Acoustic measurement of the fish assemblage beneath killer whale pods in the Pacific Northwest

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ABSTRACT

This study demonstrates the utility of acoustic techniques for making quantitative measurements of marine mammal prey. High densities of large single fish targets in the upper 30 m of the water column were measured during feeding by killer whales *(Orcinus orca)* in the Greater Puget Sound area. In summer, adult Pacific salmon (*Oncorhynchus* spp.) represented the dominant species of large single fish in the upper 30 m of water during daylight. Simultaneous visual and acoustic observations were made when a resident pod of killer whales switched from foraging to travelling as the near surface density of salmon decreased by sevenfold. High numbers of near-surface fish schools were also measured beneath a transient pod of milling killer whales and beneath a feeding minke whale *(Balaenoptera acutorostrata)*. The application of these procedures can enhance the study of feeding ecology in marine mammals and the evaluation of the type and extent of fishery interactions.

INTRODUCTION

The use of acoustic methods in assessing fish abundance and behaviour has been described in detail by Forbes and Nakken (1972), Bruczynsky (1979), Thorne (1983), Mitson (1983) and others. Acoustic assessment of marine fishes, especially Pacific salmon (*Oncorhynchus* spp.), has become a routine practice by many fisheries management agencies in the Pacific Northwest (Thorne 1983). Recently, acoustic techniques also have been applied to the measurement of fishes in the vicinity of known concentrations of marine mammals (Whitehead and Glass 1985; Krieger and Wing 1986).

Killer whales *(Orcinus orca)* prey on many different species and exhibit varying degrees of cooperative foraging that may be related to the size and schooling tendencies of their prey (Felleman 1986). Although cooperative foraging techniques facilitate the detection and capture of a wide variety of prey, different killer whale ecotypes appear to show different specializations in prey choice. These are most evident where populations of the ecotypes are sympatric (Berzin and Vladimirov 1983; Felleman *et al.* in press). The development of acoustic techniques to determine prey choice would significantly aid in the study of the feeding ecology of killer whales and other marine mammals.

Killer whales are historic residents of the Greater Puget Sound area (the waters of the San Juan Islands of Washington and the Gulf Islands of British Columbia) (Curtis 1915), and we assume they are familiar with the temporal and spatial characteristics of their prey's availability (Heimlich-Boran 1986 in press; Felleman *et al.* in press). The live-capture of killer whales in Greater Puget Sound 1962–1973 prompted scientists to begin studying the species' biology in about 1973 (Bigg and Wolman 1975; Bigg 1982; Balcomb *et al.* 1982; Bigg *et al.* 1987). Photoidentification of individual whales has enabled investigators to document the stability of group structure. The infrequency of immigration or emigration suggests that killer whale groups in Washington and British Columbia, at least, are composed of extended families or pods (Bigg 1982). Pods in the Pacific Northwest have been described as three discrete "stocks" or clans: northern "resident", southern "resident", and "transient" (Bigg 1982). The southern resident stock, which frequents Greater Puget Sound, consists of about 81 resident whales in three pods (J, K and L). Also, at least six of the 30 transient pods known from Washington and British Columbia (Bigg *et al.* 1987) occasionally enter this region.

Bigg (1982) noted that movements of resident pods from headland to headland along the major straits were more systematic than those of transient pods, which tended to enter embayments. He suggested that this dissimilarity might be a result of the transients' unfamiliarity with the habitat. Felleman *et al.* (in press) suggested that such differences reflect differences in prey choice of the two whale ecotypes. Furthermore, they presented data indicating that from spring to fall resident pods prey primarily on fish, especially salmon, whereas transient pods more frequently prey on harbor seals *(Phoca vitulina)*.

The present study demonstrates the use of acoustical techniques to quantify the fish assemblages associated with killer whale pods in Greater Puget Sound. Specifically, fish targets that co-occur with whale pods are classified by depth, and whale behaviour is examined in relation to changes in fish density and distribution.

