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An Assessment of Killer Whale (*Orcinus orca*) Stocks off Vancouver Island, British Columbia

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ABSTRACT

A study of photographically identifiable individual killer whales was undertaken during 1973–81. In all, 30 pods were found, containing about 260 whales. A pod is a long term family or kinship group which periodically joins with others to form communities. Around Vancouver Island there are two resident communities and one transient community. The three communities do not associate with one another. Resident and transient killer whales differ in pod size and behaviour. The coastal range of movements for most resident pods is probably about 300 nm. Transient pods appear to range further. Births occur mainly during fall and winter. At birth, lengths average about 8 ft. First pregnancies generally occur at 16 ft, or at an age of at least 6.7 years. Sexual maturity occurs in males at 19 ft, or at an age of at least 12 yrs. A long term stability in pod composition permits direct measurement of vital statistics. The rate of calf production to an average age of six months is 10.30% per cow. The minimum interval between calving is three years. Many cows apparently rarely give birth. Annual natural mortality rates average 2.80% for bulls, 0.70% for cows and 2.30% for juveniles. Pods increase at an average net rate of 2.52% per year. Exploited pods have a slightly higher productivity than unexploited pods.

INTRODUCTION

A small live-capture fishery for killer whales occurred in British Columbia and Washington during 1962–77 to supply oceanaria (see Bigg and Wolman, 1975). This resulted in the need for an assessment of stocks in local inshore waters. Although the species was known to be relatively common here, no estimates were made of abundance or other population parameters. Prior to the live-capture fishery the species was unexploited in this region.

During 1973–81 a study was undertaken to determine abundance, movements and population biology of the species around Vancouver Island. As will be shown later, most of the whales inhabiting waters of British Columbia and Washington are probably seen here at various times of the year. The study was based on observations recorded while following photographically identifiable individual whales. Such individuals were encountered repeatedly.

The study began at the end of the live-capture fishery and thus monitors pod changes following exploitation as well as those in pods which were not exploited. Most pods cropped prior to the start of the study have now been identified from early photographs and tape recordings of vocalizations taken at the site of the live-captures. Ford and Fisher (1982) show that vocalizations of local killer whales exhibit unique features for each pod.

Bigg, MacAskie and Ellis (1976) prepared a preliminary report on abundance and movements of the species in local waters. K. C. Balcomb, J. Boran and co-workers (Orca Survey, Friday Harbor, Washington) have also conducted studies of the population biology and behaviour of some of the same whales using photographic identification of individuals. Two reports concerning their findings from 1976 to 1980 are available (Balcomb, Boran, Osborne and Haenel, 1980; Balcomb, Boran and Heimlich, 1982).

This report is a summary of analyses which are still in progress. Emphasis is placed on estimating the age at sexual maturity and comparing birth rates, natural mortality rates and changes in population size between exploited and unexploited pods. Only brief treatment is given for three basic findings of the study on individual identification and behaviour. These findings are now well established in the form of unpublished data at the Pacific Biological Station and to some extent in the preliminary reports by Bigg *et al.* (1976) and Balcomb *et al.* (1980, 1982). Detailed supporting data will be provided at a later date. The first finding is that each killer whale is uniquely marked and thus identifiable from a good photograph. This fact permits a count of all individuals within a pod. Secondly, pods are discrete long term breeding units which are composed of the same individuals. The absence of movement by individuals between pods permits an estimation of birth and mortality rates within each pod. Finally, the species in this region is non-migratory and thus the environmental controls which act on the population dynamics of pods occur within local waters.

METHODS

Killer whales were located primarily by volunteer observers who live or travel along the shore. Such people relayed by telephone, information on the location, time of sighting and direction of pod travel. Pods were intercepted using a 16 ft boat equipped with a 50 hp motor. As many as possible of the whales present were photographed and counted. Encounters were also made by waiting in areas frequently used by killer whales.

Photographs were taken with a 35 mm SLR camera and a 300 mm telephoto lens mounted on a shoulder brace. The film used was *Kodak* Tri X Pan taken and developed at 1200 ASA. Typically the shutter speed was 1/1000 sec. The most useful photographs were taken within 100 ft of the whale, at a right angle to the dorsal fin.

About 24,000 photographs were taken. J. Ford (University of British Columbia) took an additional 4,000 photographs while studying the acoustic behaviour of the species. These data are included in the current study. Several thousand other photographs were examined which were taken by a variety of people such as observers at the live-capture sites and boaters who encountered whales

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incidentally to marine activities. Individual whales were identified from negatives examined with a dissecting microscope. Some whales were so distinctively marked as to be identifiable by eye without a photograph.

The individual composition of pods J, K and L off southern Vancouver Island was determined from an exchange of information and photographs with K. C. Balcomb, J. Boran and co-workers (Orca Survey). The individual whale composition of these pods are the only data from this research group which are incorporated into the current study.

RESULTS AND DISCUSSION

1. Study area

The main study area was eastern Vancouver Island (Fig. 1). This was the most easily studied region in British Columbia because of the greater abundance of whales, the relatively protected waterways and the large number of observers here compared to other localities. Additional areas studied include Puget Sound, Washington, western Vancouver Island and the inshore coast north of Vancouver Island. No field studies were done on the Queen Charlotte Islands. Apparently there are few killer whales to be found there, according to fishermen.

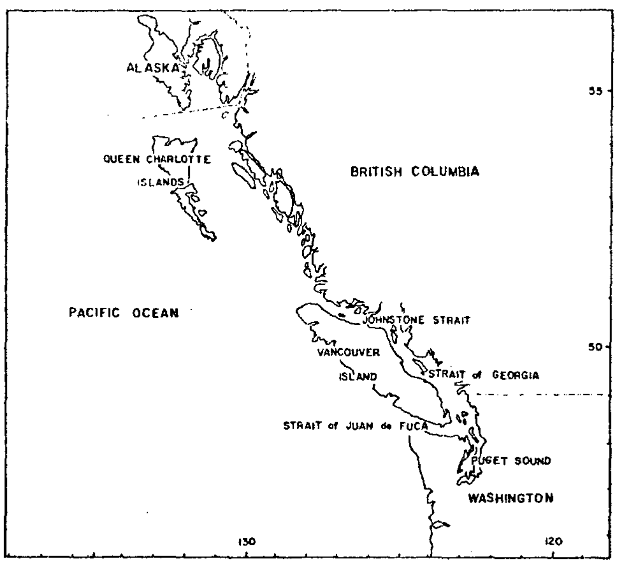

Fig. 1. Geographical locations mentioned in the text.

2. Number of encounters

Based on early photographs and current data, killer whales were recorded on 359 days during 1965–81. Generally whales were observed on 25–40 days during each year from 1973–80, except in 1974–75 when they were encountered on 58 and 80 days respectively. There were five encounters from early 1981 included in this study. Approximately 40% of encounters occurred during July–August with the remaining proportion from all other months of the year.

