing wing and an enclosure ('pot') with a narrow entrance ('throat'). The reduction has been ascribed first of all to increased predation by cormorants in pound nets as a consequence of the increased population of breeding (*Phalacrocorax carbo sinensis*) and wintering (*P. carbo carbo* and *P. carbo sinensis*) birds, but has also been ascribed to a general reduction in commercially exploited fish species as a consequence of increased cormorant predation in free waters. Consequently, research has been undertaken to assess the problem and to find ways to minimise cormorant predation in pound nets (Bildsøe 1994, Bildsøe & Jensen 1997, Christensen & Cornelisse 1992).

In the attempts to minimise cormorant predation in pound nets, basic knowledge about the normal hunting behaviour of the species is essential. The cormorant is a "foot-propelled pursuit driver" (Ashmole 1971) that usually catches its prey after diving pursuits over variable distances. The duration of the dives varies from a few seconds to more than one minute (e.g. Cooper 1986, Wilson & Wilson 1988), and the average dive duration has been found to be positively correlated with water depth at the foraging locality (e.g. Wilson & Wilson 1988).

Assuming that an average dive lasts about 30 seconds (e.g. Wilson & Wilson 1988, Voslamber, Platteeuw & van Eerden 1995, Bildsøe 1994) and that the average swimming speed is about 1 m/sec., the average dive distance amounts to about 30 m. It has been shown that during the pursuit of a fish a cormorant can obtain a maximum swimming speed of 1.7-2.0 m/sec. (Wilson & Wilson 1988, Bildsøe 1994). Furthermore, the maximum speed can probably only be maintained for about 10 seconds, i.e. for a distance of about 20 m (Bildsøe 1994). This knowledge has been exploited in the present study which was designed to minimise predation in pound nets by placing obstructions in the pot as an attempt to interfere with the cormorants' hunting and consequently reduce their hunting success.

The overall idea of the present study was to make it unprofitable for the cormorants to hunt in the pound nets so that they would leave the nets and hunt elsewhere. In this study we tested the effects of obstructions to the cormorants' hunting in the form of barrel-nets mounted vertically from the bottom to 0.5 m above the surface inside the pots of the pound nets. We used barrel-nets with a mesh size that would allow the fish to swim through at maximum velocity, whereas at the same time we attempted to construct the barrel-nets so that they would distract the cormorants and consequently reduce their hunting speed. In total, four different barrel nets were designed and tested in an experimental pound net and compared to a control situation with no barrel nets placed in the pot.

Methods

Study area

The experiments were undertaken from May through August 1995 at Nakke Hage in the Isefjord, Sealand, Denmark.

The selected area was situated far away from human activities and during the breeding season it was frequently visited by birds (*P. c. sinensis*) from a colony at Hov Bay, approximately 2 km away.

Experimental set-up

The experimental set-up (Fig. 1) consisted of a 'net-

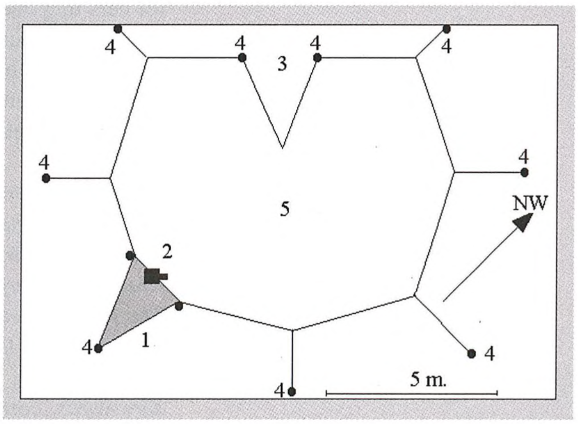

Figure 1. Plan of the experimental set-up as seen from above with platform (1), camera mounted above the water surface (2), throat (3), fishing stakes (4) and pot (5).

cage' of 8 x 8 m in area and 3.5 m deep. The mesh width (between knots) was 18 mm.