METHODS

Study area

The study was conducted in Greater Puget Sound (Fig. 1). This region is the center of distribution for the southern resident killer whale population (Felleman *et al.* in press) and is a

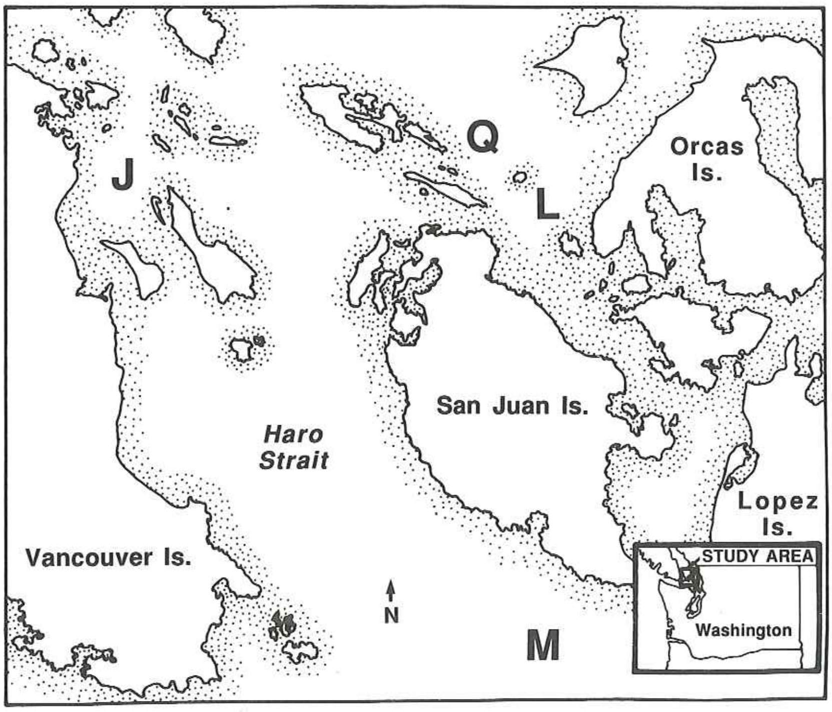

Fig. 1. Location of encounters with resident (J and L) and transient (Q) killer whale pods and a feeding minke whale (M) in the San Juan and Gulf Islands along the U.S.-Canada border.

