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The activities of a wild, solitary bottlenose dolphin (*Tursiops truncatus*)

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Abstract

The movements and activities of a wild, solitary bottlenose dolphin with a small home range have been studied through six 24 hour watches, conducted between June 1989 and January 1992. Possible relationships with environmental factors were investigated. The opportunity was also taken to compare these results with patterns indicated by reports from informal watches.

Foraging activity accounted for more than half the dolphin's time budget. The proportion of foraging noted during daylight hours alone differed significantly from records for entire 24 hour periods. Tidal rhythms appeared to be the major influence on the dolphin's position, showing a strong preference for the harbour mouth during ebb tide, where he was generally found foraging. The dolphin spent a considerable part of his time associating with boats and swimmers (averaging 34% during daylight), which was termed 'recreational' activity. However, the number of recreational opportunities accepted by the dolphin varied considerably from watch to watch (27% to 83%), and had no apparent pattern. This suggests that the animal was able to prevent visitors from dictating his entire pattern of behaviour.

Data from informal watches indicated a higher incidence of recreational activity, lower resting, and lower foraging than from the formal watches. These results were to be expected, since the informal data was often gathered by people involved in recreation activity with the dolphin.

Acoustic monitoring of foraging greatly aided determination of this activity at night, and throughout the entire watch provided a more accurate method of detecting hunting events than purely visual observation. A regular patrol pattern and steady echolocation were common features during foraging, whereas travel from one area to another within the dolphin's home range was observed with no discernible echolocation activity. Resting behaviour was also acoustically monitored and proved to be essentially silent.

Introduction

Wild bottlenose dolphins (*Tursiops truncatus*) have been extensively studied (e.g. Shane, Wells & Wursig, 1986; Connor & Smolker, 1985; Dos Santos & Lacerda, 1985; Saayman & Tayler, 1973; Wursig & Wursig, 1979; Hussenot, 1980; Irvine *et al.*, 1981; Wells *et al.*, 1987; Scott *et al.*, 1990; Shane, 1990; Wursig & Harris, 1990). The most recent documented occurrences of solitary dolphins off the British Isles featured home ranges which included harbours and/or river mouths, bringing the animals into close and regular contact with boats and swimmers.

Irvine *et al.* (1979) found that groups of *Tursiops* in the western North Atlantic had a mean home range of 85 km^2. Wells *et al.* (1980) report that the mean home range for adult male *Tursiops* groups off Sarasota, Florida, was lower at 20.84 km^2 (standard deviation s.d. = 10.53 km^2). Donald/Beaky (Lockyer, 1978) inhabited three large south-west facing peninsulas starting from the Isle of Man in 1972, from where he moved to south-west Wales, and finally to south-west Cornwall before disappearing in 1976. The dolphin Percy (Lockyer & Morris, 1986), another mature male, had territory stretching along 24 km of south-west Cornwall and extending 3–3.5 km seaward giving a home range of around 77 km^2. An immature male, named Simo (Morris & Lockyer, 1988), initially had a home range of no more than 10 km^2 in 1984, extending to 25 km^2 towards the end of 1985. A fifth solitary dolphin, Fungie (Fitzgibbon, 1989), off the coast of south-west Ireland, resident since the mid 1980's, is most often found around Dingle and Ventry bays, giving a home range of perhaps 10–20 km^2.

A wild, solitary dolphin, known locally as Freddy, resided around the entrance of Warkworth Harbour, Amble, Northumberland, north-east England, (Figure 1) for the four years to 1992 (Bloom, 1991, 1992). The river Coquet flows out of the narrow harbour entrance, forming a concentrated fishing zone for salmon and sea trout migrating in and out all year round. These fish, together with other inshore and estuarine species, appeared to form his diet. This dolphin first arrived in mid-April 1987, and remained in a small triangular (less than 0.5 km^2) home range, which he was rarely seen to leave (Bloom, 1992). The fact that the home range of the Amble dolphin was completely observable from the pier head provided a remarkable study opportunity.