3. Individual identification

The features used for identification include shape and size of the dorsal fin, shape of the saddle patch, nicks and tears in the dorsal fin and scars on the saddle patch and back. Figure 2a–d shows examples of identifying features. The shape of the dorsal fin varies considerably from falcate to erect and from rounded at the apex to pointed. Numerous subtle differences exist when the fin is viewed in silhouette from the side. Relative size can usually be estimated by comparison with that of other killer whales. The fins of adult females do not change in shape or size with increasing age. Those of adult males seem to develop structural weaknesses eventually, which result in curling at the tip, less rigidity of the fin and, in three cases, complete collapse of the fin to lie flat along the side of the body.

The shape of the saddle patch is variable from closed, or horizontal tear drop pattern, to open as in the form of a thin S shape, with many intermediate patterns. Its shape on the left and right sides of the body is generally slightly different in detail, but it can differ substantially. Newborn calves do not have a pigmented saddle pattern for several months. Once formed the pattern does not change.

Nicks and tears occur most frequently on the posterior edge of the dorsal fin. These injuries range from barely noticeable to major tissue loss. In one case about two thirds of the fin was gone. Nicks and tears are permanent markings which do not fill with replacement tissue. Thus the shape and location of injuries are characteristic for individuals. This was shown to be true experimentally in an adult male. On 23 October 1973, a bull (K1) which had been captured by Sealand of the Pacific, Victoria, was surgically marked with two nicks, as shown in Fig. 3a–b, and then released. Since then the whale has been photographed each year up to 1980. The marks remained essentially unchanged. An important point to note concerning the shape of injuries on a growing fin is that these tend to elongate slightly and become more shallow.

Scars frequently occur on the saddle patch either as dark or white lines. If a scar remains for about two years it will become a permanent and useful mark. Some scars are not injurious enough to last a year. Nevertheless, such scars are still useful for identifying calves and young individuals which often have few other unique features.

4. Recognition of sex and maturity

Adult males are the most easily recognized category, having an erect dorsal fin generally 3.5–5.5 ft in height. The identification for most bulls is probably certain. Some subjectivity exists when designating the year in which a maturing male should be called a bull when it is followed for several years.

Adult females are distinguished by a dorsal fin 1.5–2.5 ft in height which does not change in size or shape over several years. The shape for individuals varies considerably from falcate to triangular. Individuals which are accompanied by a calf are assumed to be adult females.

Most juveniles are distinguished by their obviously small fin and body size. Changes in dorsal fin size and subtle changes in shape are apparent each year as the whale grows. Difficulties in identification of this category arise when females approach maturity and the fin changes only slightly each year. Some cows are probably included in the juvenile category. Juvenile males and females cannot be distinguished from the shape of the dorsal fin or saddle patch.

Calves, during their first year, are recognizable by their very small size and close association with their mothers. The fin is short and usually falcate in shape. Calves do not have a saddle patch for the first few months.

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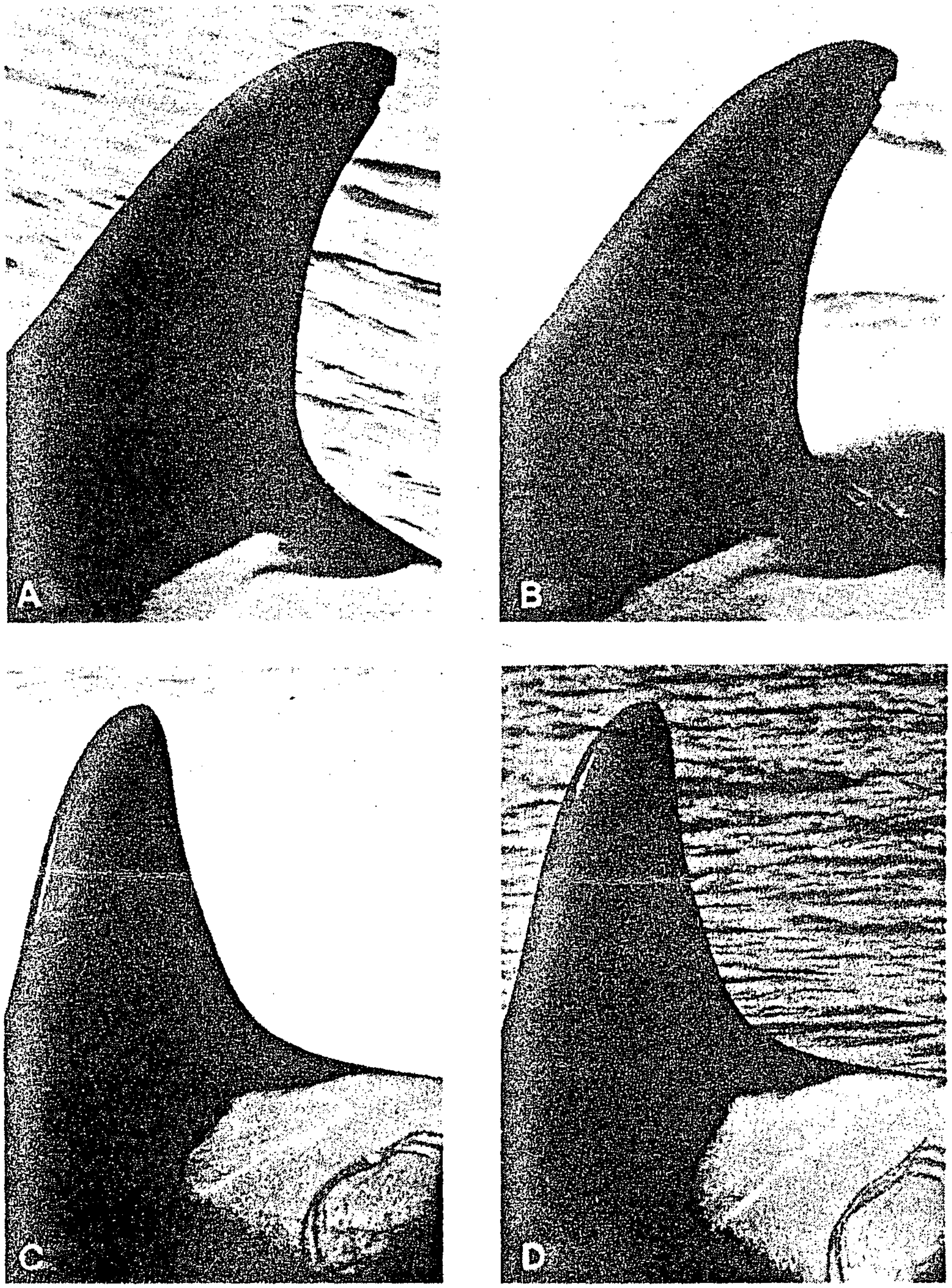

Fig. 2. Examples of the permanence of natural markings used to identify individual killer whales.
A. Cow J4 on 2 August 1975;
B. Cow J4 on 2 June 1980;
C. Cow J8 on 26 May 1975;
D. Cow J8 on 18 May 1979.