The net cage was designed like a pot of a real pound net including a 'throat' for the fish to enter the pot. The throat, however, was closed so that neither fish nor cormorants could leave or enter the pot this way. The net cage was placed approximately 85 m from the shore at a water depth varying between 2.5 and 3.2 m. At the southeast rim of the net there was a platform 1.5 m above sea level. One video-camera was placed on the platform 2.5 m above sea level and another video-camera was placed below the first approximately 1.5 m beneath the water surface. Both cameras were mounted with a 120° wide-angle lens. The camera mounted above the water covered 95% of the water surface of the pot, whereas the underwater camera allowed recordings of various activities by cormorants and fish. The range of the underwater camera, however, was dependent upon the water turbidity, which varied between 0.5 and 5 min.

A tent on the shore, approximately 120 m from the pot, served as an observation post. The tent was sheltered and partly hidden behind a group of pine trees.

Recordings were made either at normal recording speed (25 frames/sec.), or in time-lapse (6 frames/sec.). Recordings included a time code from either an internal (normal recordings) or an external time generator (time-lapse recordings).

Barrel nets

Experiments were carried out using four different barrel nets as well as no barrel net, i.e. the control situation (Fig. 2). Barrel net types 1, 2 and 3 were made of polyethylene tapes that were assembled by the authors, whereas type 4 was made of 3-stringed nylon line and provided by a commercial dragnet supplier (see Table 1).

All barrel nets were supplied with sinkers on the

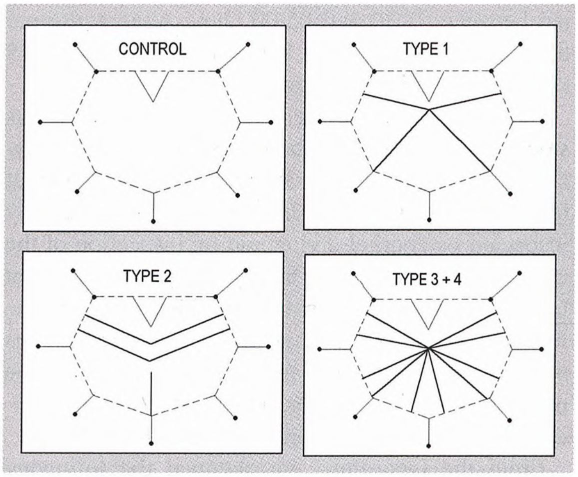

Figure 2. Placing of the barrel nets as seen from above during the five experimental situations.

lower line, and mounted vertically from the bottom and up to 20-50 cm above the water surface, depending on the tide and wind conditions. Their actual placing within the pot is shown in Figure 2.

Since schooling fish may tend to avoid pound nets if there are shadows from algae hanging down in the centre, we used tapes of polyethylene which minimise the tendency of drifting algae to adhere.

Video recordings and experimental procedures

All results were based on video recordings. The surface recordings were obtained in the periods indicated for each situation in Table 1. They were all made at normal speed during the four hours starting immediately before sunrise. Additionally, time-lapse recordings were made on a 24-hour basis. Both types of recordings were used in the analysis, however, recordings from periods of low light intensity (mainly during the night hours) were discarded. Sunrise var-

Table 1. Type of material and mesh size of the barrel nets, extension of experimental period and total duration of the video recordings (in hours) (including the control period) used for analysis. All barrel nets were about 10 m long and 3.5 m deep.

	Type of material	Mesh size (mm)	Experimental period	Total duration of video recordings
Control	(without barrel net)		1/6-21/6	39.5
Type 1	5 cm PVC tape (transparent, 0.10 mm)	300 × 250	21/6-27/6	22.5
Type 2	5 cm PVC tape (transparent, 0.10 mm)	300 × 250	29/6-12/8	32.5
Type 3	3 cm PVC tape (transparent 0.15 mm)	250 × 190	12/8-17/8	86.5
Type 4	3 mm nylon string (green, 0.15 mm)	150 × 150	23/8-30/8	76.5

ied between 03:30 and 05:00 (June-August, normal time) and sunset varied between 21:00 and 19:15 (June-August, normal time).

Before the start of each experiment the pot was stocked with 40-100 rainbow trout *Oncorhyncus mykiss*, each weighing 250-350 g, provided by a trout farm. The fish content in the net was frequently inspected by snorkel diving and by inspection of the underwater recordings. Only recordings showing at least 10 trout in the pot were analysed. Furthermore, for each situation the analysis of video recordings was balanced according to the time of day and the number of fish in the pot. The total duration of recordings for each situation is given in Table 1.

