BIOENERGETIC CHANGES FROM 1986 TO 2001 IN THE SOUTHERN RESIDENT KILLER WHALE POPULATION, *ORCINUS ORCA*

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May 2002

This Research was supported by a grant from ORCA

INTRODUCTION

From 1995 to 2001 the population size of the southern resident population of killer whales (*Orcinus orca*) has decreased from a high of 98 individuals to a low of 79 animals, which is a reduction of 20% of the entire population in only 6 years (pers. obs. 2002, Bain 2002). While at this point we do not understand the entire web of causation for this decline, several contributing factors have been reported, such as prey availability and the decrease in salmon stocks, the exposure to toxic chemicals and in particular PCB's (Ross 2001, Dahlheim et al. 2000), as well as the increase in commercial and private vessels mostly for whale watching over the last 10 years (Bain 2002).

Studies determining the impact of vessel traffic on different whale species have shown that the animals change their swimming behavior and/or avoid boats (Bauer et al. 1986, Fraker et al. 1995). In the northern resident community of killer whales it was shown that the whales swam significantly faster, increasing the angle between successive dives or choosing less direct paths in their swimming direction in order to avoid boats when vessels were in the vicinity (Williams et al. 2002, Kruse 1991). These changes in behavior were determined with only one boat situated a distance of 100 m from the closest whale. This distance (100 m) has been the suggested distance any boat should be from the closest whale in order to minimize disturbance (Johnstone Strait Killer Whale Committee 1996). Trites and Bain (2000) estimated theoretically that the male killer whales added an extra 13% in traveling distance when followed by boats.

In order to measure physiological data on the actual energy expenditure in killer whales potentially increased due to boat traffic, a study which had been conducted from 1986 to 1989 by Kriete (1995) was continued. Kriete (1995) had measured respiration rates related to swimming velocities in the mid 1980's on killer whales of the southern resident community, at a time when whale watching was non-existent or in its infancy. She further collected data only when whales were not followed by boats. Actual energy requirements of wild as well as captive orcas were determined by measuring actual oxygen consumption during different activity rates in captive animals and then combining these data with respiration rates from free-swimming orcas (Kriete 1995).

To determine if the physiological requirements of the southern resident orcas had changed – a phenomenon which can occur if an individual is stressed for any or a particular reason – the same study of the wild whales was conducted in 2001 to compare to the data of the pre-whale watching era and to determine if the whale-watching industry possibly carries the high price of excessive stress on individual whales or their population. Whale-watching ecotourism has increased by 4500% over the past 15 years, from 2 commercial boats in this area in 1987 to over 90 commercial whale-watch operations in 2000 (Bain 2002). While there are other factors to consider which very likely contribute to the strong decline of the southern resident killer whale population such as boat noise, decrease in food availability and toxins, this study was designed to measure and compare the energy consumption of the southern resident killer whale population between pre-whale watching days and today.

METHODS

To determine if swimming velocities and respiration rates, and, hence, energetic requirements have changed over the last 15 years, another season of theodolite tracking was conducted. Swimming velocities and respiration rates of free-ranging killer whales were measured in the previous summer study area for free-ranging southern resident killer whales in eastern Haro Strait on the west side of San Juan Island, Washington, USA. Between early May and mid-September 2002 killer whales were observed at the same site where observations were collected in 1986 and 1987, approximately 2 nautical miles south of the Limekiln Lighthouse (48° 30′ N, 123° 10′W). Data were collected during daylight hours from a vantage point 62.9m above mean low low water (MLLW), only approximately 30 m east of the site used in 1986 and 1987 and therefore almost exactly where observations had been collected in the 1980's. This site provided an expansive view over Haro Strait as far as Discovery and Chatham Island, Cadboro Bay, ranging from South Bank (48° 29′ N, 123° 05′ W) south of the observation site to Edwards Point (48° 30′ N, 123° 29′ W) north of the site. Tracked whales traveled along the west side of San Juan Island within 3 km of the coastline or crossed over from Discovery Island to the west side of San Juan Island.

The study animals were easily observed and identified at a distance of 2 km and distinctive individuals could be identified up to a distance of 4 km. When a pod of whales was sighted, an individual animal, which was swimming separate from other whales, was chosen as a focal animal to avoid confusion with others and to avoid potential alteration of actual energy requirements measured due to swimming in the echelon position with other whales. Individual killer whales were identified by saddle patches and nicks and scratches on their dorsal fins and saddle patch area (Sugarman and Shepard 1984, Bigg *et al.* 1987, Ginneken *et al.* 2000).

The theodolite was used to establish the vertical angle between the observation site and the whale's position during an exhalation. For each subsequent surfacing and respiration, new vertical angles and the horizontal angles between surfacings were measured (Figure 1).

Observations of killer whales and measurements of diving distances were made using a Pentax ETH-10E Digital Theodolite with a precision of ±10" of arc, with a 160 mm telescope and a magnification factor of 30x. Individual animals and their behaviors were observed through the 30x spotting scope of the theodolite and with 8x40 Leitz binoculars.

When the focal whale came to the surface to breathe, it's position at each surfacing was measured and recorded with a Sony digital tape recorder. The procedure was continued until the whale disappeared from view or could no longer be positively identified.