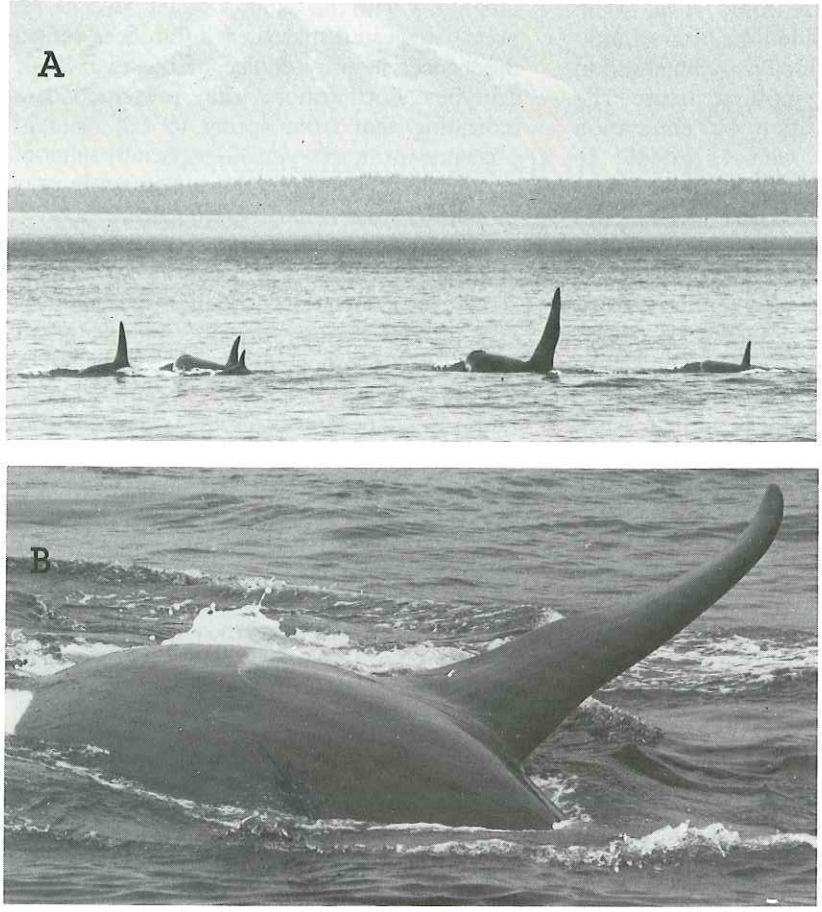

Fig. 2. A. Killer whales foraging in flank formation in Boundary Pass, Washington; Mount Baker is in the background.
B. Single male killer whale milling in pursuit of a salmon (visually observed but not in photo).

major route for mature salmon returning to the Frazer River to spawn (Stasko *et al.* 1976). The study area is a deep (100–300 m), glacially carved, estuarine habitat with strong tidal currents, often exceeding 1 m/s. High and low tides have unequal, semidiurnal patterns; maximum high and low tides are about plus 3 m and minus 1 m, respectively (Mofjeld and Larsen 1984).

Acoustic data acquisition

A portable SIMRAD EYM scientific echosounder was used to transmit and receive acoustic data. The frequency was 70 kHz, the pulse length was 0.6 ms and the half-angle of the transducer at the –3 dB points on the directivity was 14 degrees. The transducer was mounted on the transom of 6 m Boston Whaler which was run about 2 m/s during the collection of acoustical data. The boat was steered to remain within 25 m of the killer whale pod under study. Acoustic returns and calibration signals were monitored in real time on the SIMRAD chart recorder and SONY-TEKTRONICS 305 oscilloscope. Data were recorded for analysis on analog tape with a SONY TCDM5 cassette recorder. System gain was set in the field to permit recording the largest targets without tape saturation.

Acoustic data processing

Acoustic data from magnetic tapes were analyzed with a 7000 series TEKTRONICS storage oscilloscope and BIOSONICS dual beam