5. Pod characteristics

(a) Individual associations

Among the types of social groupings found in cetaceans, the killer whale pod is unique. Evidence on file at the Pacific Biological Station, is now extensive that the pod consists of the same individuals which travel together throughout the year and over a period of at least seven years. In addition, photographs taken at a live-capture in 1968 indicate that four individuals from one pod (J) have been in association for 13 years. A pod may join with others on occasion for varying lengths of time, although typically for no more than a few weeks. When the aggregation divides it does so according to the respective components of each pod. Periodic joining of pods can create difficulties in determining which individuals occur in a pod when that pod is encountered infrequently. Except for one large pod (L pod, 50 whales), which may be in the process of fragmenting, pods generally do not split for more than a few hours or days. Thus, recognition of a single individual will generally indicate that the remaining members of its pods are nearby.

No new pods were observed to form during this study. It is likely that new pods form through the gradual splitting of established pods over perhaps several decades. In this case, related pods would probably spend gradually less time in association with one another. Also, it may well be that new pod formation occurs along the maternal lineage. Evidence is now compelling that within a pod the young remain associated with their mothers into adulthood. Maternal

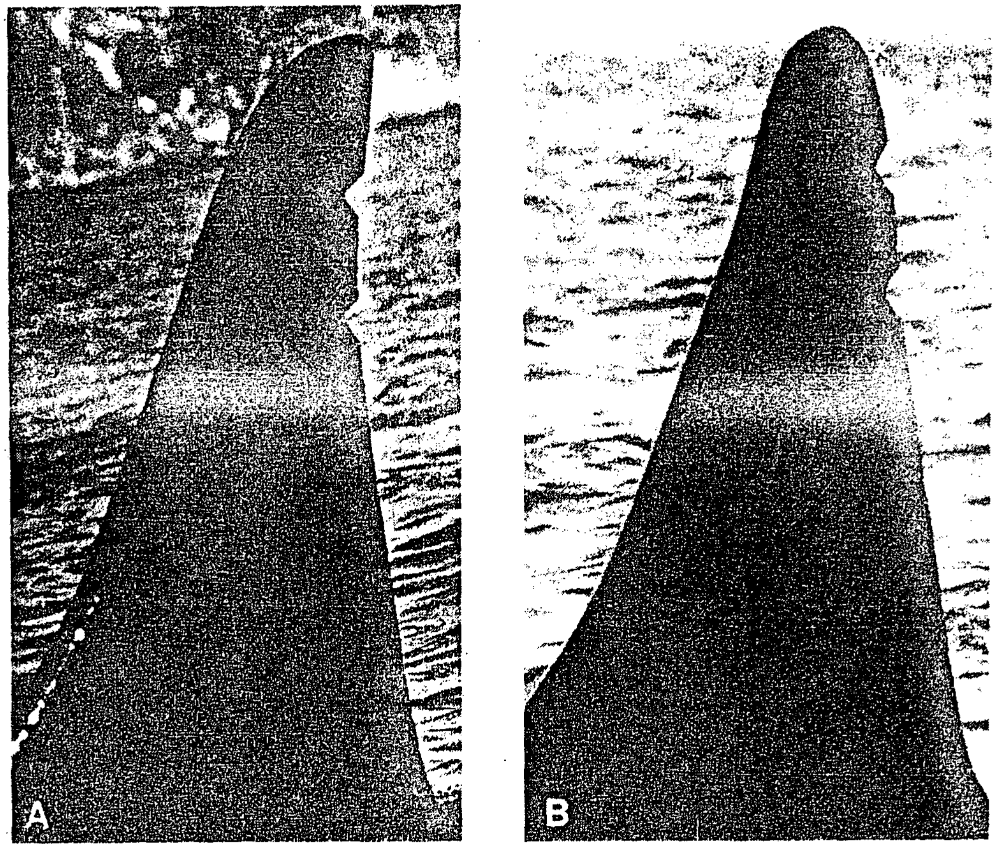

Fig. 3. Experiment showing the permanence of two surgically made nicks on the posterior edge of the dorsal fin. The nicks were made on 23 October 1973.
A. Bull K1 on 27 July 1974;
B. Bull K1 on 22 June 1980; fin tip differs slightly in shape from A due to curling.

associations tend to form distinct subgroups within pods. In no cases were individuals observed to move out of one pod and into another on a permanent basis.

(b) Pod size and composition

Table 1 presents the size of each pod identified during the most recent or most accurate count and notes the estimated sex and maturity composition. The accuracy given for pod size is thought to be exact for most and probably within one individual for the remainder. There are 30 pods recorded totalling 261 individuals. Typically a pod contains 5–20 whales but can range from 1–50. Solitary individuals are rare and can be either male or female. Some small pods (<7 whales) contain no adult males. At the other extreme is one pod (B) of eight whales which contains five adult males.

Usually a pod contains adult males, adult females, some juveniles and occasionally a new calf. An average composition for the pod can be derived from Table 1 by using data from selected pods for which the appropriate number of each sex and maturity are known. Based on all pods except E, the bull composition of which is unknown, bulls comprise an average of 23.0% (59/256) of individuals in a pod. The average proportion of cows, using all pods except E, P, R, S1, T, U, V, W, X and Z, is 34.1% (70/205). This figure is probably somewhat lower than actual because the juvenile category probably contains some cows. Calves, or young of the year, comprise 4.4% (11/252) when pods E and T are omitted. Finally, juveniles comprise 38.5%, the remaining proportion to total 100%.

(c) Pod types

Pods which occur in the study area are either resident or transient. These differ in behaviour and pod size. Around Vancouver Island there are 15 resident pods totalling 214 individuals and 15 transient pods with 47 whales. Resident pods are seen frequently during the summer months and in some cases all year. Transient pods are seen infrequently and during irregular times of the year. Residents tend to travel continuously going from headland to headland along the coast in a predictable manner while transients tend to travel along the shoreline and in an unpredictable manner. They often change directions and diving times, and sometimes remain at one feeding reef for several hours. Resident pods only associate with other resident pods while transients associate only with other transients. Resident pods all contain more than five individuals while transients have five or fewer. Resident pods tend to have a smaller range than transients. Residents exist in two communities with a distinct boundary while transients travel throughout the ranges of all resident pods. It is unclear whether transient pods originate from resident pods or from a stock located elsewhere.

(d) Pod movements

Resident pods are divided into northern and southern communities which do not mix, although the pods within each community do associate with one another. Off eastern Vancouver Island, the two communities have a boundary line located across northern Georgia Strait as shown in Fig. 4. The southern community consists of three pods, J, K, and L, totalling 79 whales in 1980. The range of J pod is

Table 1

Pod size and composition from the most recent or most accurate count off Vancouver Island.