The same criteria to avoid incorrect measurements were used in 1986/87 as well as for 2001. Observations were rejected if any of the following occurred:

1. there was any uncertainty about the whale's identity during sampling,
2. breaking waves were such that they could be mistaken for a spout (i.e. whale at the surface),
3. behaviors such as play, chasing fish or feeding took place, or the individual whale suddenly changed direction and/or changed position within the pod.

During dives it was assumed that the whale swam in a straight line between surfacing points. After each session, the recorded data were transcribed onto specifically designed data sheets, along with tide and current conditions at that time, the number of boats in the vicinity and close to the whale.

While during the 1986/87 field research seasons boats were uncommon (as it was the era before major commercial whale watching was established) and whales were tracked without boats following them, this situation was extremely rare during the 2001 field season. Commercial whale watching vessels were with the orcas from 08:00 until 20:00 every day during the research period. Whenever boats were close to or approaching the individual whale being tracked, theodolite location of the boat(s) in relation to the focal individual were recorded to determine the boat's distance to the whale.

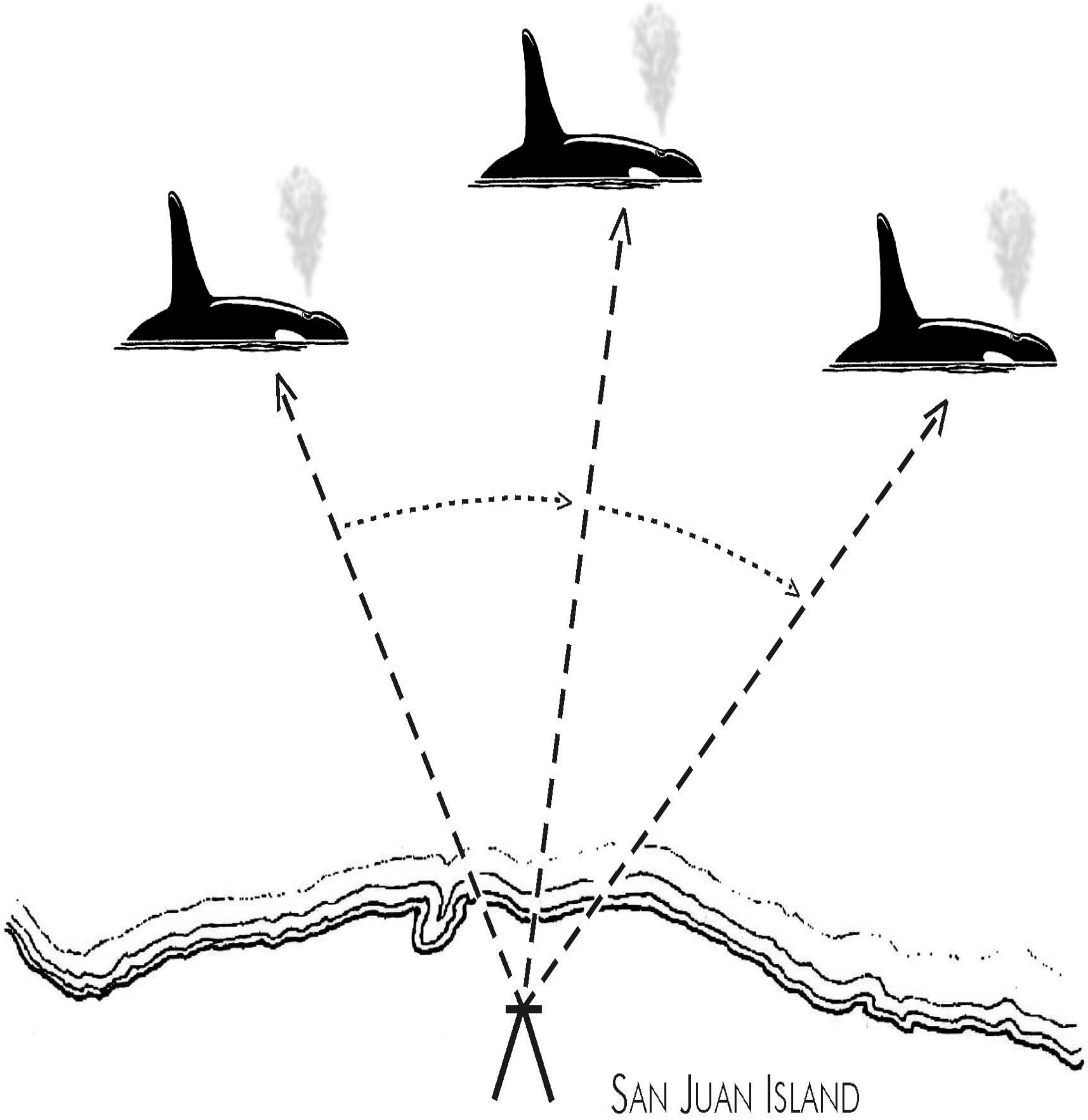

Figure 1: Theodolite Tracking of Killer Whales

Track Distance Calculations:

To determine the distance the animals traveled between respirations, several variables needed to be known: the height of the theodolite station and the vertical and horizontal angles of the location where the focal animal surfaced to breathe. The height of the theodolite above the sea surface was professionally determined and was corrected for tides from predictive tide tables (Harbor Tides, 2002). The distance between the theodolite station and the whale was calculated using the exact height of the theodolite and the vertical angles measured by the theodolite. After the vertical angles were converted from degrees, minutes and seconds to fractions of degrees, the tangents of these angles were multiplied by the height of the theodolite to determine the distance of the animal tracked from the theodolite. The horizontal angle measured between two vertical angles determined the distance the animal had swum between two respirations (see Figure 1). Again, minutes and seconds of the angle were converted to fractions of degrees, and the cosine of the horizontal angle was computed to determine the distance between the two vertical angles to calculate the distance of two surfacings to the shore. The successive positions were added to determine the distance over which the animal was tracked along the water surface.