From the recordings we obtained the following data for all cormorants that entered the pot:

1) time of arrival and of flying away for each individual (to the nearest second),
2) time for the start and end of each dive for each individual (seconds),
3) whether or not a fish was caught during the dive and brought to the surface,
4) number of cormorants present at any time in the pot.

From these data the following variables were calculated:
a) pot-time; the total time spent in the pot by each individual visiting the pot,
b) dive duration; the duration of each dive by each individual,
c) diving time; the total time spent diving by each individual during its visit to the pot,
d) surface time; the total time spent on the water surface of the pot during a visit,
e) number of dives; the total number of dives by an individual during its visit to the pot, and
f) total catch; the number of fish caught by an individual during a visit to the pot.

In a few cases, we were not able to obtain all the above data for a visit. Such visits were then regarded as missing data and deleted from the analysis.

Statistical analysis

ANOVA's and t-tests were used whenever the data (or their log-transforms) fulfilled the underlying assumptions. In fact, most data were log transformed before tests to obtain normality and to stabilise the variance. Also the residuals from all ANOVA's were examined for normality. Some of the variables only allowed the use of non-parametric analyses and these included χ^2-tests, Kruskal-Wallis tests and Kolmogorov-Smirnov tests. All tests were conducted using SAS/STAT software programmes (SAS Institute, Inc. 1989).

Material

In this study we observed a total of 303 cormorants entering the pot, and we assumed that they mostly came from the nearby colony at Hov Bay. It is likely that some of the birds were observed several times, and that the following analysis thus contains a number of resamplings. However, considering the number of birds in the Hov Bay colony during that year (approximately 1,100 breeding pairs) we believe that the number of resamplings are limited and further, we find it safe to assume that all birds entering the pot were a random sample from the colony. Thus, we conclude that the problem of resamplings does not affect our result.

Results

Visits by cormorants and total catch

Analyses were made from a total of 257.5 hours of video recordings obtained during 21 days. In total, 303 cormorants were observed and their total catch was 125 trout corresponding to 0.485 trout per hour of observation. On the assumption that this catch per hour was independent of the five experimental situations, the expected number for each situation can be calculated as the catch per hour multiplied by the number of hours of observation for each situation (Tables 1 and 2). The results for the situations with barrel net types 1 and 2 were almost the same and were consequently pooled before further analysis. Catching differed significantly between situations (see Table 2; $\chi^2 = 42.4$, df = 3, $P < 0.001$). The observed catch in the control situation corresponded to 173% of the expected catch.

Expressing observed values in situations with barrel nets in relation to observed values in the control situation (after correcting for differences in observation time between situations) observed catches per time unit were reduced by 70% in the situation with barrel net type 3 and by 65% with barrel net type 4. However, with barrel nets type 1+2 (combined) there was an increase of 4% as compared to the control situation.

Table 2. Expected and observed number of catches and cormorants in the pot for each experimental situation. The results for barrel nets type 1 and 2 have been pooled.

Experimental situation	Number of fish caught in the pot		Number of cormorants in the pot	
	Observed	Expected	Observed	Expected
Control	33	19	58	47
Type 1+2	48	27	136	65
Type 3	22	42	45	102
Type 4	22	37	64	90

The number of visiting cormorants in the pot was calculated to be 1.177 cormorants per hour of observation. From this number, the total number of visits to the pots in the different situations could be calculated as above for catches. The numbers of cormorants visiting the pot differed significantly between situations ($\chi^2 = 119.5$, df = 3, P < 0.001; see Table 2). In the control situation the observed number of cormorants amounted to 123% of the expected number. The corresponding percentages for situations 1+2, 3 and 4 were 209%, 44% and 71%, respectively.

In comparison to the control situation, the number of cormorants visiting the pot per time unit corresponded to 135% for barrel net type 3 and 57% for barrel net type 4. However, in the situation with barrel net types 1+2 (combined) the observed number of cormorants amounted to 268% as compared to the control situation.