	Pod	Size	Number of bulls	Number of cows	Number of juveniles	Number of calves
N	A1	14	5	4	5	0
N	A4	7	1	3	2	1
N	A5	12	1	4	6	1
N	B	8	5	1	2	0
N	C	9	4	3	2	0
N	D	10	4	2	4	0
T	E	5*	1+	?	?	?
T	F	1	1	0	0	0
N	G	19*	4	5	11	1
N	H	6	1	2	3	0
N	I1	16*	4	5	6	1
N	I11	6	0	3	3	0
S	J	19	3	8	7	1
S	K	10	2	5	3	0
S	L	50*	9	16	24	2
T	M	3	1	1	0	1
T	N	1	1	0	0	0
T	O	5	1	3	1	0
T	P	2*	1	?	?	0
T	Q	5	0	3	2	0
N	R	19*	3	?	?	1
T	S1	4	0	?	?	0
T	S8	1	0	1	0	0
T	T	4*	2	?	?	?
T	U	4	0	1+	?	1
T	V	2	1	?	?	0
N	W	9*	3	?	?	0
T	X	5	0	1+	?	1
T	Y	3	1	1	1	0
T	Z	2	1	?	?	0
	Total	261	60	72	82	11

* Size accuracy is probably within one individual; all other pod sizes are thought to be exact. The juvenile category excludes calves but may include a few cows.

confined year round to Georgia Strait and Puget Sound, about 230 nm (425 km). Pods K and L travel throughout the range of J pod and also into Juan de Fuca Strait and to areas of unknown extent off the west coast of Vancouver Island and Washington. However,

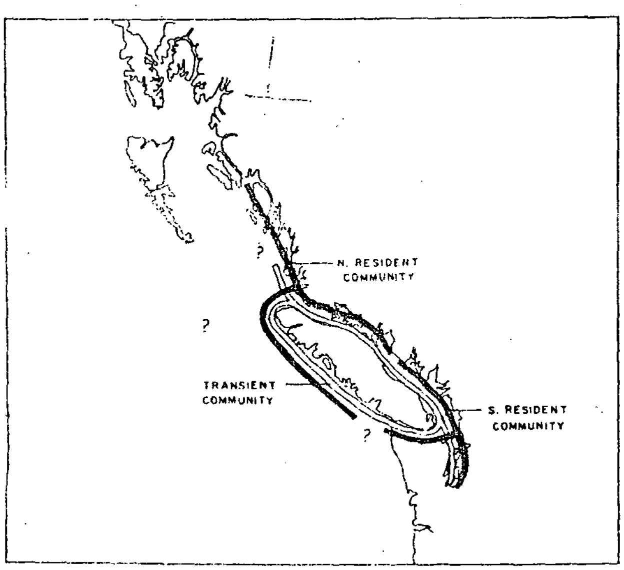

Fig. 4. The usual ranges of two resident communities and one transient community of killer whales around Vancouver Island.

these two pods occur off eastern Vancouver Island during all months of the year and thus do not range far beyond the study area. Their range is at least 300 nm (556 km).

The northern community consists of 12 pods, A1, A4, A5, B, C, D, G, H, I1, I11, R, and W, with about 135 whales. Its coastal range is about 300 nm (556 km) from northern Georgia Strait to about 100 nm (185 km) south of the northern border of British Columbia. Summer studies indicate that killer whales rarely occur off the northern border. Pod A5 is known to range along the coast for at least 270 nm (497 km). As with the southern community the range of individual pods varies. Some pods (G, I11) are known to frequent the west coast of Vancouver Island. The extent of travel to offshore areas is unknown. The coastal range of most resident pods is probably about 300 nm.

The geographical discreteness of the two resident communities suggests a territorial division of the waters off eastern Vancouver Island. Only on rare occasions do pods from one community travel into the range of the other. About 210 nm (390 km) separate the central areas of summer abundance of the two communities along eastern Vancouver Island. This is only 2.5 days travelling time at an average speed of 3.5 knots.

The transient pods form a community similar to that of the residents. Of the 15 transient pods identified ten are known to associate with one another. Unlike the resident pods, they comprise a single community which forms a loose network of associations encircling Vancouver Island. The transient pods do not respect the boundary line of resident pods. The largest range of a transient pod (Q) is 340 nm (630 km). The ranges of other pods vary. The extent of movement offshore is not known.

(e) Pods cropped

The identity of pods which were cropped during the live-capture fishery was determined from photographs and tape recordings of vocalizations. The photographs used were those of distinctively marked individuals which were caught and later released or were not captured but remained near the entrapped whales. Generally only a few useful photographs were available for most captures. Because pods sometimes travel together it is possible that some other captured pods were also present but not photographed. J. Ford (pers. comm.) identified several pods which were captured, by recognizing the unique vocalizations of each. He used tape recordings obtained at the capture site or from whales which had been taken to oceanaria.

Table 2 gives data on the number, sex and length of whales removed from pods identified as having been cropped. From 1962 to 1977, a total of 65 killer whales was removed from pods around Vancouver Island. Of these, the pods for 53 whales were identified. A total of 14 whales in 3–4 pods were removed from the northern resident community, 34 whales in three pods from the southern resident community and five whales from two transient pods. An additional 12 whales were removed from pods which have not yet been identified. Data on these latter captures are given in Table 3. Only one whale came from northern Vancouver Island, ten came from southern Vancouver Island and one from the west coast of Washington.

Of the 30 pods recorded around Vancouver Island only nine are known to have been cropped. By far the largest number (34) were removed from the three pods in the

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Table 2

Number, sex and length of individuals removed from pods known or suspected of having been cropped.

Pod	Capture date	Number removed	Immature					Mature	
			8–11 ft			12–15 ft	12–18 ft	16 ft+	19 ft+
			F	M	?	F	M	F	M
N. Resident									
C[1,2]	June/65	1							1
I11[1]	July/67	1					1		
A(A5)[2]	Apr/68	6		1		1	1	3	
A5[1,2]	Dec/69	6	1			2	2	1	
		14	1	1		3	4	4	1
S. Resident									
J or K or L[2]	July/64	1					1		
J or K or L[2]	Oct/65	2				1		1	
K[1,2]	Feb/67	8	1	2		1	2	1	1
J[1], L[2]	Oct/68	5		1			3		1
J, K, L[1,3]	Aug/70	11	1	4	2	1	2	1	
L[1]	Aug/71	3				2	1		
J[1]	Mar/72	1					1		
K[1]	Aug/73	1						1	
L[2]	Aug/73	2					1	1	
		34	2	7	2	5	11	5	2
Transient									
M[1]	Mar/70	3	1			1		1	
Q[1]	Aug/75	2				1		1	
		5	1			2		2	
Total		53	4	8	2	10	15	11	3

[1] Evidence of pod identification from photographs.
[2] Evidence of pod or identification from vocalizations provided by J. Ford (pers. comm.).
[3] J not identified but almost certainly present due to the large number captured (80 whales) and the fact that these three pods often travel together and with no other pods.

southern resident community. Most, if not all, of the ten whales taken from the as yet unidentified captured pods off southern Vancouver Island probably also came from the same three pods. These are by far the most accessible for capture in this area. Assuming that the southern resident community was cropped of 44 whales it is possible to determine the likely extent of reduction. In 1974, which was essentially the end of the cropping period, these three pods contained 67 individuals (J = 14; K = 10; L = 43). It will be shown later that cropped pods have an annual net increase of 3.01%. By back calculating the population level to 1967, using the annual increase less annual cropping, a reduction in total abundance of about 27% (89 to 65) occurred from 1967 to 1973. These pods were thus moderately reduced and were included as cropped pods in the following comparisons between cropped and uncropped pods.

