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Sonar observations of killer whales (*Orcinus orca*) feeding on herring schools

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Abstract

Behavior of killer whales feeding on herring schools was recorded with a high frequency (455 kHz) sonar and recorded on a SVHS tape. Synchronization of surfacing behavior of killer whales was analyzed from 8 mm videotapes recorded between 1990–92. Two different feeding techniques, carousel feeding, where killer whales cooperatively herd herring schools into a tight ball towards the surface and feed on herring which have been stunned by tailslaps, and subsurface feeding were observed and compared. Subsurface feeding killer whales showed less coordination and spent less time around the herring schools than carousel feeding killer whales. Both feeding techniques were employed mainly in the upper 20 m of water but only carousel feeding killer whales brought the herring school to the surface. Subsurface feeding killer whales were observed approaching herring schools down to 98 m, but no feeding could be verified when the whales were deeper than 20 m. The possible causes for different techniques employed by killer whales feeding on herring are discussed as well as the apparent similarity of predator–antipredator behavior between schooling fish and their predators regardless of the species in question.

Introduction

Killer whales (*Orcinus orca*) have adapted to living in all oceans from polar ice edges to tropical waters and feed on a variety of prey including several species of fish, squid, seabirds, pinnipeds and cetaceans (Matkin & Leatherwood, 1986). However, killer whale populations show seasonal prey preferences (Bigg *et al*., 1987; Felleman *et al*., 1991) and the methods developed for catching different prey species, should play a central role in adaptation to different environments. Common to the feeding techniques described for killer whales feeding on different prey types is that they involve a certain degree of cooperation (Christensen, 1978, 1982; Steiner *et al*., 1979; Smith, 1981; Lopez & Lopez, 1985; Felleman *et al*., 1991; Guinet, 1991; Baird & Dill, 1995). In northern Norway, killer whales feed cooperatively on wintering herring (*Clupea harengus*) (Similä & Ugarte, 1993).

Underwater observations combined with knowledge of the behavior of the prey species are needed for better understanding of the feeding techniques used by killer whales. One of the feeding methods of the Norwegian killer whales, carousel feeding, has been studied with underwater videocameras (Similä & Ugarte, 1993). When carousel feeding, whales chase herring schools into a tight ball towards the surface and feed on herring which have been stunned by tailslaps. Because the use of an underwater videocamera is restricted to the upper water column, the present study addressed the feasibility of a high-frequency sonar to study the feeding behavior of killer whales at greater depths. The aim was to compare carousel feeding to other feeding techniques, especially to subsurface feeding which is the most common technique Norwegian killer whales use to catch herring.

Material and methods

The study was conducted between 12–17 November 1993 in Tysfjord, northern Norway, as a part of a larger study on the behavioral ecology of killer whales in the area (Similä & Ugarte, 1993; Similä *et al*., 1996). Tysfjord is part of the main wintering area of the Norwegian spring-spawning herring where an estimated 3.5 million ton of herring wintered from October 1993 to January 1994 (Anon, 1994). Feeding killer whales were located visually from a 10 m cabin cruiser. The feeding behavior was divided into three different categories: (1) 'Carousel feeding'; whales herded herring into a tight ball close to the surface with the whales lobtailing, porpoising, releasing bubbles and showing the white underside of their bodies while herding the fish. Fish scales, pieces of fish and stunned fish were observed at the surface (for a more detailed description, see Similä & Ugarte, 1993), (2) 'Subsurface feeding'; whales were actively milling in