Dive Models

Dive models were applied as described by Kriete (1995). The dive model chosen for this study was the same as for Kriete (1995), the V-shaped model.

Swimming Velocities

Swimming velocities, using the dive model which fit best (see Kriete 1995), were determined from the equation:

[1] velocity = (Distance from the V-shaped model)/Time,

where: Velocity=m/sec; Distance=meters; and time-the total time elapsed (sec) during the observation.

The number of respirations the animal took were counted from beginning to end of each track. Observations were separated into mean swimming velocities and mean breathing rates for each age and sex category.

Breathing rates were graphed as a function of swimming velocities for the different age and sex classes.

Energetic Demands

The increases in energy requirements were estimated by following the methods by Kriete (1995).

RESULTS

Observations

Of a total of 82 observations of the summer 2001 theodolite trackings, 52 were considered acceptable. This constituted a total time of 13.44 hours and covered 116.8 km of tracking.

Diving Depths and Dive Models

The same diving depths as measured by Kriete (1995) for all age and sex classes were used in this study.

The V-shaped dive model, described as:

[2] $2* V[(\text{Distance}^2/2)+\text{depth}^2]$,

where: distance and depth is in m.

The V-shaped dive model was used for further analysis to calculate the distance the whales traveled between surfacings as it had been used by Kriete (1995). This model had produced the least variance in the majority of the tracks.

Bias

In order to eliminate an inherent bias towards overestimation of respiration rates for short theodolite tracks as established by Kriete (1995), all tracks less than 10 minutes in length were discarded.

Breathing Rates and Swimming Velocities

Simple linear regressions were fitted to the data of breathing rates of adult males, adult females and juveniles as a function of swimming velocities and respiration rates (Figures 2, 3, and 4). Slopes and intercepts were calculated for the different age and sex classes and presented with the 1980's data (Table 1). Statistics for the relationship between respiration rates and swimming velocities are presented for the different age/sex classes in Table 2.

The females' and juveniles' regression coefficients were statistically significant; in males it was not significant. As the regression coefficient was significant for males in the 1980's, it can already be seen that there is a difference in swimming velocities and respiration rates for males.

A box plot was performed for swimming velocities and respiration rates for males, females and juveniles (Figures 5 and 6), showing all 6 data sets for the 1980's and 2001 for all age/sex classes. The median (the number in the middle of a set of given numbers) is documented as a horizontal line, as well as the 25th and 75th percentile. To clearly show the median line, it is highlighted and surrounded by stars. 25% of the values lie below, and 25% above the median value. The vertical lines (whiskers) lie within 1.5 times the height of the box and are denoted by +signs. Values farther than 1.5 times the height of the box are considered extreme values and are represented as circles; even more extreme values are displayed as stars.

The schematic plots clearly indicate that all three age/sex classes swam faster and had higher respiration rates on 2001 than the whales did in the 1980's. Juveniles were never measured to swim at low or medium velocities, but were only recorded swimming as fast as the top 25% of the animals in the 1980's. As this is a non-parametric presentation, it is independent of the distribution.

An ANOVA was performed, separated for respiratory rates and swimming velocity as the dependent variables. Sex (males, females) and year (1980's and 2001) were treated as independent variables, as well as their interaction (sex*year), establishing a model for a 2-factorial (2x2) analysis of variance with interaction (Table 3). There was no statistical interaction for respiration rates, however, the year is highly significant statistically. The t-test (S-N-K-test) showed that in 2001 respiration rates increased independently of the sex of the animal.

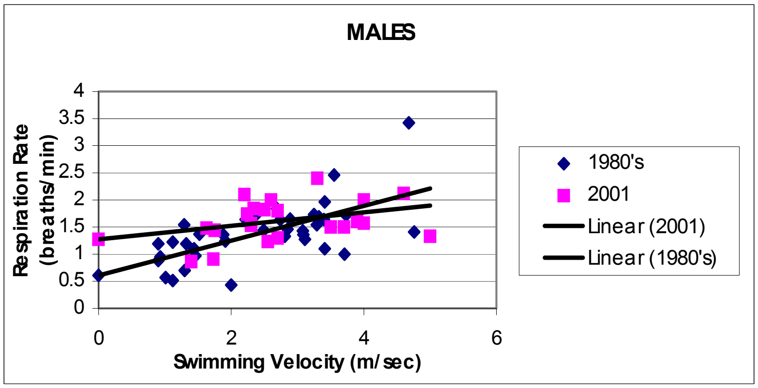

Figure 2: Respiration rates as a function of swimming velocity In male killer whales, *Orcinus orca*.