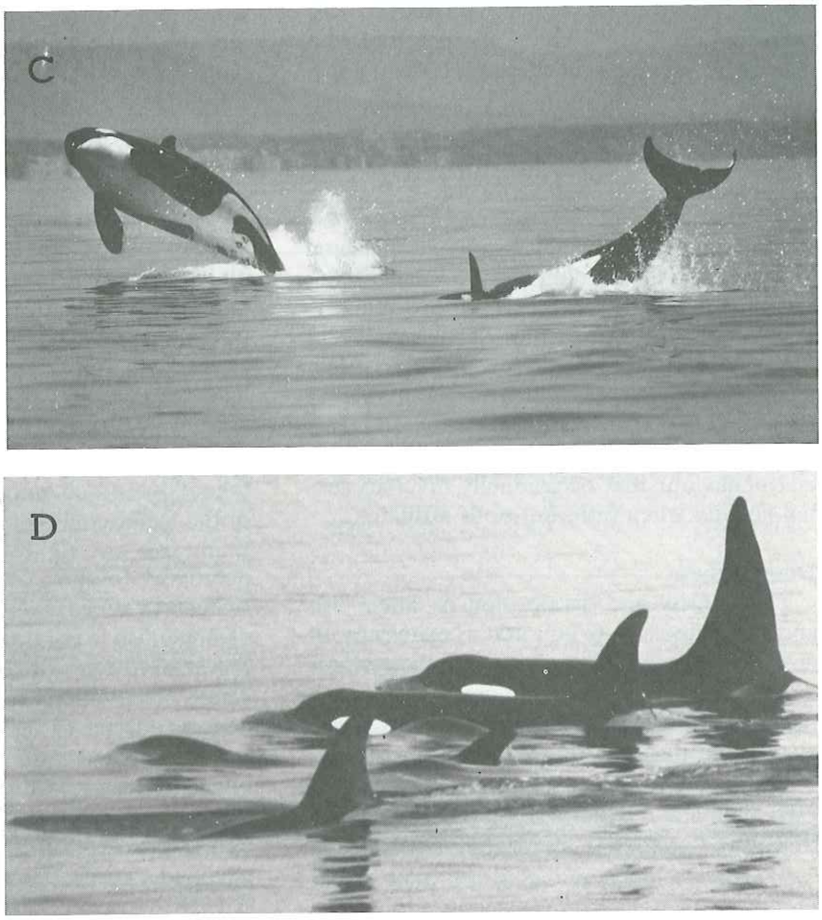

Fig. 2. C. Percussive foraging of killer whales. D. Killer whales showing tight, synchronous activities, often indicative of resting behaviour. (Photos by F. L. Felleman).

processor. The BIOSONICS version 5.02 dual beam data reduction program was used to count single and multiple targets using the minimum and maximum –6 dB pulse widths of 0.3 and 0.8 ms, and 0.8 and 3.0 ms, respectively. These thresholds were determined by examining the acoustic data tapes on a storage oscilloscope prior to analysis. Data logs included time of day, type of target, and target depth.

The beam directivity pattern was determined by the duration-in-beam technique (Thorne 1987). The selection of depth intervals for acoustic processing was based on the vertical distribution of fishes, as recommended by Thorne and Thomas (1984). Previous studies have shown that in the daytime Pacific salmon are in the upper 30 m of the water column (Mathisen and Nunnallee 1975), while Pacific hake *(Merluccius productus),* another possible prey of the killer whale in the study area, are between 50 and 100 m (Thorne 1973, 1977). Therefore, analysis was conducted for 10 m depth intervals from the surface to 100 m or the bottom. Whale behaviour was recorded every 15 min using a scan-sampling procedure (Altmann 1974), and acoustic and behavioural data were cross-referenced using time-of-day marks on the data logs.

The whales' surface behaviour was classified using the eight categories defined by Osborne (1986) as follows: traveling – directional movement of the pod at about 3 to 5 knots;

percussive traveling – characterized by fast travel, in excess of 5 knots, interspersed with splashing; foraging – feeding typically characterized by travel of the pod in flank-formation, interspersed with bouts of milling (Fig. 2 A); milling – fast non-directional surface movement that indicates pursuit of surface-oriented prey (Fig. 2 B); percussive foraging – various movement which produces splashing and may aid in herding prey (Würsig 1986; Heimlich-Boran in press) and coordinating changes in group direction (Felleman 1986; Fig. 2 C); resting – a slow, synchronous, directional movement of a tightly grouped pod (Fig. 2 D); play- characterized by extensive breaching activities; and intermingling – a social behaviour that occasionally involves sexual activity when different pods affiliate.

Data analysis

The density and distribution of single fish and fish schools were counted as echoes by 10 m depth intervals as an index of their abundance. These data were summarized for each period in which the behaviour of a whale pod was monitored for 15 min or more. Fish schools were not echo-integrated because of their small size and high packing densities (Fig. 3).

