STUDIES OF FORAGING IN “SOUTHERN RESIDENT” KILLER WHALES DURING JULY 2002: DIVE DEPTHS, BURSTS IN SPEED, AND THE USE OF A “CRITTERCAM” SYSTEM FOR EXAMINING SUB-SURFACE BEHAVIOR

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Summary

The "southern resident" population of killer whales (*Orcinus orca)* around southern Vancouver Island and in Washington state is known to feed primarily on fish. While salmon (*Oncorhynchus* spp.) are widely considered to comprise the vast majority of their diet, the proportion of the diet they do comprise is unclear. During July 2002 we attempted to examine three aspects of foraging for "southern resident" killer whales: 1) where animals are foraging in the water column, using suction-cup attached time-depth recorder (TDR)/velocity meters, and examining the depth distribution of bursts in speed, which might reflect fish chases; 2) whether fish-scale sampling as a tool to determine killer whale diet is biased towards fish captured in near-surface waters; and 3) directly determining prey species taken using a suction-cup attached video camera system (the National Geographic Crittercam system). Although close access to the whales was limited by attempts to minimize conflicts with the whale watching fleet, over a 10-day period we tagged eight whales, collecting 79 hours of depth data (59 hours of which included velocity data), and one hour of video data. Tagged whales were followed for 15 hours, though no fish scales were observed at the water's surface during these follows. Maximum dive depth recorded exceeded 228 m (the depth limit of the TDR), and the average of maximum dive depths of the seven whales tagged with TDRs was 141 m. Despite such deep dives, an average of only 2.4% of their time was spent below 30 m in depth. However, 8-9% of velocity spikes were recorded below 30 m, suggesting that deep dives are disproportionately important for foraging. It is currently unclear which prey species are important at these depths (chinook salmon, *O. tshawytscha,* versus bottom fish). Although no fish chases were documented in the one-hour of video data obtained, the camera deployment does demonstrate the feasibility of using suction-cup attached video camera systems for examining sub-surface behavior of killer whales. Future deployments of such systems (particularly a system incorporating a velocity meter), combined with hydroacoustic monitoring of the prey field, should be useful in determining whether velocity spikes truly represent fish chases, as well as directly determining prey species captured.

Introduction

There are two discrete types or forms of killer whales (*Orcinus* spp.) in the nearshore waters of the eastern North Pacific, one that specializes in foraging on fish (the so-called "residents"), and one that specializes in foraging on marine mammals (the so-called "transients"). The first-eating form is further sub-divided into two distinct populations in the inland waters of Washington state and British Columbia. The population of "northern residents" is found primarily from central Vancouver Island north to southeast Alaska, while the population of "southern residents" is found primarily from central Vancouver Island south throughout the inland and coastal waters of the state of Washington. Despite continuous behavioral and population research since the mid-1970s, surprisingly little is known about the precise species of fish eaten by whales in either population, or whether the diet varies seasonally, geographically, or between "pods" (ie., stable social groups) of whales. Based primarily on sampling of fish scales found floating or in the top meter or so of the water behind foraging whales, Ford et al. (1998) suggested that these whales feed primarily on salmon (*Oncorhynchus* spp.), particularly on the largest species of salmon, chinook (*O. tshawytscha*), though other species of fish were also occasionally recorded from scale samples. Two primary biases may exist with this technique: 1) fish scales floating at the surface may only be representative of fish caught near the surface (Ford et al. 1998); and 2) scales from larger prey (such as chinook salmon), which may be broken up before consumption, may be more likely to be recovered (Baird 2000). Ford et al. (1998) also report on stomach contents recovered from eight fish-eating whales, seven of which contained salmon remains, and six of which contained remains or evidence (e.g., fish hooks) from a number of other (primarily epibenthic or demersal) species, including Pacific halibut (*Hippocampus stenolepis*), lingcod (*Ophiodon elongates),* and English sole (*Parophrys vetulus*).