Within the northern community probably only one pod, A5, was cropped to any extent. In 1968–69, at least six and probably 12 whales were removed. Not until 1973 was a count of the pod made, at which time it contained ten individuals. As this is a substantial reduction it was included as a cropped pod in subsequent analyses. The removal of single individuals from pods C and I11 in 1965 and 1967 can probably be considered as having a negligible effect on productivity of these pods during 1973–80. Thus, for purposes of subsequent analyses, these pods were considered uncropped. The two transient pods which were cropped both experienced large proportional reductions (although small in numbers) and were included as cropped pods.

The sex ratio of whales removed from pods was about equal (31 females, 30 males). All sizes were taken although most were immature.

6. Body growth

(a) Birth size

Nishiwaki and Handa (1958, p. 91) examined records kept by whalers off Japan and concluded that birth occurred at about 9 ft. Based on the same type of data, Jonsgård and Lyshoel (1970, p. 47) suggested that off Norway birth lengths were close to 7 ft. Lengths taken from five newly born stranded calves in British Columbia indicate a birth size of about 8 ft. Four males were examined by staff of the Pacific Biological Station and found to be 7 ft 4.5 in, 7 ft 5 in, 8 ft 0 in and 8 ft 2.5 in. Carl (1946, p. 27) reported a newly born female killer whale at Cherry Pt., Vancouver Island of length 8 ft 1 in.

(b) Postnatal growth

Males attain an average maximum length of 29.2 ft and females an average of 25.6 ft based on records of whalers. The maximum lengths given for males and females, respectively, in five separate studies were as follows: 31 ft and 27 ft off Japan (Nishiwaki and Handa, 1958, p. 91); 32 ft and 28 ft off Norway (Jonsgård and Lyshoel, 1970, p. 48); 24 ft and 23 ft off Norway (Christensen, 1980, p. 12); 29 ft and 25 ft in the Southern Hemisphere

Table 3

Number, sex and length of individuals removed from captures for which no pod identity has yet been assigned.

Region	Capture date	Number removed	?	Immature 8–11 ft F	Immature 8–11 ft M	Immature 12–15 ft F	Immature 12–15 ft ?	Immature 12–18 ft M	Mature 16 ft+ F	Mature 19 ft+ M
NE Vancouver Is.	July/68	1						1		
S. Vancouver Is.	Sept/62	2							1	1
	July/66	1						1		
	Feb/68	2			1				1	
	Apr/69	1								1
	Oct/69	1	1							
	Feb/70	1					1			
	Aug/70	1		1						
	Aug/77	1		1						
		11	1	2	1		1	2	2	2
W. Washington	Mar/73	1							1	
Total		12	1	2	1		1	2	3	2

(Mikhalev, Ivashin, Savusin and Zelenaya, 1981, p. 556); and 30 ft and 25 ft in the Antarctic (Ivashin, 1981, p. 225).

The body growth rate recorded in captive killer whales provides a guide to the growth rate potential in the wild. Fig. 5 depicts the likely growth pattern of males and females from 9.5 ft to 23 ft based on three captive males and five captive females. The growth curves for individual whales have been aligned approximately, to show the general growth pattern for each sex. Up to about 16 ft in length males and females grow at similar linear rates averaging 1.2 ft/yr for the five year period required to increase from 10 ft to 16 ft. There are data on only two males and one female longer than 16 ft. Growth after 16 ft appears to slow in both sexes with the female ceasing growth after 19 ft while the two males continue to grow.

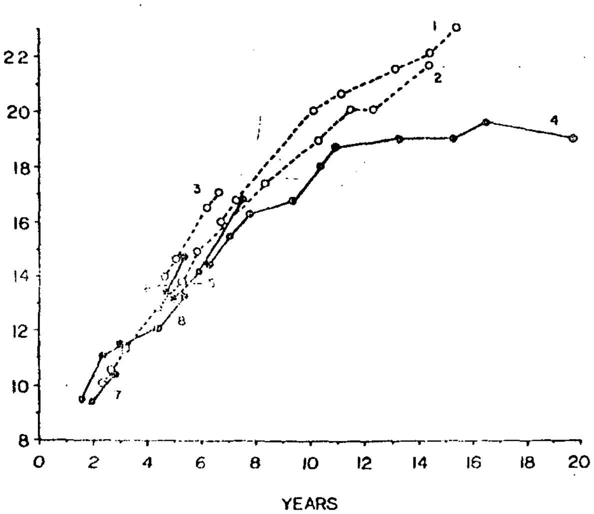

Fig. 5. Body growth in three captive male and five captive female killer whales. Open circles = male; solid circles = female; 1 = Haida (Sealand of the Pacific); 2 = Hyak (Vancouver Public Aquarium); 3 = Orky (Marineland of the Pacific); 4 = Skana (Vancouver Public Aquarium); 5 = Corky I (Marineland of the Pacific); 6 = Shamu (Sea World); 7 = Patches (Marineland of the Pacific); 8 = Miracle (Sealand of the Pacific).

7. Reproduction

(a) Length and age at sexual maturity

Most females appear to become pregnant for the first time at 16 ft in length. Jonsgård and Lyshoel (1970, p. 46) report length frequencies for 59 pregnant females taken off Norway (Table 4). The smallest pregnant female was 15 ft. A marked increase in the number of pregnancies occurred at 16 ft. Data collected by Christensen (1980), also off Norway, confirm these findings (Table 4). Mikhalev *et al.* (1981, p. 559) observed that all females 17–25 ft in length taken in the Southern Hemisphere were mature (Table 4). Only one smaller female was examined, it being 12 ft and immature. Assuming that births occur at 8 ft, most first pregnancies at 16 ft and the annual growth rate is 1.2 ft/yr, then females mature at about age 6.7 yr. However, this figure is probably too low for killer whales in the wild as the latter probably grow more slowly than captive whales.