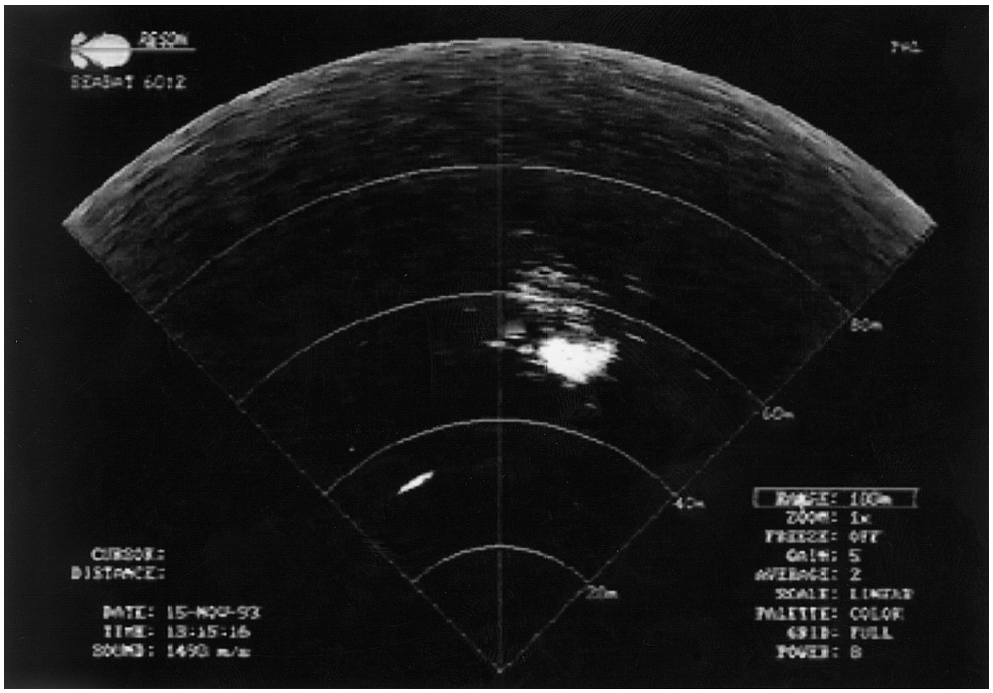

Figure 1. Subsurface feeding killer whale approaching a herring school; recorded with a 455 kHz sonar (set at 100 m range).

a limited area, at times porpoising and lobtailing. The fish school was not observed at the surface but fish scales or pieces of herring were observed at the surface, and (3) 'Travel-feeding', the whales were travelling, stopping occasionally to feed individually.

When the boat approached feeding killer whales, their behavior was observed on a continuous basis from the surface and at the same time the underwater behavior was recorded using a portable 455 kHz multibeam sonar (SeaBat 6012) which was mounted on an aluminum rig and operated from the cabin cruiser. The frequency of the sonar was outside the hearing range of both herring and killer whales (Enger, 1967; Hall & Johnson, 1972; Bain & Dahlheim, 1994). The angle of the sonarhead could be tilted on the vertical plane. The sonar sends out 60 beams of 1.5° each which gives a 90° view, the vertical width of the beam is 15°. The range resolution was 5–20 cm depending on the range. The sonar could be operated at ranges 2.5, 5, 10, 25, 50, 100 or 200 m and the update rate of the sonar increased from 3.5 times/second at 200 m range to 30 times/second at 2.5–20 m range. The details of the image increased with decreasing range due to the faster update rate and larger scale of the display at shorter ranges. The data was recorded on a SVHS-video tape.

The sonar tapes were sampled at 1 min intervals to observe the number of killer whales present close (closer than 20 m) to the herring school and the depths at which killer whales approached the herring schools.

Synchronization of surfacing patterns during carousel feeding and subsurface feeding were analyzed from surface video tapes recorded between 1990–1992. A total of 92 min of carousel feeding and 68 min of subsurface feeding were analyzed, all observations of synchronized surfacings of two or more killer whales were recorded from the tapes.

Results

Sonar recordings of killer whales and herring schools were made on ten occasions for a total of 208 min 16 s. Most of the recordings were made with the sonar range set at 50 or 100 m, which gave the best combination of overall view and detailed picture (Fig. 1). Two of the observations were of carousel feeding (40 min 33 s) and eight were of subsurface feeding (167 min 43 s) (Table 1). No observations were made of the travel-feeding behavior. All observations started when killer whales were already feeding.

While carousel feeding, killer whales were observed around the herring school during most of

Table 1. Subsurface and carousel feeding events recorded with sonar. Duration of the recordings, depth range where the herring school and killer whales were observed during the recording, number of sampling occasions with one minute intervals, number of sampling occasions where the herring school was with/without the killer whales and the number of whales observed in close proximity of the herring school at the sampling occasions