Successful and unsuccessful birds

Only about 40% of the cormorants (107 individuals) visiting the pot were successful in catching a fish (successful birds), whereas the remaining 60% of the birds did not catch a fish during their visit (unsuccessful birds). This pattern did not differ significantly between the experimental situations ($\chi^2 = 6.2$, df = 3, P = 0.1) and it is therefore likely that birds with different foraging potential were visiting the experimental pot, whether it contained a barrel net or not. It was also considered likely that the two types of birds would differ with respect to their reaction to barrel nets and in the further analysis we therefore distinguish between the two categories.

For the control situation significant differences were found between the two categories in the number of dives and in pot-time, the median values for number of dives being 9.5 and 5.0 for successful and unsuccessful birds, respectively (Mann-Whitney U-test, z = 2.3, P < 0.025), and the corresponding geometrical means of pot-times being 179 and 86 seconds, respectively (t = 2.98, P < 0.005). A two-factor ANOVA testing the effect of bird category (successful or unsuccessful) and of social situation (alone or in company with other birds) on the pot-time revealed significant interaction between bird category and social situation (P < 0.05; Fig. 3). Thus, while unsuccessful birds showed reduced pot-time when in company with others, the pot-time of successful birds was increased.

These results show that unsuccessful birds leave the pot sooner when in company with other birds

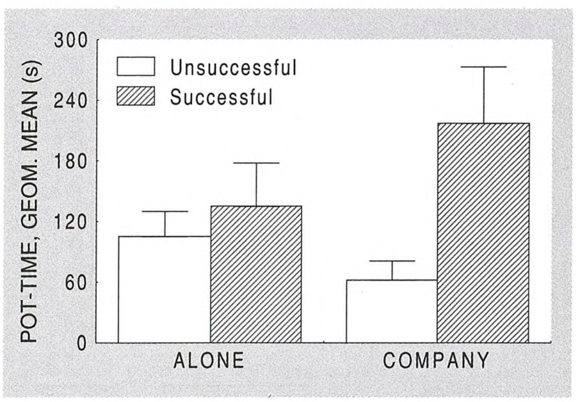

Figure 3. Pot-time expressed as geometrical means ± SE (in seconds) for successful and unsuccessful birds when alone or in company with other birds.

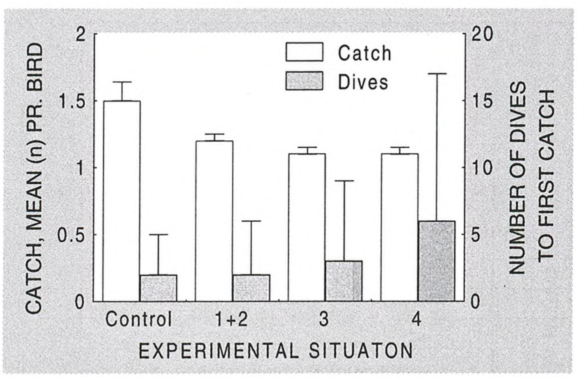

Figure 4. Catch of fish per bird (mean number ± SE) for successful and unsuccessful birds and number of dives to first catch for successful birds (median values + 75 percentiles) in each experimental situation.

than when alone in the pot, whereas successful birds tend to increase pot-time when in company with other birds.

Catches

The mean total catch for successful birds was reduced in all experimental situations with barrel nets in the pot as compared to the control situation (Kruskal-Wallis analysis of variance; $\chi^2 = 15.9$, $P < 0.001$; Fig. 4). Furthermore, the catching of more than one fish was significantly more frequent in the control situation than when barrel nets were used ($\chi^2 = 14.8$, df = 1, $P < 0.001$).

Pot-time

The average pot-times were 86 and 178 seconds for successful and unsuccessful birds, respectively. However, the pot-time decreased from net type 1+2 to type 4 (Fig.5): Both bird category and experimental situation significantly influenced pot-time (ANOVA, $P < 0.001$ for both factors), and additionally a significant interaction effect was found ($P < 0.05$). The barrel nets thus had a significantly larger reducing effect on pot-time for unsuccessful than for successful birds (75% and 55% reduction, respectively).