Available data suggest that males mature at about 19 ft in length. Jonsgård and Lyshoel (1970, p. 46–47) examined the testes of three males taken off Norway and found that two, of body lengths 22 ft 10 in and 21 ft 8 in, were sexually mature while one, of 18 ft 4 in, was approaching maturity. They concluded that maturity occurs at 19 ft. Mikhalev *et al.* (1981, p. 557) recorded the weight of one testis from each of 57 males of body lengths 18–28 ft taken in the Southern Hemisphere. Weights increased sharply from 18 ft (4.4 kg, $n = 2$) to 19–20 ft (7.0 kg, $n = 6$), increased slightly at 21 ft (8.8 kg, $n = 6$) and again at 22–28 ft (11.5 kg, $n = 43$). On the basis of increases in testis weight, these authors felt that sexual maturity probably begins at 21 ft. However, these data could also be interpreted to suggest maturity at 19–20 ft.

Length at sexual maturity in males can be indicated by the body length at which the dorsal fin of the male is clearly longer than that of the female as the large size of the dorsal fin in the male is a secondary sex characteristic. Fig. 6 shows the relationship between dorsal fin height and body length in both sexes. The data come from measurements of three captive whales, 17 stranded killer whales reported by Carl (1946, p. 23) and from unpublished data collected by the Pacific Biological Station. The dorsal fin of the adult female (≥16 ft) reaches 1.5–2.5 ft in height. In males the fin reaches 3 ft in height beginning at about 17–18 ft in body length. By 19 ft the fin averages about 3.5 ft. In field observations of the current study, a whale with a dorsal fin of about this height would be classified as a young bull.

Assuming maturity to occur at 19 ft, then the age at sexual maturity would occur at about 10 yrs according to the growth curve of two captive males in Fig. 5. However, as the growth rate in wild killer whales is probably slower, the age at maturity would be later. Based on photographs, a preliminary examination of the growth rate in the dorsal fin of males suggests an age at sexual maturity of at least 12 yrs. For this method the shape and size of the fin was observed in males from calves to age 6–7 yrs and in those which were encountered as medium sized juveniles and then followed annually into adulthood. Juveniles were sexed occasionally from the appearance of the external genitalia which were photographed when the whale jumped clear of the water.

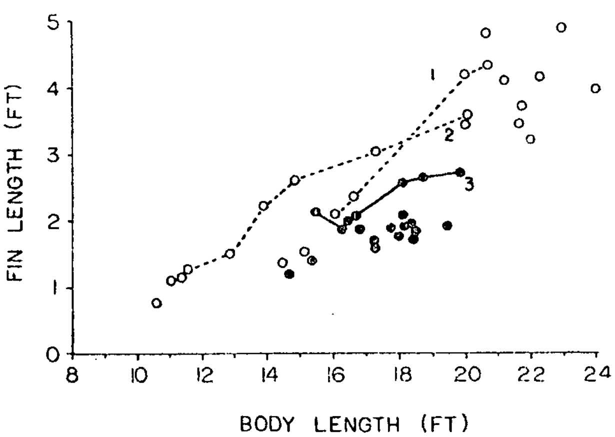

Fig. 6. Relationship between body length and dorsal fin height in males (open circles) and females (solid circles). 1 = Haida (Sealand of the Pacific); 2 = Hyak (Vancouver Public Aquarium); 3 = Skana (Vancouver Public Aquarium); for the source of other points see text.

(b) Pregnancy rate

Data collected by whalers produce conflicting results on the incidence of pregnancy in adult females (≥16 ft) off Norway, in the Southern Hemisphere and in the Antarctic. Pregnancy rate can be estimated for Norway during 1938–67 using data derived from two histograms presented by Jonsgård and Lyshoel (1970, p. 46–47). These authors note (p. 41) that whalers provided data on body lengths and pregnancy for each whale caught. The number pregnant at each length can be accurately taken from their Fig. 4 and the total number of females killed for each length closely approximated from their Fig. 5. These data are given in Table 4. From this the pregnancy rate for mature females is 14.8%.

This rate is much lower than that derived from similar data provided by Christensen (1980) for Norway during 1978–79, by Mikhalev *et al.* (1981) for the Southern Hemisphere during 1961/62–1978/79 and by Ivashin (1981) for the Antarctic in 1979/80. These data are also presented in Table 4. However, unlike the data from Jonsgård and Lyshoel (1970), theirs are based on samples of the total kill. At this time it is unclear if these samples were collected randomly. Their results indicate that mature females have a pregnancy rate of 40.5% off Norway, 27.5% in the Southern Hemisphere and 42.3% in the Antarctic. Reasons for the diversity of values remain unclear particularly for the two studies off Norway. It is important to note here that the rates given assume a gestation length of 12 months or less. If the gestation length is greater than 12 months then the pregnancy rate will be lower. At present the duration is unknown. There are no data on pregnancy rates for killer whales around Vancouver Island.

(c) Birth rate

An estimate of birth rate in cows from exploited and unexploited pods can be made from the incidence of calving in individual cows followed for consecutive years off Vancouver Island. This rate was calculated from the proportion of the summed number of consecutive years for

Table 4

Pregnancy rates, by length and maturity from four studies.

Study	Length (ft)														
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Total
Jonsgård and Lyshoel (1970)															
Number females	39	48	55	83	72	53	29	28	9	6	4	2	1	1	430
Number pregnant	1	8	9	12	10	4	4	5	3	2	0	0	0	1	59
% pregnant—by length	2.6	16.7	16.4	14.5	13.9	7.5	13.8	17.9	33.3	33.3	0.0	0.0	0.0	100.0	13.7
—≥16 ft = 14.8															
Christensen (1980)[1]															
Number of females	8	20	35	26	17	16	3	3	1						129
Number pregnant	1	11	15	12	5	4	1	0	1						50
% pregnant—by length	12.5	55.0	42.9	46.2	29.4	25.0	33.3	0.0	100.0						38.8
—≥16 ft = 40.5															
Mikhalev *et al.* (1981)															
Number females			2	8	7	15	16	21	15	4	3				91
Number pregnant			0	4	8	4	2	7	4	1	1				25
% pregnant—by length			0.0	50.0	28.6	26.7	12.5	33.3	26.7	25.0	33.3				27.5
—≥16 ft = 27.5															
Ivashin (1981)															
% pregnant for mature females = 42.3 (141/333)															

[1] One 19 ft female omitted due to uncertain pregnancy.

which all cows were followed against the total number of calves born during these 'cow years'. The year in which a cow was first observed was designated as year 1. The use of 'cow year' in this instance required knowing whether a cow gave birth in the preceding year, or year 0. Thus, for the calculation, if a cow was observed for five consecutive years after year 0 and was seen to give birth once during this time, then the annual birth rate would be 20.0%. Table 5 gives these data for cropped, uncropped, and combined pods. The average birth rate for cropped pods is 9.77%, for uncropped pods 6.94% and for combined pods 9.17%.