The extent to which the limited sample sizes and biases associated with the methods of Ford et al. (1998) influenced their results is unclear, but the potential for misinterpretation is large. Only eight stomachs and 135 scale samples were collected over a 23-year period, and this was done opportunistically. Only five of the stomachs and 33 of the scale samples (J. Ford pers. comm.) came from the "southern resident" population, thus there is considerably less certainty regarding the diet of this population than for the "northern residents". No directed research focusing on fish scale sampling to assess dietary preference of the "southern residents" has been undertaken. It has been well documented that salmon are extremely important in the diet of both the "northern" and "southern residents"; correlations with salmon and whale abundance exist for both populations (Heimlich-Boran 1986; Nichol and Shackleton 1996). However, it is unknown which of the numerous potentially available species/runs of salmon are the most important, or the extent to which other species of fish may contribute to their diet. Salmon from the Fraser River and its tributaries are probably extremely important to "southern resident" killer whales, due both to their pattern of distribution (Heimlich-Boran 1986), and to the numerical dominance of salmon from that river system (Northcote and Atagi 1997).

It is also unknown whether there are age, sex, pod-specific, or seasonal differences in diet of the "southern resident" population. Such variation likely does exist. Pod-specific differences in diet do appear to exist for the "northern resident" community – Nichol and Shackleton (1996) found that the occurrence of different pods correlated with different runs and species of salmon. Bain (1989) notes that adult males often forage in deeper water than females, or in a peripheral position in a group, possibly feeding on different sizes or species of prey. And some particular occurrences of "southern resident" killer whales in Puget Sound in the fall do correlate strongly with chum salmon (*Oncorhynchus keta*) runs in that area at the time (Osborne 1999).

Although there is only limited information on the depth distribution of salmon in inland waters, available data suggests that salmon are found primarily in surface (<30 m) waters (Quinn and terHart 1987; Quinn et al. 1989; Ruggerone et al. 1990; Olson and Quinn 1993), though chinook salmon appear to spend more time deeper in the water column than other species, particularly at night (Candy and Quinn 1999). Time-depth recorder (TDR) studies of the diving behavior of "southern resident" killer whales around southern Vancouver Island and in the inland waters of Washington have shown that these whales do spend the vast majority of their time in near-surface (<30 m) waters (Baird 1994, Baird et al. 1998, unpublished). However, regular dives to or close to the bottom in depths of over 100 m, with a maximum dive depth recorded of 260 m, have been documented (Baird 2000), implying that some foraging may occur for species, other than salmon, that typically inhabit waters deeper than 30 m (e.g., bottom fish).

Knowledge of the diet of "southern resident" killer whales is particularly important given the decline of the population over the last six years (Baird 2001). Three main candidate causes for the decline have been proposed (Baird 2001): 1) immuno-suppression due to accumulation of anthropogenic toxins (see e.g., Ross et al. 2000); 2) a reduction in the prey base; and 3) increased stress or masking of echolocation signals associated with high levels of vessel traffic (e.g., Bain and Dahlheim 1994; Erbe 2002). This latter effect is not thought to be directly resulting in the deaths of individuals, but may be making it more difficult to feed on an already depressed prey base. High levels of uncertainty are associated with all three of these potential causes. One factor which is relevant to all three is what the whales eat; as the pathway for accumulation of toxins, in terms of assessing prey availability and the potential for overlap with human fisheries, and in terms of the location and depth of prey and thus feeding behavior (with implications for susceptibility to vessel traffic effects).

In July 2002 we attempted to examine three aspects of the foraging of "southern resident" killer whales: 1) depths the animals were foraging in the water column, through the attachment of time-depth recorders and examination of bursts in speed that may be associated with fish chases; 2) whether fish-scale sampling is a biased method for examination of diet, by collection of fish scale samples from behind whales instrumented with time-depth recorders, to determine whether scales are preferentially collected from whales foraging in near-surface waters; and 3) directly determine what species of prey are captured, and the depth at which they are captured, by using a video camera/time-depth recorder system attached to a whale (the National Geographic Crittercam system; Marshall 1998), that would film prey capture attempts.