The Amble area has a 12 hour tidal cycle (Figures 3, 5, 6, 7, 8, and 9). There are two high and two low water times, each associated with a slack tidal flow period of approximately two to two and a half hours duration when there is little tidal rise and fall or water movement. Between high and low tide the water level may change by five metres in as little as three and a half hours, generating considerable water movement.

Materials and methods

Acoustic data were recorded from B & K 8104 and Sonar International HS70 and HS300 hydrophones via radio telemetry links on either a wideband Racal Store 4DS Instrumentation recorder or Nagra IV-S and IV-SJ recorders situated at the base station at the landward end of the pier (Figure 1). When conditions permitted, direct recordings were also carried out at the pier head using Racal and Nagra recorders directly from the hydrophones. Various hydrophone deployments were tested to try and combat the problems of boat traffic, wave and water flow noise, tidal movements, strumming effects on cables, and the harbour entrance virtually drying out during low water spring tides.

The most successful hydrophone deployments at the harbour entrance used an endless loop of cord from the south pier to a pulley attached to a buoyed anchor set about 50 metres from the pier (Figure 2). To this loop was attached either the complete sonobuoy and hydrophone assembly (Method 1) or, as in the last four watches, a high quality hydrophone and pre-amplifier (Method 2), with the cables led back along the endless loop to the top of the pier. The latter technique had the advantage of retaining the power supply, gain controls and the telemetry transmitters on the pier, allowing easy battery changes as well as permitting a direct connection for wide band recordings. During the last two watches, three hydrophones set at one metre intervals in a linear array were deployed on the endless loop to provide additional directional information.

For the offshore area, a sonobuoy, with its attached hydrophones, was deployed between an anchored float and the sewer buoy. Once deployed the sonobuoy was not regularly serviced, which would have required boat traffic, but allowed to transmit until failure (Method 3).

The bandwidth of the radio telemetry channels and the economic tape speed selected for the instrumentation tape recorder limited the upper frequency response recorded at the base station to 37 kHz. The sonobuoys, (SSQ41, UEL30059 and SSQ904 types) were all modified before deployment to extend their response to over 20 kHz, although uncorrected hydrophone resonances produced peaks at 2 kHz or 5 kHz. The pier head wideband hydrophones, preamplifiers and cables were calibrated and characterized for use to over 150 kHz when directly connected to the Racal recorder. In the later deployments both sonobuoys and pier head preamplifiers were modified to reject seastate noise below 200 Hz. The acoustic sensitivity of the equipment proved sufficient to detect echolocation activity at ranges exceeding 500 metres when the dolphin pointed towards the sensor. At closer ranges the clicks could be detected from all orientations. Masking of the south pier hydrophones could occur if the animal chose to forage behind the north pier, but in quiet seastate conditions such activity could often be detected by the off-shore sonobuoy. Thus in good conditions the complete range could be monitored acoustically using these two sensing positions.

Pier head observers at the seaward end of the pier, exposed to the elements, recorded what could be seen using a pre-printed chronological log, filled in routinely every 15 minutes throughout the whole 24 hour period, a voice tape for recording more detailed entries, and a video camera for periods of particular interest. A communications receiver at the pier head, tuned to the radio telemetry frequency, helped interpret visual observations; it also allowed echolocation sounds to be fed onto the video camera sound track. Hand held VHF transceivers provided communication and co-ordination between the pier head, boat handlers and base, and also allowed observer commentary to be recorded simultaneously onto the Racal recorder at base whenever any significant event occurred. This facility was most useful at night and in poor weather when the video camera was of little use. A team of six pier head observers, working in pairs on a split-shift system, was found to work best.