Table 5

Annual birth rate for female adult killer whales off Vancouver Island.

Pod	Number Cows	Number Cow yrs	Number Calves	Birth rate (%)
Cropped				
A5	5	37	4	10.81
J	8	64	7	10.94
K	5	35	1	2.86
L	16	112	11	9.82
M	1	6	1	16.67
Q	2	12	2	16.67
	37	266	26	9.77
Uncropped				
A1	5	35	3	8.57
A4	3	24	2	8.33
O	3	13	0	0.00
	11	72	5	6.94
Total	48	338	31	9.17

An estimate of birth rate for cows can also be made more directly from the ratio of calves to cows as given in the most recent or most accurate census for each pod in Table 1. This method would give the same results as that preceding if the same pods and individual whales were involved in both methods. However, while there is some overlap, the data are different enough to allow a second interpretation from more of the data base. Using the second method, the proportion of calves to cows in exploited pods A5, J, K, L, M and Q is 13.51% (5 calves, 37 cows) while for unexploited pods A1, A4, B, C, D, G, H, I1, I11, O, S8, and Y it is 9.09% (3 calves, 33 cows). The average for combined pods is 11.43%. When the two methods are averaged the birth rate for cows in cropped pods is 11.64%, in uncropped pods 8.02% and in combined pods 10.30%. Thus, exploited pods have a higher birth rate than unexploited pods.

Table 6

The calving interval based on consecutive year observations of 26 cows.

	Years						
	1	2	3	4	5	6	7
1. Completed interval							
Cropped pods			5	1			
2. Minimum interval							
Cropped	2	4	7	4	2	9	4
Uncropped		1		1	1		4

The birth rate in exploited pods is slightly less than the pregnancy rate derived from Jonsgård and Lyshoel (1970) for the species off Norway. The latter population can also be considered exploited as it has been hunted for many years. It should be noted that the birth rate for whales off Vancouver Island is actually the production of calves to an average age of about six months rather than to birth. Births occur mainly during the fall and winter in this region while most field observations are during the summer. The pregnancy rate is likely to be higher than the birth rate as some mortalities would be expected between birth and six months of age.

The net recruitment rate of calves, expressed as a percent of calves against all other whales in the pod, can be determined from Table 1. Here the average rate for exploited pods A5, J, K, L, M and Q is 5.32% (5 calves, 94 other ages) and the rate for the unexploited pods, which consist of all other pods except E and T, is 4.08% (6 calves, 147 other ages). The average rate for all pods is 4.56%. The rate can also be determined by applying the birth rate from cows to the percentage composition which cows comprise in the population. The birth rates for cows has already been calculated and the percentage of cows in the population can be taken from Table 11. The result, when adjusted for the proportion of calves against other ages, is 3.79% in cropped pods, 2.21% in uncropped pods and 3.23% for combined pods. The averages for the two methods are 4.56%, 3.15% and 3.90%. These figures are in general agreement with the International Whaling Commission (1981, p. 142) which reported 6.95% calves and small juveniles (7–12 ft long) travelling with 734 individuals of other ages in the Antarctic. The proportion of calves only would be less.

(d) Calving interval

The interval between successive births in individual cows off Vancouver Island was recorded on six occasions. For most cows, only the minimum calving interval could be noted. This is the period for which a cow was followed and either did not produce another calf or the date for the preceding birth could not be established because it occurred prior to the start of the study. These data are given in Table 6. The shortest interval recorded between births in cropped pods was three years. No complete intervals were recorded in uncropped pods. An interesting finding is that there were many cows for which the minimum birth interval was 6–7 years. These cows were either barren, which seems unlikely for such a large component of the cow population, or did not breed, perhaps for social reasons.

An average annual birth rate of 11.64% for cows from cropped pods indicates an average calving interval of 8.59 years. For cows in unexploited pods with a birth rate of 8.02% the interval is 12.47 years. These intervals are very long when compared to the minimum observed completed interval of three years (Table 6). The species is clearly breeding at a much lower rate than its potential even within the exploited pods.

8. Natural mortality rates

Ohsumi (1979, p. 403) provides the only estimate of natural mortality rate for the species. To do this, he established the relationship between length, natural mortality rate, maximum life span and maximum body length for various species of toothed and baleen whales which were studied and used these relationships to derive

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mortality rates for the unstudied species. He concluded that the natural mortality coefficient for male and female killer whales was 0.094–0.095 (= annual mortality rate of 8.97–9.06%).

Mortalities recorded in pods off Vancouver Island were those which resulted from natural causes as there was essentially no fishery for the species during the study. An estimate of the average annual natural mortality rate for bulls, cows and juveniles was made using the 'whale year' unit, as with the estimate for birth rates. Here the mortality rate is the proportion of the number of years in which all individuals of a category were followed against the number of individuals of that category which died during these years. Death was assumed to have occurred when a whale was recorded as missing from its pod, as there is no evidence that killer whales leave their pod permanently under any other circumstances. The individuals used in deriving mortality rates were those which were relatively well marked to ensure that their absence from the pod was noticeable. The year in which a whale was first observed is designated as year 0. Application of the 'whale year' unit to mortality rates, unlike birth rates, requires knowledge of events (deaths) following the initial encounter. Thus, for this calculation, if a whale was observed to be alive for four consecutive years after year 0 and then was observed to die (i.e. was missing) in year five, the annual mortality rate would be 20.0%.

(a) Bulls

Table 7 lists the number of 'bull years' and mortalities in cropped and uncropped pods. Only those males which were identified as bulls when first encountered were included. Juvenile males which became adults during the course of the study were omitted. Bulls in cropped pods had a slightly lower mortality than those in uncropped pods. The average annual rate for all pods was 2.80%. This is considerably less than that suggested by Ohsumi (1979) for the species and is also lower than for other cetaceans noted by him. Converting the average annual mortality rate to life span indicates that males live for an average of 36 yrs as adults. When the estimated maturation period is added, which is at least 12 yrs, bulls live for an average of at least 48 yrs.

Table 7

Annual natural mortality rate of adult males off Vancouver Island.

Pod	Number bulls	Number bull yrs	Number bulls dead	Annual mortality rate (%)
Cropped				
A5	1	7	0	0.00
J	3	21	0	0.00
K	3	12	1	8.33
L[1]	6	35	1	2.86
M	1	5	0	0.00
	14	80	2	2.50
Uncropped				
A1	3	20	1	5.00
A4	1	7	0	0.00
B	2	14	0	0.00
C	4	28	0	0.00
D	2	12	0	0.00
H	1	7	0	0.00
O	1	4	1	25.00
Y	1	5	0	0.00
I11	1	1	1	100.00
	16	98	3	3.06
Total	30	178	5	2.81

[1] Excludes one bull (L8) which apparently drowned accidentally from entanglement in a fishing net (Orca Survey, pers. comm., 9 May 1981).