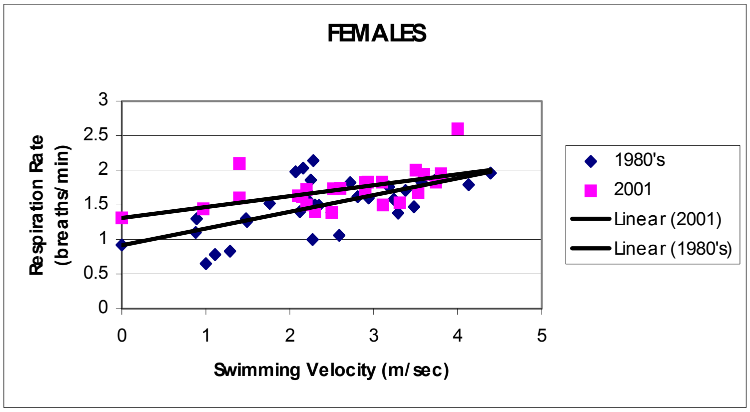

Figure 3: Respiration rates as a function of swimming velocity In female killer whales, *Orcinus orca*.

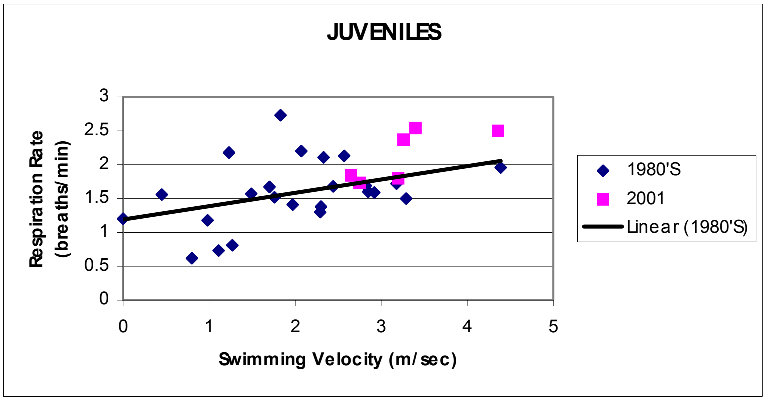

Figure 4: Respiration rates as a function of swimming velocity In juvenile killer whales, *Orcinus orca*.

Table 1: Swimming velocities and respiration rates in free-ranging killer whales In 2001

Mean Velocity (m/sec)	Mean	Range	Standard Deviation	Number of Observations
Males 2001	2.85	1.4 - 5.0	0.95	23
1980's	2.41	0.9 - 4.7	1.16	22
Females 2001	2.73	0.97- 4.0	0.8	23
1980's	2.40	1.5 – 4.4	0.81	16
Juveniles 2001	3.27	2.65- 4.4	0.56	6
1980's	2.16	0.5 – 4.4	0.96	15

Mean Respiration Rate	Mean	Range	Standard Deviation	Number of Observations
Males 2001	1.63	0.86- 2.4	0.36	23
1980's	1.58	0.9 – 3.4	0.58	22
Females 2001	1.74	1.39- 2.6	0.26	23
1980's	1.72	1.4 – 2.1	0.28	16
Juveniles 2001	2.13	1.73-2.54	0.35	6
1980's	1.79	1.2 – 2.7	0.43	15

Table 2: Regression equations and statistics for the relationship between respiration rates (RR in breaths/min) and swimming velocities (m/sec) in male, female and juvenile killer whales.

Sex	Equation	Number of Observations	r^2	Significance Level	SE of y Intercept	SE of x Intercept
Males	RR=1.27+0.124 Vel	23	0.1	$p<0.13$	0.36	0.08
Females	RR=1.31+0.158 Vel	23	0.23	$p<0.001$	0.24	0.06
Juveniles	RR+0.61+0.464 Vel	6	0.56	$p<0.08$	0.28	0.20