Number of dives and diving time

The reduced pot-time for unsuccessful birds was associated with a reduced number of dives by the same birds (Kruskal-Wallis test of variance; $\chi^2 = 9.3$, df = 3, $P < 0.023$; see Fig. 5). For successful birds, however, this effect was not significant ($\chi^2 = 0.66$, df = 3, $P < 0.88$). An ANOVA testing the effect of bird category and experimental situation on diving time showed that the barrel nets only had a slight and non-significant reducing effect on the diving time ($P = 0.08$) whereas there was a strong and significant effect of bird category ($P < 0.001$), with unsuccessful birds showing much lower diving times.

Dives in relation to catch

The median number of dives performed by successful birds before their first catch of fish varied between 2 and 6 dives over all experimental situations (see Fig. 4) with the highest median value for experimental situation 4. The experimental situation significantly influenced the number of dives until the first catch (Median one-way analysis; $\chi^2 = 9.69$, df = 3, $P < 0.021$).

For the total catch rate, i.e. number of fish caught per dive, however, there was no significant effect of the experimental situation (Kruskal-Wallis test, $\chi^2 = 0.159$, $P < 0.98$).

Surface time and dive duration

Both bird category and experimental situation significantly influenced surface time (ANOVA; $P < 0.001$). Unsuccessful birds had shorter surface times than successful birds and barrel nets seemed to reduce surface times in both bird categories (Fig. 6). A multiple range test (Bonferroni) revealed that for both bird categories the surface time was reduced in experimental situation 3 and 4 as compared to the control situation and situation 1+2 ($P < 0.05$), which did not differ significantly.

The average dive duration (average of the mean diving time for each individual) was influenced significantly by experimental situation and the effect of bird category approached significance (Two-way

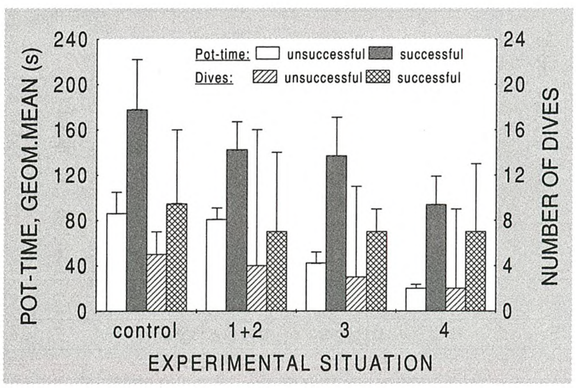

Figure 5. Average pot-times ± SE (in seconds) and number of dives (median values + 75 percentiles) for successful and unsuccessful birds in each experimental situation.

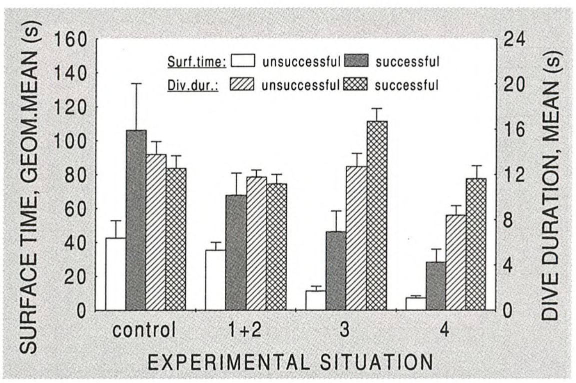

Figure 6. Surface time expressed as geometrical means ± SE (in seconds) and duration of dives (mean ± SE) for successful and unsuccessful birds in each experimental situation.

ANOVA; P < 0.001 and P < 0.062, respectively). Furthermore, there was a significant interaction effect (P < 0.018); thus successful birds reacted to situation 3 with increased dive duration while unsuccessful birds reacted to situation 4 with reduced dive duration (see Fig. 6).

Discussion

The results of this study strongly indicate that the placing of barrel nets in the pot may reduce predation by cormorants in pound nets. When barrel nets were present, a smaller fraction of the visiting cormorants caught a fish in the pot than in the the control situation. Furthermore, the barrel nets not only reduced the hunting success because more dives were required before the first catch, but they also reduced the time at the pot (pot-time) for all birds and the number of dives for unsuccessful birds. Finally, experimental situation affected the mean dive duration differently according to bird category. The reduction in pot-time and the influence on the number of dives were probably the causes of the reduced hunting success in the situations with barrel nets placed in the pot. This, again, indicated that the barrel nets made it more difficult for cormorants to catch a fish in the pound net.