(b) Cows

Table 8 reports the number of cows which died within exploited and unexploited pods. Only females which were considered to have been adults throughout the study were included.

Table 8

Annual natural mortality rate of adult female killer whales off Vancouver Island.

Pods	Number cows	Number cow yrs	Number cows dead	Annual mortality rate (%)
Cropped				
A5	5	32	1	3.13
J	8	56	0	0.00
K	5	30	0	0.00
L	16	96	0	0.00
M	1	5	0	0.00
	35	219	1	0.46
Uncropped				
A1	5	30	1	3.33
A4	3	21	0	0.00
O	3	10	0	0.00
Y	1	5	0	0.00
	12	66	1	1.52
Total	47	285	2	0.70

Only two cows were recorded as dying during 285 cow years observed. The average annual rate for cows in all pods was 0.70% which implies an average life span of 143 years as an adult. This appears to be an unrealistically low mortality rate although no obvious bias is apparent and the sample is large. The rate for cows should be lower than that for bulls as there are more cows than bulls. The low rate could be a random error as the death of only 2–3 cows by the next year of sampling would raise the mortality rate to a more realistic level.

(c) Juveniles

Table 9 gives the natural mortality rates for juveniles by pod. Males and females are combined. Here juveniles

Table 9

Annual mortality rate of juvenile killer whales off Vancouver Island.

Pod	Number juveniles	Number juvenile yrs	Number juveniles dead	Annual mortality rate (%)
Cropped				
A5	7	28	1	3.57
J	8	39	1	2.56
K	3	15	0	0.00
L	13	66	0	0.00
M	1	3	1	33.33
	32	151	3	1.99
Uncropped				
A1	4	17	1	5.88
A4	2	6	0	0.00
	6	23	1	4.35
Total	38	174	4	2.30

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consist of calves (av. age six months) and other immatures. Thus, the mortality rate does not include the period from birth to six months. The small number of juveniles followed in unexploited pods makes comparisons of mortality rates between exploited and unexploited pods of limited value. However, as with bulls and cows, mortality is slightly higher in the uncropped pods. The overall average annual mortality rate for juveniles is 2.30%.

9. Net population change

Net population change off Vancouver Island was calculated in two ways. First, the rate was determined directly from the observed change in pod size over several years and secondly, by subtracting the total natural mortality rate from the net recruitment rate of calves. As with the two methods for estimating birth rate for cows, these two techniques have some overlap of data. However, the subsets are sufficiently different to warrant an analysis of both. Table 10 gives the results of the first method. For this, the pod size at year 0 and at the most recent year of census was plotted on graph paper. The size of the pod at year 1 was then determined to the nearest 0.1 whale. The results indicate that exploited pods have an annual rate of increase of 3.01% while the unexploited pods have a slightly lower rate of 1.67%. The rate for all pods combined is 2.52%.

The second method involves subtracting from the net recruitment rate of calves the combined mortality rates for bulls, cows and juveniles (calves included) after weighting these categories by their respective proportions within the population. The relevant data from these calculations are given in Table 11 for exploited, unexploited and combined pods. The only figures not previously determined were the proportions of bulls and cows in cropped and uncropped pods. These are established from selected pods listed in Table 1. By the second method, the net annual population change is 3.06% in exploited pods, 0.03% in unexploited pods and 2.02% in combined pods. These rates are very similar to those derived by the first method and thus confirm the trend of greater productivity in exploited pods. However, the second method is not likely to be as accurate as the first because of weaknessess in the data for estimation of mortality rates in cows and juveniles. Thus, the rates based on the first method are considered the best estimate.

Table 10

Percent annual net change in population size of killer whales off Vancouver Island using pod sizes.

Pod	Pod size (yr)	Pod size (yr)	Number (yr)	Pod size at yr 1	% change
Cropped					
A5	10 (1973)	12 (1980)	7	10.3	3.00
J	14 (1974)	19 (1981)	7	14.7	5.00
K	10 (1974)	10 (1980)	6	10.0	0.00
L	43 (1974)	50 (1980)	6	44.2	2.79
M	2 (1970)	3 (1979)	9	2.1	5.00
Q	4 (1975)	5 (1980)	4	4.2	5.00
	83			85.5	3.01
Uncropped					
A1	13 (1973)	14 (1979)	6	13.2	1.54
A4	5 (1973)	7 (1980)	7	5.3	6.00
B	8 (1973)	8 (1980)	7	8.0	0.00
C	10 (1973)	10 (1980)	7	10.0	0.00
O	6 (1975)	5 (1980)	5	5.8	−3.33
U	3 (1978)	4 (1980)	2	3.5	16.67
Y	3 (1975)	3 (1980)	5	3.0	0.00
	48			48.8	1.67
Total	131			134.3	2.52

Table 11

Percent annual net change in population size of killer whales off Vancouver Island based on population composition, mortality rates and net recruitment rate of calves.

Category	% pod composition	% mortality[4]	Weighted % mortality	Net calf rec. rate	Net % change
Cropped pods					
Bulls	16.2[1]	2.50	0.41		
Cows	37.4[1]	0.46	0.17		
Juv. + Calves	46.4	1.99	0.92		
Total	100.0		1.50	4.56	3.06
Uncropped pods					
Bulls	27.4[2]	3.06	0.84		
Cows	31.1[3]	1.52	0.47		
Juv. + Calves	41.5	4.35	1.81		
Total	100.0		3.12	3.15	0.03
Combined pods					
Bulls	23.0	2.81	0.65		
Cows	34.1	0.70	0.24		
Juv. + Calves	42.9	2.30	0.99		
Total	100.0		1.88	3.90	2.02

[1] Table 1 pods A5, J, K, L, M and Q.
[2] Table 1 all pods except A5, J, K, L, M, Q and E.
[3] Table 1 pods A1, A4, B, C, D, F, G, H, I1, I11, N, O, S8, Y.
[4] Table 7, 8 and 9.

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Results of this study suggest that the recent cropping of killer whales off Vancouver Island has increased their productivity, although not substantially. Cropped pods have slightly higher rates of birth and net annual increase and slightly lower rates of natural mortality than uncropped pods. Few data are currently available on the mechanism by which this has occurred. Birth rates can be elevated by reducing the age at sexual maturity and by increasing individual fertility. At this point comment can only be made on the latter which is a reasonable possibility. The large number of nonbreeding adult females in the population suggests that the species might be controlling its birth rate in a manner similar to that of wolves and African wild dogs. In these species only a few selected adult females breed. Perhaps a reduced population size induces more adult female killer whales to breed.

The manner by which survival is increased through cropping is only speculative at present. It could involve greater food availability for other members of the cropped pod. Each pod has its own range which, while overlapping with those of others, is sufficiently different to perhaps have its own food base. A reduction in the size of a pod would allow for more food and thus greater survival for remaining members.

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