Time min. sec	Depth range of obs. (m)	Number of samples	Herring school		Number of whales			
			with whales	without	1	2	3	>4
Subsurface feeding								
3.13	69–89	3	2	1	1	1		
5.54	82–98	6	1	5	1			
19.12	65–98	20	2	18		2		
8.58	69–92	8	1	7	1			
5.30	9–19	5	2	3	1	1		
4.50	1–10	5	1	4			1	
39.43	1–13	39	7	32	2	2	3	
80.23	5–17	80	12	68	7	2	2	1
167.43	1–98	166	28	138	13	8	6	1
Carousel feeding								
26.48	0–10	26	16	10		1	2	13
13.45	0–15	13	10	3	2	1	3	4
40.33	0–15	39	26	13	2	2	5	17

the feeding bout (65% of the sampling occasions) and usually three or more killer whales (max. eight) were observed around the school at the same time (Table 1) and up to four killer whales were observed moving synchronously. The analysis of surface videos of carousel feeding revealed a high degree of synchronization; 6.9 synchronous surfacings/minute were recorded for the 92 min of videotape recorded during three different feeding bouts. The sonar observations of carousel feeding were similar to the description of Similä & Ugarte (1993) although it often could not be determined if the whales presented their dorsal or ventral side towards the fish (Figs 1 and 2). The killer whales were observed feeding on several small schools of herring simultaneously. It was not possible to determine whether the pod members had divided the herring schools between them or whether they circled and fed on all of them. During both observations of carousel feeding there was a larger shoal (40×60 m) at 60–80 m depth but the whales preferred feeding on the smaller patches at the surface.

While subsurface feeding, the whales were observed in close proximity to the herring school on 16.7% of the occasions sampled (Table 1). In contrast to carousel feeding, most of the time only one or two killer whales interacted with the ball of herring (Table 1) and the proportion of short approaches to longer circles around the fish school was larger compared to carousel feeding. Synchronized dives were observed only twice, and on four occasions more than three whales were observed interacting with the herring school. The number of synchronous surfacings was lower than during carousel feeding; an average of 2.5 synchronous surfacing/minute was recorded from the 68 min of videotape of surface behavior.

In the longest observation of subsurface feeding (80 min 23 s), a group of 12 killer whales (two adult males, two females, six adults/subadults and two juveniles) were feeding at two locations (500–600 m apart) at the same time. The killer whales spent most of the time feeding on herring at the location which was not observed with the sonar (500–600 m from the boat). Two different subgroups of the main group of 12 animals; a pair of adult/subadult whales or a group of four (a female and her calf and two adults/subadults) occasionally came to feed and dive around the ball of herring which was located closer to the boat and tracked continuously. In total, the whales spent 14 min 36 s (on four different occasions) with this herring school, which was observed swimming close to the surface (5-17 m) in a ball formation even without the presence of killer whales. The longest continuous period the herring ball was observed without any approaches from killer whales was 41 min 14 s. The size of the herring ball varied between 10–20 m in diameter as a result of changes in the density of the school.

Figure 2. Carousel feeding killer whale; image from a Hi-8 videorecording.

During all the observations of subsurface feeding (n=4), where feeding could be verified from pieces of prey floating at the surface, the whales and the herring school were at 1–20 m depth. A tailslap was observed once during these recordings. During four observations of subsurface feeding, killer whales were interacting with herring schools located at a depth of 50–100 m (the deepest dive recorded was approximately 98 m). Six approaches were observed to these schools, five by a single killer whale and one approach by two killer whales. No feeding could be verified. The killer whales either swam through (once) or passed the herring schools and no tail slaps were observed.

Discussion

Carousel and subsurface feeding techniques

During this study, as well as during previous field seasons, subsurface feeding was the feeding technique observed most frequently when killer whales were catching wintering herring in Norway, followed by carousel feeding and travel feeding. Since travel feeding was not observed during this study, only differences between subsurface and carousel feeding will be discussed. The surface behavior of subsurface feeding killer whales is less coordinated than of carousel feeding killer whales and the whales never bring the herring schools to the surface or use bubbles while herding. They also lobtail less than when carousel feeding. The sonar observations of subsurface feeding showed that the number of killer whales interacting simultaneously with the herring school was smaller than during carousel feeding and single whales were observed feeding successfully. In addition, the subsurface feeding killer whales spent less time around the herring school than when carousel feeding. Successful prey capture could be registered during both feeding methods through fish scales and pieces of prey floating at the surface. The sonar recordings were in general not suitable for observing prey capture since the images were not detailed enough, but tailslaps presumed to be used to stun fish were registered both during carousel feeding and once during subsurface feeding. The twenty meters which was used in this study as the limit for analyzing interactions between killer whales and the herring school, should be regarded as a minimum, since the encounter between the predator and prey could have started from a greater distance.