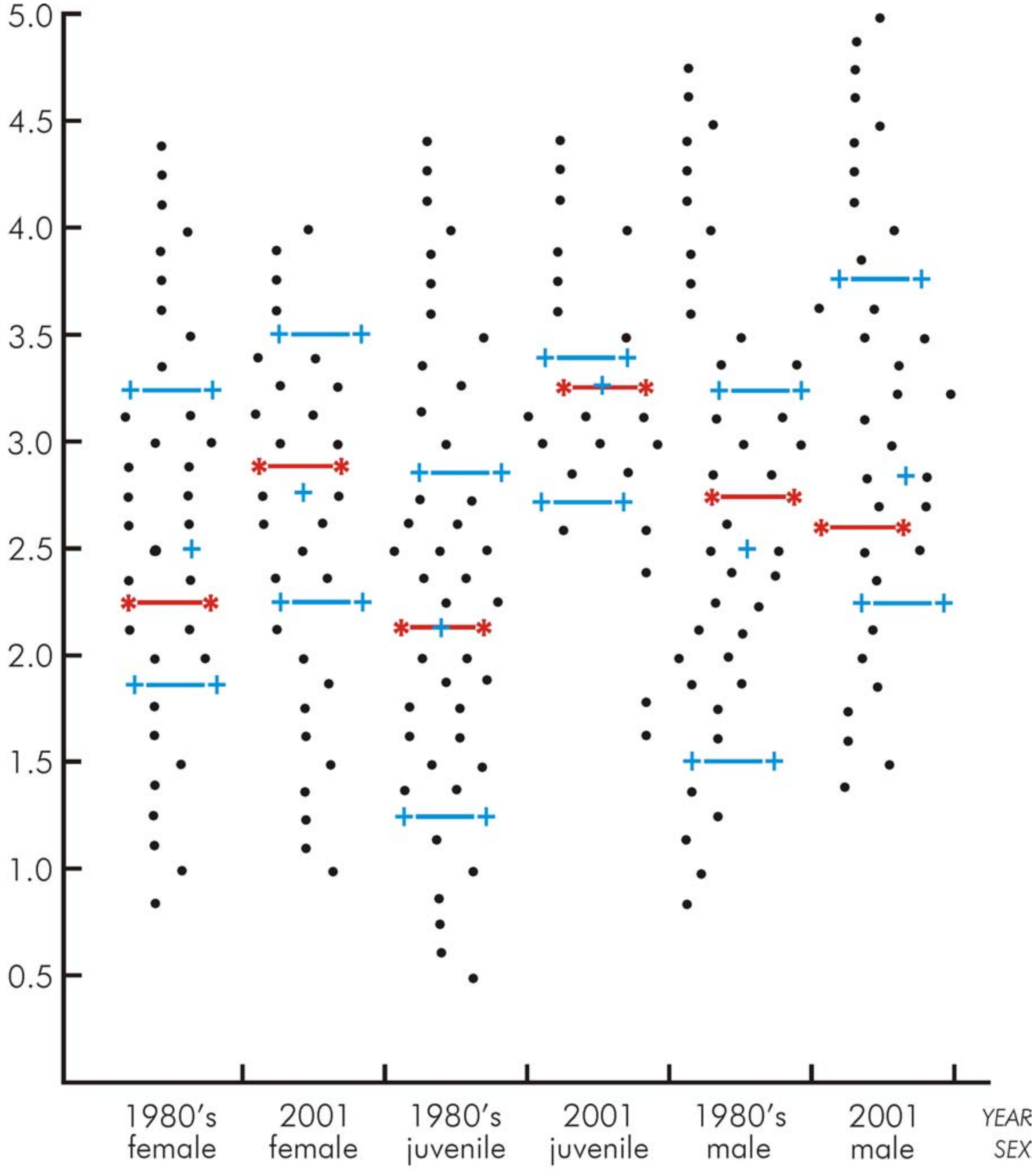

Figure 5: Box Plot showing Differences in Swimming Velocity for Different Age/Sex Classes in the 1980's and 2001.

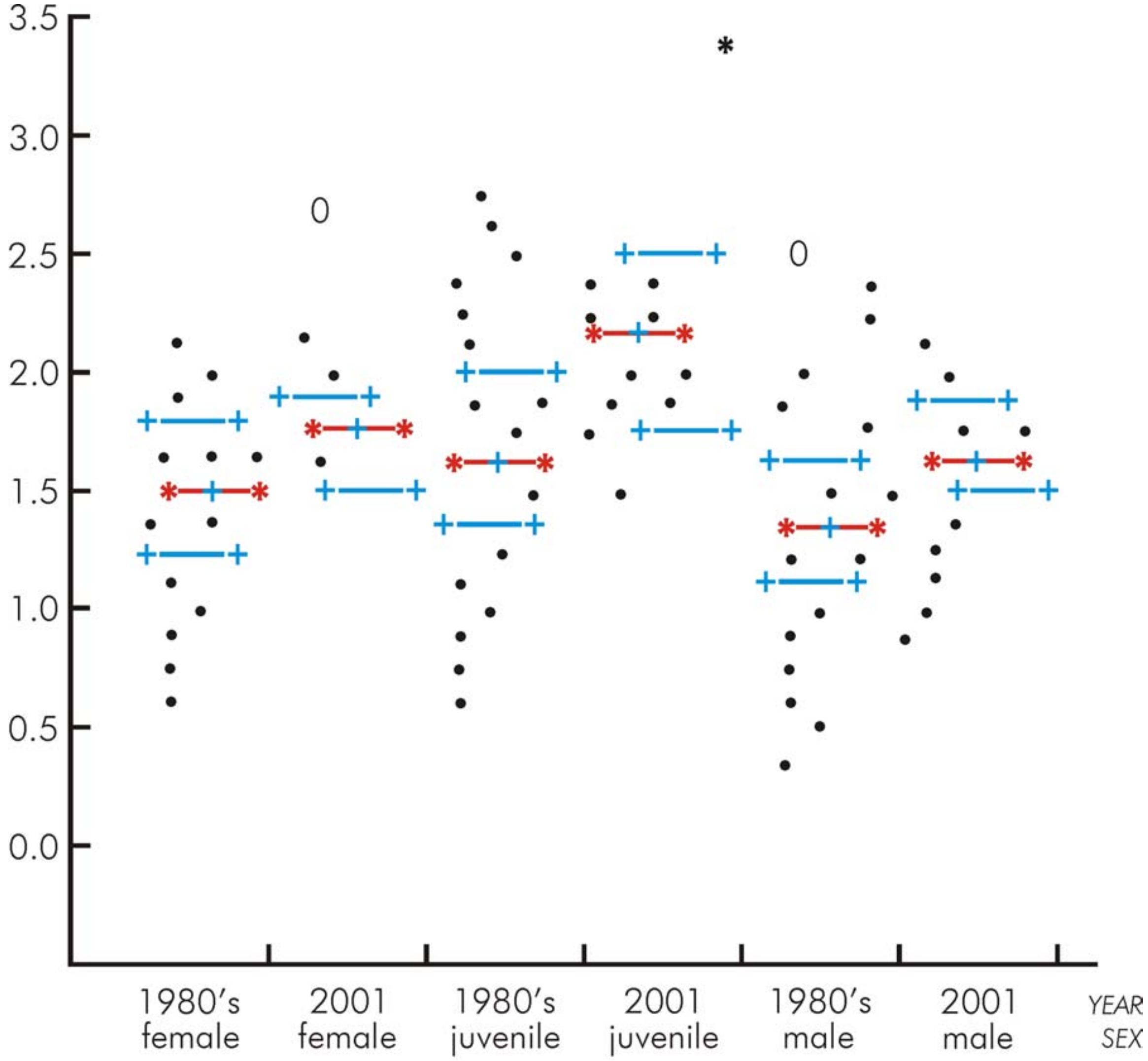

Figure 6: Box Plot Showing the Difference in Respiration Rates for Different Age/Sex Classes for the 1980's and 2001.