Methods

Field-work was undertaken in U.S. waters of eastern Juan de Fuca Strait, Haro Strait, and Boundary Pass, Washington, from July 1-10, 2002. Bottom depths in the study area where whales are typically found range from 50 to 250 m, with a maximum depth in the area of approximately 350 m. Two vessels were used simultaneously in this study: 1) a 5.5-m Boston Whaler, for scale sample collection and behavioral follows of tagged animals; and 2) a 7- m Almar, for tagging, tag recovery, and supplementary behavioral follows of tagged animals (when multiple whales were tagged). As large numbers of commercial and recreational whale watching vessels operate in the study area (see Otis and Osborne 2001; Baird 2001), the 5.5-m vessel was chosen in part because of its low profile, thus minimizing any visual impact the boat may have for land- or boat-based whale watching operations. The 7-m vessel had a bow-extension, allowing the individual who was attempting to tag to stand in front of the bow of the vessel.

Time-depth recorder tags used were the same as those used previously on killer whales (Baird et al. 1998). Each tag weighed about 400 grams (approx. 0.01-0.02% of the body mass of a killer whale) and contained a VHF radio transmitter (MOD-125, Telonics, Mesa, AZ, USA) with a 30 cm semi-rigid wire antenna, and a TDR (Mk6 or Mk8, Wildlife Computers, Redmond, WA, USA), which was set to sample depth and velocity once per second. The TDRs recorded depth at 1 or 0.5 m increments (accuracy +/- 1 or 0.5 m, respectively), and the maximum depth range of the instruments was 228 m or 1000 m (for the Mk6 and Mk8 units respectively). Velocity was measured by rotation of a paddlewheel; these readings are presented as relative velocity, as precise calibration varies with position of the tag on the body (Baird 1998), as well as likely variation with body size. Tag bodies were constructed from syntactic foam (to allow tags to float after they fall off) and were attached with an 8 cm diameter suction cup (Canadian Tire, Canada). Tags were attached to the end of crossbow bolt and deployed from a 67 kg Barnett crossbow at distances ranging from 4-7 m. The video camera system used (a National Geographic "Crittercam" system) included a digital-video camera inside a 35 cm long cylindrical watertight housing (8.75 cm outer diameter) that was positively buoyant, attached with a 14 cm diameter suction-cup, and included a VHF transmitter (Telonics). The suction-cup was on a swivel bracket, allowing the camera to orient in the direction of water flow, so that video footage was obtained past the front of the whale. This system recorded video information for one hour, and also recorded depth at 1-second intervals. The Crittercam system was attached with a 5-m pole.

Tags were deployed opportunistically, due to the limited amount of time the whales can be closely approached for tagging. This limitation was due primarily to an effort to reduce potential conflicts or misunderstandings with whale watchers or shore-based observers, by generally confining tagging operations to periods or areas where few if any boats or land-based observers were within visual range of our tagging boat (e.g., <1 km from the tagging boat). Although we attempted to find whales early in the morning before commercial whale watching operations had commenced, the majority of whales were encountered after whale watching vessels had already arrived on scene. As a result, many tagging attempts were made late in the afternoon or evening after whale watching vessels had ceased operation for the day, thus substantially reducing the number of tagging opportunities and significantly reducing the amount of monitoring that could be conducted during daylight hours. Once a tag was deployed, if sea conditions and light levels allowed, the tagged whale was followed and information on location (determined using a GPS) and surface behavior was recorded. We attempted to follow tagged whales at distances of less than 100 m, to potentially allow for collection of fish scales from behind these whales. However, when tagged whales were close to shore in areas with large numbers of land-based observers, follows were discontinued. Surface behavior recorded every 5-minutes during focal follows included group size (within 50 m of the tagged whale), directionality of movement (directional versus non-directional or "milling" behavior), speed of travel, and distance between the tagged whale and it's nearest neighbor. Behavioral events (e.g., fast-non-directional surfacings, breaches, tail-lobs, spy-hops) were recorded as they occurred. If high-speed, non-directional surfacings were observed, which may be indicative of fish chases (e.g., Hoelzel 1993), tagged whales were approached closely and attempts were made to collect fish scales, if any were visible in the water column behind or near the tagged whale. During periods when no whales were tagged, the small vessel would conduct short focal follows on untagged whales for the purposes of determining the rate of occurrence of fast-non-directional surfacings that might be indicative of potential scale sampling opportunities.