In this study the various situations, i.e. the control situation and the situations with the different barrel nets were applied at different times during the breeding season. The control situation without barrel nets was examined early in the season, whereas the various barrel net situations were examined later. This may potentially indicate that what we have found was exclusively some change over the season in the hunting success of cormorants hunting in pound nets. This explanation, however, is very unlikely because the hunting success was higher during the start of the season (control and situation 1+2) when the cormorants were less experienced. Later in the season while we tested situations 3 and 4 the number of visits by cormorants to the pot was lower as also indicated by observations during a previous season (Bildsøe & Carlsen, unpubl. data), but in spite of the lower interaction and competition between birds a lower catching rate was found during these situations. Indeed, results from this study indicated that situations with more than one bird in the pot resulted in reduced pot-time (for unsuccessful birds) and accordingly a lower chance of hunting success. Very few fledglings were seen (during experimental situation 3 and 4) so the reduced hunting success was not caused by inexperienced birds. Water turbidity may also potentially have influenced hunting success (van Eerden & Voslamber 1995), however, no systematic variation in turbidity was seen during the different experimental situations. Finally, the reduced hunting success in situations with barrel nets in the pot could be explained by the distraction of the cormorants during a hunt (dive) by the barrel nets resulting in more dives required before the catch of a fish. In conclusion, it is most likely that the placing of the barrel nets and not the time of the season was the cause of the reduced hunting success in situations with barrel nets present in the pot.

One effect of barrel nets may be that the cormorants experience a reduced hunting success and therefore 'decide' to hunt elsewhere. The low number of visits during experimental situations 3 and 4 may illustrate this effect.

Interestingly, this study revealed that there may be two categories of cormorants visiting pound nets, i.e. birds that catch one or more fish and birds that leave the pot without having caught a fish. The successful birds differed significantly from the unsuccessful birds in a number of ways. They had a longer pot-time, a larger number of dives, longer diving times and shorter surface times. The categories may represent individual differences in hunting ability indicating that some cormorants are more efficient hunters in pound nets than others. It is also possible that the two categories may represent different motivational situations, e.g., that the successful birds were more hungry and therefore more motivated to hunt. However, this is less likely because the dives by unsuccessful birds tended to be longer.

The results indicate that the successful and unsuccessful birds differed in their reactions to other birds being present, and accordingly the different hunting strategies may in fact be related to social factors. Nonetheless, experimental studies with marked birds are required before a final conclusion concerning this issue can be made.

The results of this study have practical implications for the pound net fishery in Denmark and elsewhere. If the barrel nets, maybe especially those used during situation types 3 and 4, can be used under commercial conditions there is a possibility of reducing predation by cormorants in the pound nets and accordingly a potentially larger catch for the fishermen. If the catch by cormorants in pound nets can be reduced or prevented, it is likely that less or even no demand for bird regulation, for example by shooting can be practised in Denmark and elsewhere. That would be beneficial for managing practises because it would lead to a reduction in the total population, and furthermore with no shooting sighting distance would possibly be reduced. However, more studies under practical conditions are required to evaluate and confirm the beneficial effects of barrel nets for the commercial pound net fishery. Such studies are presently being carried out.

Considering the heavy cormorant predation in pound nets (Bildsøe & Jensen 1997), it is likely that a large fraction of their catch is obtained from this source. This may be a contributing factor to locally maintaining unnaturally high cormorant populations. Similarly, unnaturally high populations as a consequence of foraging possibilities at dumps have been reported for herring-gull *Larus argentatus* (Petersen 1984). A third example is provided by brent geese *Branta bernicla* feeding on winter rape seed (McKay, Bishop, Feare & Stevens 1993). In the case of cormorants the use of barrel nets reduce predation in pound nets substantially, and the birds are left to forage in free waters and probably in a less profitable way. This may in turn lead to a reduced cormorant population that better fits the carrying capacity of their natural environment.

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