RESULTS AND DISCUSSION

From June to October 1984, about 100 hours of behavioural data were collected on over 40 pod encounters. However, sea surface roughness or variable swimming speeds of

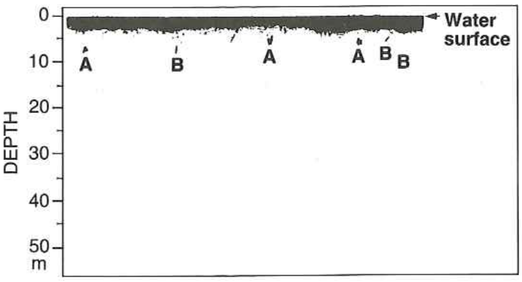

Fig. 3. Chart recording of the acoustic returns from near-surface, small herring school (A) and single salmon (B) targets in Puget Sound, Washington State.

whale pods often produced high noise levels and thereby prevented collection of acoustic data. In fact, the conditions were favourable for collecting acoustical data on near-surface fish density during only three encounters totalling only 6 hours. These encounters involved two resident pods (J and L) and one transient pod (Q). Acoustic data from an encounter with a feeding minke whale *(Balaenoptera acutorostrata)* are included to illustrate the applicability of the technique to this species. During these four encounters 12,987 fish targets were recorded, of which 78% were single fish and 22% were fish schools (Table 1).

More than 85% of the single fish and schools observed were within the upper 30 m of the water column (Table 1). The density of single fish was highest $9.33 \times 10^{-4}/m^3$ during percussive foraging by a resident pod. The pod switced to slow travel as the average densities of single fish in the upper 30 m decreased from that high to a low of $1.26 \times 10^{-4}/m^3$ (Table 1). These observations suggest the importance of concentrations of large, single fish near the surface to these resident whales in choosing to begin and end feeding. The density of fish schools was highest during the brief (24 minutes) observation of feeding by the minke whale (Table 1). The two highest ratios of fish schools to single fish occurred during the obsevations of the minke whale (1058:2546) and during observations of feeding by a transient pod (819:2203) (Table 1). Collectively, these data suggest that fish schools may be important to the diet of both minke whales (as suggested by Dorsey 1983) and transient killer whales in this area. The densities of single fish and fish schools were lowest during observations of slow traveling by a resident pod.

Sources of error

Thorne (1983) states that the use of hydroacoustic techniques has three specific limitations when applied to the assessment of fish density and distribution: 1) the detection of targets near boundaries, such as the surface and bottom, 2) the acquisition of biological information (such as identity of species) on the

TABLE 1

Vertical distribution of single fish 1) and fish schools 2) in the vicinity of pods of killer whales. Except where noted, average fish density is expressed as the number of fish × $10^{-6}/m^3$. Pods are identified in Bigg (1982).

Date/Time of encounter	*29 Aug/1610–1840*				*16 Sept/0935–1115*		*20 Sept/1657–1830*		*29 Sept/1446–1500*	
Pod	*J (Percussive foraging)*		*J (Slow travel)*		*L (Resting)*		*Q (Milling)*		*Minke whale (Feeding)*	
Depth interval (meters)	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*
0–10	2000	263	213	30	1630	486	1990	714	2100	900
10–20	650	71	105	11	127	24	149	73	231	80
20–30	151	17	61	6	282	44	46	22	90	32
30–40	37	6	19	3	14	1	14	9	50	14
40–50	14	2	10	1	7	1	3	1	31	8
50–60	5	0	5	0	5	0	1	0	20	7
60–70	5	0	3	0	3	0	0	0	8	5
70–80	0	0	2	0	0	0	0	0	5	4
80–90	0	0	19	0	0	0	0	0	5	4
90–100	0	0	10	0	0	0	0	0	6	4
0–100	2862	359	447	51	2086	556	2203	819	2546	1058
Percent	89	11	90	10	79	21	73	27	71	29
Average density of single fish upper 30 m (per m^3) . .	9.33×10^{-4}		1.26×10^{-4}		6.80×10^{-4}		7.28×10^{-4}		8.09×10^{-4}	

targets, and 3) the potential bias from assuming an incorrect target strength. In this study we made assumptions concerning all three.