When TDR tags were recovered, data were downloaded to a computer in a hexadecimal format and were processed using software provided by the TDR manufacturer (Wildlife Computers). Each hexadecimal file was run through the program *Minimum-Maximum-Mean* (Version 1.22) to produce a raw ASCII file with all data values, for examination of velocity, plotting, and calculation of the percentage of time at depth. As well, Mk6 hexadecimal files were processed with *Zero-Offset-Correction* (Version 1.30) to correct for temperature-related drift in the surface values. The resulting files were processed with *Dive Analysis* (Version 4.08) to calculate statistics for each dive (dive durations, maximum depths, rates of ascent and descent).

Rates of ascent and descent were calculated with the start and end points chosen using the *Dive Analysis* program, selecting periods of relatively constant descent or ascent covering at least 40% of the depth of each dive. The outputs of this program were ASCII files, which were then imported into *Excel* (Version 2000) for statistical analysis and graphing.

In an attempt to objectively and quantitatively define bursts in velocity (velocity "spikes"), we first chose to examine all velocity readings at or greater than the 95th percentile of velocity readings. Average velocity may change over the duration of an encounter (see e.g., Table 1) for a variety of reasons, including differences in behavioral state (e.g., foraging versus rest), or changes in tag placement (ie., posterior migration of the tag on the body due to drag). As such, we broke down each deployment into hourly periods for the determination of velocity readings greater than the 95th percentile. For each potential velocity spike identified using a 95th percentile rule, a number of parameters were recorded or calculated (Table 2). In addition, based on visual plots of velocity versus time, we categorized each potential velocity burst as: 1) a velocity spike; or 2) an artifact (of the 95th percentile rule). Those in the latter category were cases where velocity reached or exceeded the 95th percentile of velocity, but were in fact part of a period of time when velocity was relatively high, that is, when the putative velocity spike did not stand out from surrounding velocity readings (see e.g., Figure 1).

Results and Discussion

A total of eight "southern resident" killer whales were tagged in 2002 (Table 3), four with Mk6 TDRs, three with Mk8 TDRs, and one with a Crittercam (CC) system. A total of 79 hours (range 2 h, 2 min – 15 h, 14 min) of depth and velocity data were collected from the seven TDR tags, and one hour of video/depth data were collected from the CC. Video data obtained from the CC were all within the top 18 m of the water column. During the camera operation the surface behavior of the tagged whale was characterized as social/travel behavior. The waters of Haro Strait have somewhat limited visibility, yet video footage clearly shows the presence of other whales in the water at distances of out to about 5 m or more[1]. Video data indicated no evidence of foraging or fish chases during the one-hour recording.

[1] A short video clip from this deployment can be viewed at http://is.dal.ca/~whitelab/rwb/kwindex.htm

For animals instrumented with TDRs, maximum dive depth recorded was 228 m, by a 10-year old whale tagged with a Mk6 instrument (Table 5). This instrument had a maximum depth range of 228 m, and two dives recorded exceeded this depth range. For the first of these two dives (recorded during the day), only 32 seconds were spent below the maximum depth range, while for the second (recorded at night) 3 minutes and 28 seconds were spent below the depth range of the instrument. Using the rates of ascent and descent documented during these dives above the points where the depth range was exceeded, and assuming a V-shaped dive, maximum theoretical depths for the dives were 258 and 452 m. With a maximum bottom depth in the study area of approximately 350 m, clearly this latter depth was not attained. However, given that the whale exceeding 228 m was only a juvenile, from such data it appears likely that killer whales can dive to the deepest portions of the study area.