Statistical Treatment of the Dependent Variable: RESPIRATION RATES

```
Source            DF        Sum of Squares        Mean Square  F Value    Pr > F
Model              3          1.92571756          0.64190585     3.66      0.0146
Error            111         19.45443549          0.17526518
Corrected Total  114         21.38015304

                 R-Square          C.V.            Root MSE      RESPRATE Mean
                 0.090070        27.13430         0.41864685      1.54286957


Source            DF           Type III SS       Mean Square  F Value    Pr > F

YEAR               1          1.50262975         1.50262975     8.57    0.0041 ***
SEX                1          0.35596082         0.35596082     2.03    0.1569
SEX*YEAR           1          0.00015885         0.00015885     0.00    0.9760
```

Dependent Variable: VELOCITY

```
Source            DF        Sum of Squares        Mean Square     F Value    Pr > F
Model              3          3.40941904          1.13647301        1.21      0.3094
Error            111        104.21987314          0.93891778
Corrected Total  114        107.62929217

                 R-Square          C.V.          Root MSE       VELOCITY Mean
                 0.031677        37.46636        0.96897770       2.58626087


Source            DF           Type III SS          Mean Square    F Value   Pr > F

YEAR               1          3.22906772          3.22906772      3.44    0.0663 *
SEX                1          0.14205998           0.14205998      0.15    0.6980
SEX*YEAR           1          0.07853249           0.07853249      0.08    0.7730
```

Multiple t-test for Respiration Rates (Student-Newman-Keuls test):

NOTE: This test controls the type I error rate under the complete null hypothesis but not under partial null hypotheses.

```
                 Alpha= 0.05  df= 111  MSE= 0.175265
                 WARNING: Cell sizes are not equal.
                  Harmonic Mean of cell sizes= 55.2

                    Number of Means        2
                    Critical Range  0.1579072

         Means with the same letter are not significantly different.

           SNK Grouping      Mean     N  YEAR

                A          1.68543    46  2001
                B          1.44783    69  1980
```

Multiple t-test for Velocity (Student-Newman-Keuls test):

```
                 Alpha= 0.05  df= 111  MSE= 0.938918
                 WARNING: Cell sizes are not equal.
                  Harmonic Mean of cell sizes= 55.2

                    Number of Means        2
                    Critical Range  0.3654837

         Means with the same letter are not significantly different.

            SNK Grouping           Mean     N  YEAR

                A          2.7913    46  2001
                A
                A          2.4496    69  1980
```

There was no variable parameter in swimming velocities; however, again the year is significant. The S-N-K-test does not show any difference in years as a result, however the swimming speed average of the year 2001 is clearly higher than in the 1980's.

The analysis was repeated including juveniles as this is methodologically acceptable. The variable 'sex' also tested statistically significant for the increase in respiration rates. Juveniles have a significantly higher respiration rate than the adult males, but not higher than adult females (Table 4). The variable year is clearly significant for swimming velocity, however, there is no difference between the sexes.

Energetic Demands

The additional energetic demands due to higher respiration rates and swimming velocities were calculated for males and females only, as the number of samples collected for juveniles was small (n=6) and data could only be collected at high swimming velocities. The same parameters were applied to both data sets for the 1980's and 2001 for males and females. Males had a 19% increase in energetic demands in 2001 compared to the 1980's, while the females' energetic requirements in 2001 were 17% higher than in the 1980's. These data are conservative as the author suspects that the whales spent less time resting and more time foraging in 2001 than in the 1980's. This fact will have to be explored further, hence there is a potential in energetic requirements being even higher in 2001; in the meanwhile, a conservative approach was taken and the same activity budgets for the southern resident killer whales were applied for all data sets.

Table 4: Analysis of Variance for Males, Females and Juveniles for Respiration Rates and Swimming Velocities in the 1980's and 2001.

Dependent Variable: **RESPIRATION RATES**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	3.90860005	0.78172001	4.22	0.0013
Error	138	25.55896592	0.18520990		
Corrected Total	143	29.46756597			

R-Square	C.V.	Root MSE	RESPRATE Mean
0.132641	27.29437	0.43036020	1.57673611

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR	**1**	**2.78815272**	**2.78815272**	**15.05**	**0.0002** ***
SEX	**2**	**1.80593858**	**0.90296929**	**4.88**	**0.0090** ***
SEX*YEAR	2	0.35272363	0.17636182	0.95	0.3884

Dependent Variable: **VELOCITY**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	11.53425488	2.30685098	2.55	0.0307
Error	138	124.95833401	0.90549517		
Corrected Total	143	136.49258889			

R-Square	C.V.	Root MSE	VELOCITY Mean
0.084505	37.53337	0.95157510	2.53527778

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR	**1**	**9.79911423**	**9.79911423**	**10.82**	**0.0013** ***
SEX	2	0.19704752	0.09852376	0.11	0.8970
SEX*YEAR	2	2.92383493	1.46191746	1.61	0.2027