Feeding behavior of killer whales has been characterized as cooperative based on group movement patterns, synchronized respirations while chasing and encircling prey, division of labor and sharing of prey (Felleman *et al.*, 1991). In this study cooperation was determined based on the number of whales within a close proximity of the herring

school at the same time and synchronization of movements. Based both on surface and underwater observations, the subsurface feeding was considered to be less cooperative than carousel feeding. However, even if the killer whales do not coordinate their movements and single animals can feed successfully, they may still cooperate through acoustic communication and use vocalisations in a joint effort to herd the fish. Until the role of acoustic communication in cooperation and the use of vocalizations in herding the prey are understood, it is not possible to say if the subsurface feeding is less cooperative than carousel feeding. The nature of cooperation between killer whales is however different in these two feeding techniques.

Other dolphin species have also been reported to use different techniques in catching schooling prey (Evans, 1987; Belkovich *et al*., 1991) but there is no reference as to whether different methods are used to catch different prey species. There is no apparent reason for the use of different feeding techniques in feeding on herring; analysis of behavioral data collected between 1990 and 1993 have shown no correlation to habitat use or diurnal or tidal cycles in the occurrence of these techniques (Similä, unpublished data). The majority of the killer whale groups which have been identified in the wintering area of herring have been observed using both subsurface and carousel feeding techniques and it is unlikely that their occurrence is based on cultural differences.

It is possible that killer whales employ these different techniques as a response to differences in the behavior of herring schools. Differences in the behavioral responses of the Norwegian spring-spawning herring to vessel noise have been reported by Olsen (1990). A herring school which has recently been attacked or frightened might be easier to herd than a herring school in a more relaxed state and subsurface feeding could be a technique employed when recently attacked schools are encountered by killer whales. However, during carousel feeding, the herring school quickly gets into a frightened state but there is no decrease in the coordination or continuous effort in the behavior of killer whales during these feeding bouts.

Another possibility is that the elaborate carousel feeding sessions are used to teach herding and prey capture techniques to young individuals. The importance of teaching and learning has been well documented in killer whales feeding on marine mammals by intentional stranding (Guinet, 1991) and learning is probably important in the acquisition of other feeding techniques as well (Heimlich-Boran and Heimlich-Boran, in press). More underwater observations are needed of both subsurface and carousel feeding techniques to evaluate both the number of possible teaching and practicing events during the different methods and the relevance of techniques learned during carousel feeding in subsurface feeding.

The incident of subsurface feeding where a killer whale pod was feeding on a herring school and at the same time few individuals came at irregular intervals to investigate and feed on another school was another puzzling result of the study. One possibility is that the pod wanted to feed first on one school and then start feeding on another one which was kept in a tight ball close to the surface by some of the pod members. However, the pod lost interest in both schools at the same time and started resting. In addition, during earlier observations (Similä & Ugarte, 1993) and during the present study, killer whales always stopped feeding before consuming the whole school of herring, so it is unlikely that the whales would eat more than one school during a feeding bout.

Killer whales feeding on small herring schools close to the surface

The results of the present study as well as earlier observations (Similä & Ugarte, 1993) show that the killer whales feed on small schools of herring in an area where herring is mainly present in large shoals. The general diurnal migration pattern of wintering herring in Tysfjord is an early morning descent to 150–350 m and ascent to 50–70 m during the night (Røttingen *et al*., 1994). Isolated schools are observed to form during the downwards migration, especially in areas with varied bottom topography (Egil Ona, pers. comm.). Small herring schools have been observed in the upper 100 m of water during daytime especially in the shallower (less than 200 m) areas of the fjord (Similä, unpublished data). It is possible that such isolated schools are the primary target of killer whales and/or that the killer whales are able to chase out schools from the wintering layer at deeper waters.

The killer whales prefer feeding close to the surface; carousel feeding occurs always close to the surface and even most (78%) of the subsurface feeding observed in this study occurred at the same depth as carousel feeding. In the minority of the observations of subsurface feeding (22%), killer whales were observed approaching herring schools located at 52–98 m depth. When killer whales were located at such depths their behavior could not be verified as feeding behavior and the approaches were short in duration (no circling around the herring). However, feeding could have taken place and remained unnoticed, since it is unlikely that fish scales or pieces of fish would have appeared at the surface from such depths.