Although the average attachment duration of TDRs was just over 11 hours, the maximum depths attained by the seven whales with TDRs averaged 141.4 m (SD = 67 m). Of the seven whales tagged with TDRs, one (K12) was not recorded diving greater than 30 m (Table 5). Baird et al. (1998) reported on a sample of about 65 hours of dive data from 12 "southern resident" killer whales, where tagged whales were frequently followed and surface behavior was categorized into periods of foraging, rest, travel or social behavior. They noted that during periods where surface behavior would be classified as foraging, all tagged whales were recorded diving to 100 m or more, and velocity was highly variable (Baird unpublished). During rest behavior these whales typically exhibited a long series of regular dives to relatively constant depths (e.g., 10-20 m), combined with relatively low and constant velocity (Baird unpublished). Travel was characterized by shallower dive depths and higher, but still somewhat steady velocity, while social/play activities were characterized by shallow and short duration dives and variable velocity readings (Baird unpublished). During the tag deployment on K12, velocity and depth data suggested periods of rest and travel, but little, if any, foraging, thus average maximum depth attained by foraging whales is likely greater than reported here.

Although "southern resident" killer whales do dive deeply, on average less than one percent of all dives examined were to depths greater than 30 m (Table 5). While less than one percent of all dives were to depths greater than 30 m, dives to greater depth are longer in duration than dives to shallower depths (e.g., regression of L87 dive depth vs. duration, $p < 0.001$, $r^2 = 0.473$). Thus the number of dives to a certain depth is less representative of how an animal spends its time than is the proportion of time spent at different depths in the water column. For the seven whales tagged with TDRs, an average of 2.4% of their time (SD=2.6) was spent below 30 m in depth (Table 5).

Velocity data collected from the three Mk8 TDRs deployed were corrupted, thus velocity data are only considered from four individuals (59 h, 20 min of data). To assess the validity of a 95th percentile rule to delineate velocity spikes, we examined the first 100 potential spikes for whale L87 (approximately the first four hours of tag deployment). Thirty-seven of the 100 sampled spikes were considered artifacts. We considered a 37% error rate to be unacceptably high, and instead of using a quantitative definition (e.g., 95th percentile) we chose to define velocity spikes visually[2]. Comparisons of parameter values for these spikes versus the artifacts showed significant differences in all parameters examined (Table 4). What we consider true spikes have higher rates of acceleration and deceleration, last longer, have higher overall velocity, and occur at greater depths than artifactual spikes. Using a visual categorization, a total of 422 velocity spikes were recorded from the four deployments, an average of about seven velocity spikes per hour (see e.g., Figure 2). While only 2.4% of their time was spent below 30 m in depth, between 8.2 and 9.06% of the velocity spikes were recorded at depths greater than 30 m. We suggest this disproportionate number of velocity spikes occurring at depth reflects that most, or all, of the time spent at such depths is for foraging, while time spent near the surface reflects a diversity of functions, including the need to breathe, social activities, rest, travel, and some foraging.

Characterizing which of the observed velocity spikes are predation attempts, as well as which species are being targeted, will require additional information. This information could potentially be collected by more video camera deployments, though the use of acoustic imaging systems (echosounders) to visualize the prey field, or a combination of these techniques. In addition to providing a better understanding of which prey are important, this may help improve

[2] We are currently attempting to develop a more objective quantitative approach to defining velocity spikes.

our understanding of predation rates and hunting strategies, which may have implications for impacts of vessels on foraging behavior.