Multiple T-Test RESPIRATION RATES (Student-Newman-Keuls test):

```
                NOTE: This test controls the type I error under the
                      complete null hypothesis but not under partial null hypotheses.

                            Alpha= 0.05  df= 138  MSE= 0.18521
                            WARNING: Cell sizes are not equal.
                           Harmonic Mean of cell sizes= 43.27054

                            Number of Means        2          3
                            Critical Range  0.1829466 0.2192161

               Means with the same letter are not significantly different.

                      SNK Grouping          Mean     N      SEX

                               A          1.71103    29    juvenile
                               A
                          B    A          1.60618    55     female
                          B
                          B               1.48483    60      male
```

Multiple T-Test VELOCITY (Student-Newman-Keuls test):

```
                            Alpha= 0.05  df= 138  MSE= 0.18521
                            WARNING: Cell sizes are not equal.
                           Harmonic Mean of cell sizes= 66.44444

                                 Number of Means        2
                                 Critical Range  0.1476356

                Means with the same letter are not significantly different.

                      SNK Grouping          Mean     N    YEAR

                               A          1.73673    52   2001

                               B           1.48630   92   1980
```

DISCUSSION

The southern resident killer whale population is one of the best- studied cohesive groups of cetaceans worldwide. Long-term photo-identification has been conducted since the mid-1970's (Bigg et al. 1990), many behavioral studies have been carried out (Baird 1999, 2000), as well as genetic (Hoelzel, 1993, Barrett-Lennart et. al. 1996), acoustical (Ford 1994) and physiological (Kriete 1995) research. Similar studies have been conducted with the northern resident orca population and comparisons in the health (Ross 2001), population size (Balcomb and Bain 2000) and behavioral differences of the animals have been observed. Unlike the northern killer whale population, however, the southern resident orcas have experienced a sharp decline in their population size in recent years (98 animals in 1995 vs. 78 animals in 2001, Bain 2002).

The regular physical activity of the southern resident killer whales has increased in recent years. Swimming velocities and respiration rates of these whales have increased since the 1980's, as shown by the same measurements conducted with consistent methods compared to the same measurements conducted with consistent methods. This is an unexpected phenomenon, as the same age and sex classes of animals were studied. However, Kruse (1991) also reported that whales in the northern resident community swam 1.48 times faster when boats were present. While normal specific variations exist among individuals, significant increases in all three age/sex classes for both swimming velocities and respiration rates suggests that physiological changes occurred since the baseline study was conducted in the 1980's. The differences in respiration rates are statistically significant; there is no interaction between respiration rates and swimming velocities in the data from the 1980's and 2001; however, there is a significant effect of the year: all age/sex classes swam faster in 2001 than in the 1980's. The difference between the increase in respiration rates and swimming velocity is caused by the difference in years.

It appears, therefore, that the significant environmental change that may contribute to the change in energy expended is the increase in whale watch traffic. While natural changes continuously happen in nature, such as differences in the amount of fish returning to local waters in order to spawn, these differences are relatively minor compared to the increase in boat traffic that has occurred over the last 12 years. Bain (2002) provided an extensive account of the increase in boat traffic and the change of engines used, particularly in small commercial whale watching boats. Erbe (2002) and Bain et al. (1994) also described the potential effects boat noise has on killer whales, and Williams (2002) recently published his findings on the behavioral responses of orcas to whale-watch boats. The effects, however, of the increase in the number of boats, effects of boats following the whales and the boat noise were either based on theoretical models or behavioral observations. This study provides a comparison of the whales' physiological changes from a period of very little boat traffic to an era of increased marine vessel commerce.

The southern resident population spent at least as much time in the study area in 2001 as in the 1980's, which leads to the conclusion that food is available. The whales were observed to mill extensively and for many hours each day in the study area, although the amount of fish caught is unknown. The time the animals spent fishing in 2001 was higher (Kriete, pers. obs.), however, than the time the whales spent foraging in the 1980's. In addition, the whales did not rest as much as they used to. Resting behavior was only observed twice during the 2001 research field season compared to daily or every other day in the 1980's. Baird (pers. comm.) and Otis (pers. comm.) also mentioned having observed different behavior activity patterns during the last seasons.

A strong indication of changes in respiration rates is shown during rest. At complete rest, representing basal metabolic rate (swimming velocity of 0 m/sec), the whales' respiration rates were between 40% (females) and 100% (males) higher than those measured in the 1980's. In addition, observations showed that the direction in which the whales were moving slowly while resting was not as direct as during the 1980's; tight groupings of whales even changed (some whales separated themselves from the group during resting) when surrounded by boats (Kriete, pers. obs.). Observation in the 1980's showed that the whales stayed tightly grouped together throughout the entire resting period and for a short while after travel behavior resumed.

Respiration rates were consistently higher for males until the animals reached a swimming velocity of 3.9 m/sec (Figure 2), and females had elevated respiration rates up to a speed of 5 m/sec (Figure 3). The whales most likely approach maximum respiratory mechanisms during higher swimming velocities. Physiologically, any animal can only breathe so often before hyperventilating.