Other dolphin species feeding on schooling fish have been reported feeding close to the surface (Norris & Dohl, 1980; Würsig & Würsig, 1980;

Belkovitch *et al*., 1991; Fertl & Würsig, 1995) and the close proximity to the surface has several benefits for the whales. For the first, the sea surface acts as a barrier aiding in herding the prey. Secondly, killer whales are able to use visual stimuli in herding fish; the black and white coloration of killer whales could act as a 'flash' effect in scaring the herring (Würsig *et al*., 1990). A third advantage is that the whales save energy when they do not have to make long and deep dives between a feeding location and the surface where they need to return for breathing. Energetic considerations have been shown to be important in the choice of food patches and feeding depth in humpback whales (*Megaptera novaeangliae*) (Dolphin, 1987).

Killer whale as a predator on herring

The antipredator behavior of a given prey species is thought to have been shaped during an 'evolutionary arms race' with its predator and the prey should be ahead of this race as a species (Dawkins & Krebs, 1979). However, Parrish (1992) and Pitcher & Parrish (1993) suggest that cetaceans that are large relative to their prey and have the advantage of long-range detection may be ahead of this arms race and actually benefit from the antipredator behavior of schooling fish. The tight ball formation dominated the antipredator behavior of herring schools recorded in this study (Leif Nøttestad, pers. comm.). The formation of a tight school, which might be an effective antipredator mechanism towards other predators, is a poor way of avoiding killer whale predation, since the whales can find these concentrations over long distances through echolocation and herd and keep the schools close to the surface. However, the herring also benefits from the formation of the tight schools. At least during carousel feeding, the whales only exploit the herring in the periphery of the school, leaving the fish individuals in the centre of the school relatively protected and unlike large baleen whales feeding on schooling fish, the killer whales do not consume most of the school.

The antipredator behavior of schooling fish as well as the behavior of their predators is surprisingly similar regardless of the predator and prey in question, which does not support the idea of a tight 'evolutionary arms race' between schooling prey and their predators. For example, the antipredator behavior of herring schools attacked by killer whales (Leif Nøttestad, pers. comm.) is very similar to the antipredator behavior of sandeel (*Ammodytes* sp.) schools attacked by mackerel (*Scomber scombrus*) (Pitcher & Wyche, 1983). The way killer whales herd herring is similar to the way bottlenose dolphins (*Tursiops truncatus*) herd jacks (Belkovich *et al*., 1991), the way dusky dolphins (*Lagenorhynchus obscurus*) herd southern anchovy (*Engraulis anchovita*) (Würsig & Würsig, 1980) and the way spotted dolphins (*Stenella frontalis*) feed on clupeid fish (Fertl & Würsig, 1995). The Norwegian killer whales have once been observed feeding on a school of mackerel during summer, and based on surface behavior the killer whales behaved like they do while feeding on herring schools.

It can be argued that the killer whale is probably a predator of marginal importance to herring (herring is also preyed on by various fish species, marine birds, toothed and baleen whales and seals) and therefore there might not be a strong evolutionary pressure to develop killer whale specific antipredator techniques. However, as suggested earlier, it seems likely that herring is either unable to discriminate predator types or the cost of developing different antipredator strategies would be too high.

Herring schools could avoid killer whale predation by escaping downwards before the killer whales close in. The extent of such behavior is not known since the herring schools studied so far have been observed when killer whales are already close to the schools but there is one documented incidence of a herring school escaping to the sea bottom when killer whales approached a fjord (Kjell Olsen, pers. com.). Herring schools have been observed escaping to deeper waters from herding killer whales a few times, but at least carousel feeding killer whales are probably preventing this by continuously swimming under the fish school (Similä & Ugarte, 1993).

Feasibility of a high-frequency sonar in studying cetacean behavior

Underwater observations are a valuable tool in studying the feeding behavior of cetaceans. The use of the SeaBat sonar-video system in studies of marine mammal behavior was introduced by Guinet *et al*. (1993). The advantage of this system is that it can easily be operated even from a small boat and the high frequency range (which limits the operation range) is outside the hearing range of both cetaceans and their prey species. Compared with a videocamera, the sonar gives a wider view of the behavioral events, allows observations to be made at considerable depths and regardless of water visibility, and since a sonar can be operated from a greater distance the possibility of disturbing the natural behavior can be minimized. The lack of details in the sonar images is the main disadvantage of a sonar compared with a videocamera.

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