Six of the eight whales were tagged in the late afternoon/evening because of our attempts to avoid conflicts with whale watching operations, thus focal follows of tagged whales for the purposes of behavioral observations and scale sample collection were limited. A total of 15.04 hours of follow data were collected from five of the eight whales tagged (mean duration of follows = 3.01 h, SD = 2.8 h). During these follows, fast-non-directional surfacings (FNDs), which might be indicative of fish chases, or actual fish chases, were observed on 12 occasions (an average of once every 1.25 hours), but no fish scales were seen in the water, thus we were not able to assess whether there is a bias in collection of fish scales towards prey caught near the surface. All 12 of these potential or actual fish-chases were documented from two individuals that had been instrumented with Mk8 TDRs, thus no velocity readings were available for comparisons of velocity spikes with fish chases/FNDs. An additional 3.73 hours of follow data were collected from 13 individual non-tagged whales (follow mean of 17.23 min, SD = 14.3 min), but no FNDs were recorded. Observers on the tagging vessel did opportunistically observe fish-scales in the water behind several non-tagged whales, but were unable to collect samples due to other activities being undertaken (ie., tagging attempts). Fish-scale sampling could be improved by using a vessel with a high bow extension (similar to the bow extension on the tagging vessel). This would increase visibility downward into the water column, by allowing a sampler to stand higher above the water's surface and out in front of the boat. As noted above however, we chose to use a lower-profile vessel for fish-scale sampling in order to minimize conflicts with whale watching operations, since this vessel would attempt to closely follow tagged whales for as long as possible, regardless of the presence of whale watching operations. Given the rate of FND behaviors documented in this study from focal follows, it is clear that substantial sampling effort will be required to obtain an appropriate sample size.

It is clear that bursts in speed may be associated with activities other than chasing fish, for example travel or social activities. While we are not able to say with certainty that velocity spikes occurring at depth are fish chases, as noted above other activities that involve high velocity readings (ie., travel and social/play behavior) appear to occur primarily in near-surface waters. As such, it is likely that some of the velocity bursts identified and examined in this study in near-surface waters may actually be associated with behaviors other than foraging. We were able to demonstrate that use of a suction-cup attached video camera system with killer whales is feasible, and future deployments of such a system that includes a velocity meter would help clarify these issues. During our study dives deeper than 30 m were only recorded an average of 0.79 /hour (Table 5), thus in order to have a reasonable probability of documenting the function of velocity spikes both near the surface and at depth it would require multiple deployments of these systems for periods greater than an hour. Video camera systems in use by National Geographic include a high-8 video system that allows for programmable sampling and recording of lower-resolution images for up to six cumulative hours. Further deployments of such systems would also help elucidate species of prey captured, both near the surface and at depth.

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Table 1. Example of velocity values[1] for killer whale L87 at and above the 95th percentile, overall, and for the first four hours of the deployment, illustrating variability in average and maximum velocity over a deployment.

Percentile	Overall	Hour 1	Hour 2	Hour 3	Hour 4
95	1.6	2	2.4	2.5	1.1
96	1.8	2.1	2.5	2.7	-
97	1.9	2.2	-	3.2	1.2
98	2.1	2.3	2.6	3.7	1.4
99	2.3	2.5	2.8	4.3	1.6
100	5.1	2.9	4.8	5.1	2.4

[1]Because velocity readings recorded depend in part on tag orientation, position on the body, and whale size (Baird 1998), velocity, acceleration and deceleration readings should not be considered absolutes, but rather as relative readings.

Table 2. Parameters recorded or calculated for each velocity spike.

Parameter	Units
Start Time	HH:MM:SS
Initial Velocity[1]	m/sec
Time at Maximum Velocity	HH:MM:SS
Maximum Velocity	m/sec
End Time	HH:MM:SS
End Velocity	m/sec
Duration	seconds
Acceleration	m/sec/sec
Deceleration	m/sec/sec
Percentile of Maximum Velocity	%
Initial Depth	m
Depth at Maximum Velocity	m
Inflection in Dive at Start of Peak	up/down
Inflection in Dive at Maximum Velocity	up/down
Dive Shape	

[1]See note to Table 1.