Williams et al. (2002) observed similar changes in the northern resident killer whales when the animals were followed by a boat. The orcas changed direction, increased swimming velocity and swimming direction while traveling and followed by a boat in Johnstone Strait. Williams et al (2002) also determined that male orcas increased their travel distance by 13% in the presence of whale watch boats. This clearly leads to the conclusion that for the southern residents an external force, which was not present in the 1980's, is altering the whales' physiological state.

Williams et al. (2002) used Howland's (1974) and Weihs & Webb's (1984) theoretical models as a strategy for the whales to evade boats. This response, which they consider 'loosely analogous to a predator-prey interaction' (Williams et. al. 2002, p. 266), where the whales are representative of the prey and the boats correspond to the predator, results in increasing swimming velocities that are considered a typical predator-avoidance approach seen in many species. Increases in respiration rates indicate that the animals are stressed.

Studies of other mammals exposed to increases in ecotourism and humans, such as Bighorn sheep (MacArthur et. al 1982) and chimpanzees (Hohns 1996), have shown that habituation (behavioral responses to human activities diminishing over time) has occurred in many mammals. Other species, such as birds have not been able to habituate to increases in human exposure; their populations returned to healthy numbers only after human traffic was removed from their habitat for several years. Wasser et. al. (1997) reported that spotted owls living in clear cuts and recently reforested areas had increased levels of stress hormones compared to owls living in old growth forests. Another thought provoking possibility is that even if the whales visually adapt to an increase in vessel traffic, the noise of the engines could potentially affect their prey and therefore the whales' supply of food. Essentially there would be no habituation for the orcas because the prey of the whales would be affected and the killer whales in response.

The increase in swimming velocity and respiration rates is metabolically very costly, an increase of 19% in males and 17% in females. Avoidance behavior carries high energetic costs as can be seen in this study. Any increase in swimming velocity and respiration rate needs to be balanced by an increase in food consumption in order to pay metabolic debts. With the decrease in salmon stocks, this poses an additional threat to the orcas. If energetic demands can not be met, females might not be able to satisfy high feeding demands of calves (lactating females require at least a 100% increase in food [Kriete 1995]), adipose tissue is reduced, which concentrates the level of toxins (Ross 2001) and immune systems are weakened. Dead southern resident killer whales were found to have extremely high levels of PCB's in their blubber (Ross 2001) Animals found dead on the beach (i.e. J18, see Huff, 2000) were very malnourished; the cause of death of J18 was a decreased immune system and infection. The increase in deaths of calves is not understood; however, if mothers cannot provide enough nutrition to the calf through nursing, calves die of starvation. Trites and Bain (2000) estimated that the southern resident killer whales increase their swimming distance by 3% annually due to disturbance and behavior alteration caused by whale watch boats. They estimated that whale watch boats follow the southern resident orcas 12 hours/day for 6 months of the year, leading to a total amount of the whales being 'watched' 25% of the year. However, commercial whale watch fleets in these waters have expanded their business to at least 10 months of the year, 'watching' whales approximately

40%+ of the time. The increase in metabolic rates hence increases significantly Additionally, most of the commercial whale watching occurs during times of high prey availability and when the orcas build up their blubber layer.

Bain (2002), Erbe (2002), and Bain and Dahlheim (1994) have demonstrated that boat noise masks communication signals and echolocation used by orcas. This reduces the distance over which killer whales can effectively find food and communicate with conspecifics. Continuous noise also poses the threat of temporary auditory threshold changes within the whales' hearing ability (Erbe 2002), not only reducing the whales' hearing ability while boats are around but also for a potential period of time (up to 12 hours) after the boats leave.

While short-term behavioral changes due to human disturbances and activities and long-term implications for the health and survival of this species are difficult to establish and link, the logical consequences of boat traffic and noise must not be underestimated. A decrease in foraging opportunity, increased energetic demands due to boat traffic and noise, a disruption of sleep patterns (Öhrenström et. al. 1990), combined with a decrease in food availability and toxic contaminants all can lead to lowered immune functions, decreased fecundity, a decrease in survivorship, starvation, decreases in population size and possibly extinction.

As this population of killer whales has been habituated to this area for thousands of years, it is extremely unlikely that the animals might emigrate to a different location which might provide sufficient food for the population and without disturbing external factors such as whale-watch traffic.

Note:

Please note that this document is only in draft format at this time and is not to be used for citation until further notice. It is simply to be used as a working document during the Orca Recovery Conference held in Seattle May 31-June 2, 2002.

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ACKNOWLEDGEMENTS

It often takes a person with perseverance and foresight to stir up and light the fire of controversy to improve conditions for living beings. Mark Anderson, President of the Orca Relief Citizen's Alliance, was one of the first people to understand the threat the southern resident killer whale population in Puget Sound has been facing for the last decade. His perseverance and dedication to funding reliable research to find solutions to save this population of whales has brought the problem to the surface and conscience of people years before it would have become known otherwise.

Patsy Huntington and Dale Pratt permitted me the use of their property to conduct this research. They were open to discussions and helpful in any way possible.

Tom Metke of MPD Inc. Land Surveying again measured the cliff height of the study site at short notice and therefore made it possible to analyze the data correctly.

Prof. Prof. Dr. Heinrich Binder of Switzerland provided inconceivable help with the statistical analysis. His knowledge of the previous study helped to further the study.

Last but not least I thank my daughter, Laura Melia Kriete-Bain for her patience with and excitement about the study. I could always rely on her keeping count of the boats and providing a synopsis of the situation as I was tracking through the theodolite's spotting scope.