Assessment of fish within 30 m of the surface by echosounders can underestimate fish density, because the fish sometimes avoid or are displaced by large survey vessels (Olsen *et al.* 1983). In this study, we used the following techniques developed by Thomas (1979) and Thomas *et al.* (1979) to reduce this problem: small planing-hull survey boat, slow survey speeds, wide transducer directivity and bowsprit mounted transducer. Thorne and Thomas (1984) showed that implementing such measures for acoustic data acquisition can permit some fishes to be assessed accurately to within 2 m of the transducer. They also presented procedures to allow estimation and correction of near-surface bias. In our study fish densities were consistently high nearest the surface, suggesting that near-surface biases were not a problem.

The identification of fish targets to species is a primary concern in most acoustic studies. This usually requires sampling of the targets by netting. However, acoustic targets can sometimes be classified with a high degree of confidence if the observer has knowledge of the fish assemblages common in the area, such as species composition, schooling behaviour, depth distribution and seasonal occurrence.

In this study the vertical distribution of single fish and fish schools was restricted primarily to the upper 30 m of the water column. In Greater Puget Sound during the summer, adult Pacific salmon and Pacific herring *(Clupea harengus)* are the common large single and school targets, respectively, near the surface during daylight periods (Thorne *et al.* 1983; Thorne and Aims 1987). Our visual observations of the catches in the local commercial and sport fisheries during 1984 indicated that sockeye salmon *(Oncorhynchus nerka)* was the most abundant salmon species in the area.

Other species, such as Pacific hake, walleye pollock *(Theragra chalcogramma),* pelagic rockfishes *(Sebastes spp.)* and spiny dogfish *(Squalus acanthias)* might have contributed to the counts of single-fish targets. In our study area and period, however, the first three are seldom near the surface during daylight (Thorne *et al.* 1983). Spiny dogfish are often at the surface near fish schools, but have low target strengths because they lack a gas bladder. The northern anchovy *(Engraulis mordax)* and Pacific sandlance *(Ammodytes hexapterus)* also form fish schools in the study area that could have contributed to the counts of fish schools.

In general, without estimates of the target strength of the fishes involved one cannot estimate absolute fish density except by using the duration-in-beam technique for echo counting of single fish (Thorne in press). In this technique, the sample volume is determined from the average number of echoes from single fish at a given depth. Although we used the duration-in-beam technique to determine sample volumes, we present the data as relative density because we did measure boat speed.

More sophisticated techniques, such as dual-beam and echo-integration, can be used to determine *in situ* target strength, for distinguishing large fish from small, and to estimate the size of fish schools (Thorne 1979). If the size distributions of fish or schools had varied, dual-beam, echo-integration, sector scanning and possibly split beam procedures would have been necessary (Thomas and Jackson 1987; Traynor and Williamson 1982). However, these techniques were not used in this study because most of the fish targets were single adult salmon or small (< 2 m^3), dense schools of Pacific herring, with the result that the two most common acoustic targets were relatively small.

Whale and fish interactions

The most serious limitation with attempts to correlate acoustic observations of fish with observations of whale behaviour is the difficulty of collecting enough whale encounters to enable statistical testing. Despite the small sample size, our obsevations provide independent corroboration of the findings of other investigators that resident killer whales in Greater Puget Sound feed on salmon (Heimlich-Boran 1986, in press; Felleman 1986; Felleman *et al.* in press). Also, the observations of transient whales milling (and presumably feeding) over concentrations of fish suggest that these transient whales do not prey exclusively on marine mammals. During our observations of feeding transient whales, the densities of both schools and single fish were high. In fact, whenever school densities were high, so also were densities of single targets. More research on the relative proportions of single fish and schools beneath transient whales may help to determine how much the diets of resident and transient killer whales overlap.

Information on the feeding behaviour of marine mammal populations suspected of competing with human fisheries is in high demand (Beddington *et al.* 1985). Acoustic techniques offer the user a synoptic view of the interaction between marine mammal predators, especially cetaceans, and their prey, and provide yet another non-lethal technique for studying protected species of marine mammals, as called for by the International Whaling Commission (1988).

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