Table 3. Details of "southern resident" killer whale taggings during 2002.

Whale ID	Age (years)	Sex	Date	Duration	Time tag on (hh.hh)	Time tag off (hh.hh)	Day Night	Tag type
K21	16	M	02-Jul	14 h, 58 min	19.84	10.82	D/N	Mk6
K12	31	F	02-Jul	15 h, 14 min	20.45	11.68	D/N	Mk6
L54	25	F	02-Jul	2 h, 2 min	20.57	22.61	D/N	Mk8
L87	10	M	07-Jul	14 h, 49 min	15.97	6.79	D/N	Mk6
L41	25	M	07-Jul	5 h, 12 min	20.16	2.04	D/N	Mk8
L91	7	U	09-Jul	12 h, 25 min	7.89	20.32	D	Mk8
L92	7	M	09-Jul	14 h, 19 min	9.62	23.96	D/N	Mk6
K25	11	M	09 Jul	1 h			D	CC
Total[1]				78 h, 59 min				
Mean[1]	17.3			11 h, 17 min				

[1]Total and mean values for time-depth recorder tags only.

Table 4. Comparison of parameters for velocity spikes (n=63) and non-spikes (n=37), determined by eye, for killer whale L87.

Parameter	Non-spikes Mean (sd)	Spikes Mean (sd)	Significance (two-sample t-tests)
Acceleration[1]	0.106 (0.041)	0.153 (0.091)	<0.001
Deceleration[1]	0.133 (0107)	0.195 (0.195)	<0.05
Duration (sec)	15.1 (8.8)	23.0 (9.6)	<0.001
Maximum Velocity[1]	1.44 (0.56)	2.67 (1.06)	<0.001
Percentile	95.5 (1.0)	97.7 (1.5)	<0.001
Depth at max. velocity (m)	4.3 (4.0)	39.1 (66.7)	<0.001

[1]See note to Table 1.

Table 5. Proportion of activities occurring below 30 m for whales instrumented with TDRs.

ID	Max. depth (m)	# Dives > 30 m	# dives > 30 m per hour	% dives > 30 m	% time > 30 m	# velocity spikes	Mean depth of velocity spikes at start of spike (SD)	% velocity spikes >30 m (at start of spike)	% velocity spikes > 30 m (at max velocity)
K21	152	3	0.20	0.31	0.48	142	7.6 (11.8)	2.82	2.82
K12	25	0	0.00	0	0	46	6.5 (3.1)	0	0
L54	194	1	0.49	-	1.67	-	-	-	-
L87	228	17	1.15	1.61	3.78	196	32.2 (58.7)	25	25.51
L41	146	9	1.73	-	7.6	-	-	-	-
L91	158	17	1.37	-	2.17	-	-	-	-
L92	87	8	0.56	1.39	1.18	38	7.7 (12.0)	5.26	7.9
Mean	141.4	-	0.79	0.83	2.41	-	13.5	8.27	9.06
SD	67		0.64	0.79	2.60		12.5	11.36	11.45

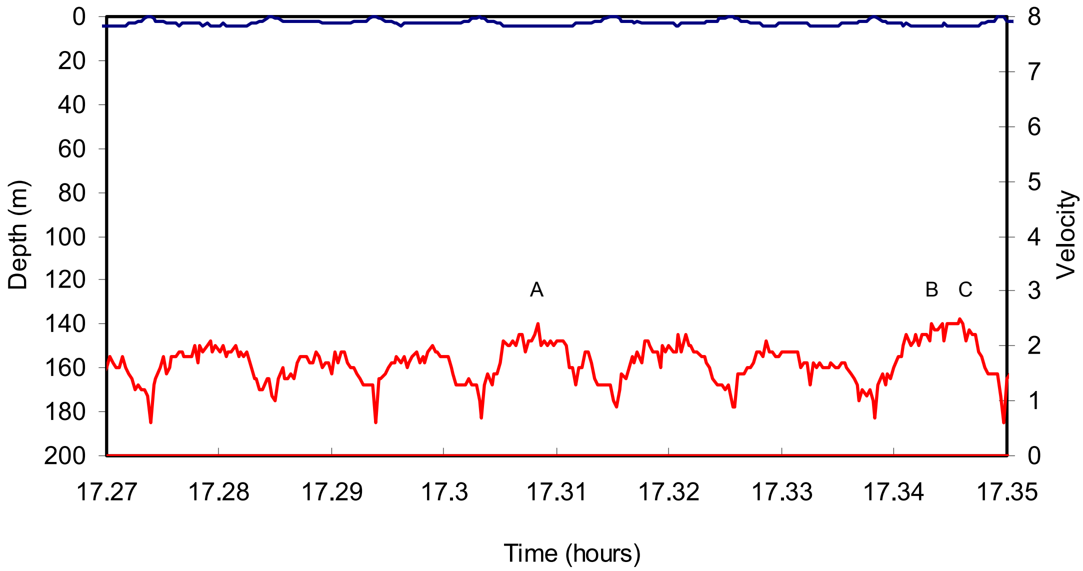

Figure 1. Example of three putative velocity spikes (A, B, C) identified using a 95th percentile rule that we consider artifacts, rather than true bursts in speed. Depth is shown in the upper portion of the graph. No units are shown for velocity readings, as velocity readings recorded by the time-depth recorders are known to vary with tag position and orientation on the body (see text). Thus velocity shown should be considered relative velocity. Scale used for depth and velocity is the same as shown in Figure 2.

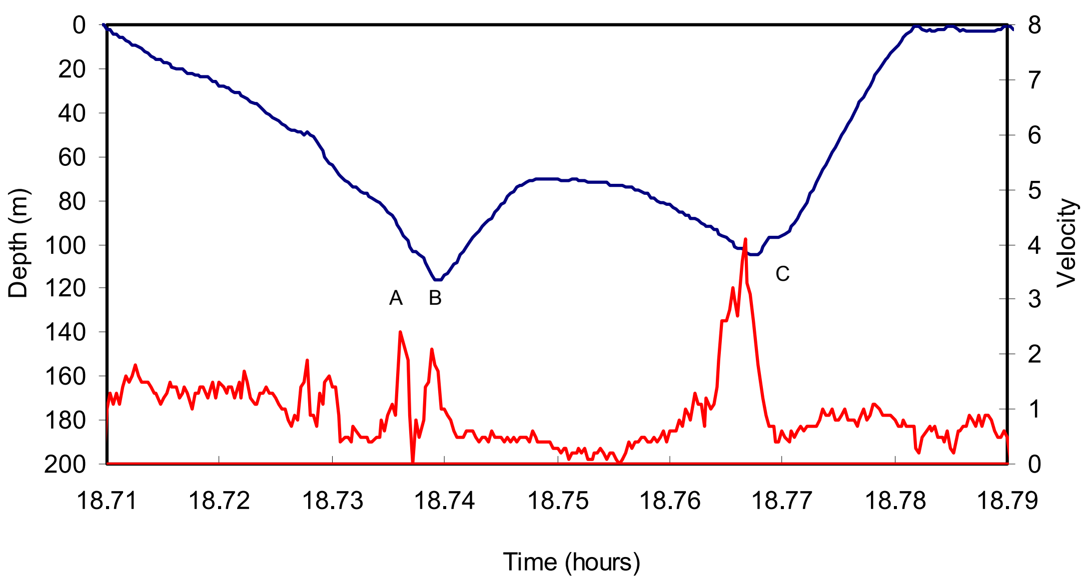

Figure 2. Example of three velocity spikes (A, B, C) recorded during a deep dive by whale L87.