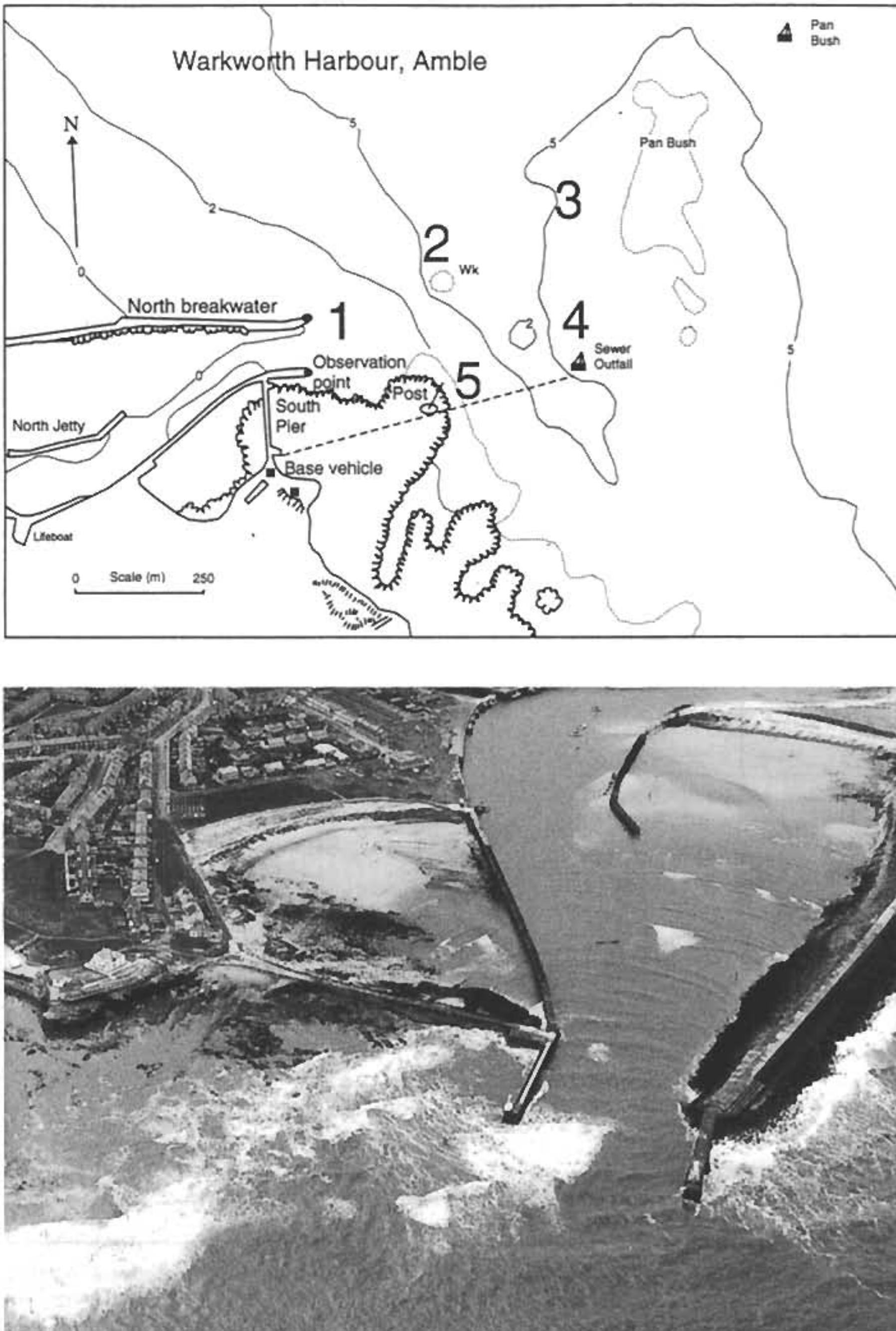


Figure 1. Warkworth harbour area, Amble. The chart above was redrawn from Admiralty Chart 1627, showing the home range with the designated areas within that range: 1 Harbour mouth; 2 Wreck; 3 Pan Bush; 4 Sewer buoy; 5 Post. Contours for water depth are marked in metres, sand banks with dotted lines, and rocks as bold irregular lines. The location of the sewer pipe to the sewer outfall buoy is marked with a dashed line. The photograph below shows an aerial view of the same area.

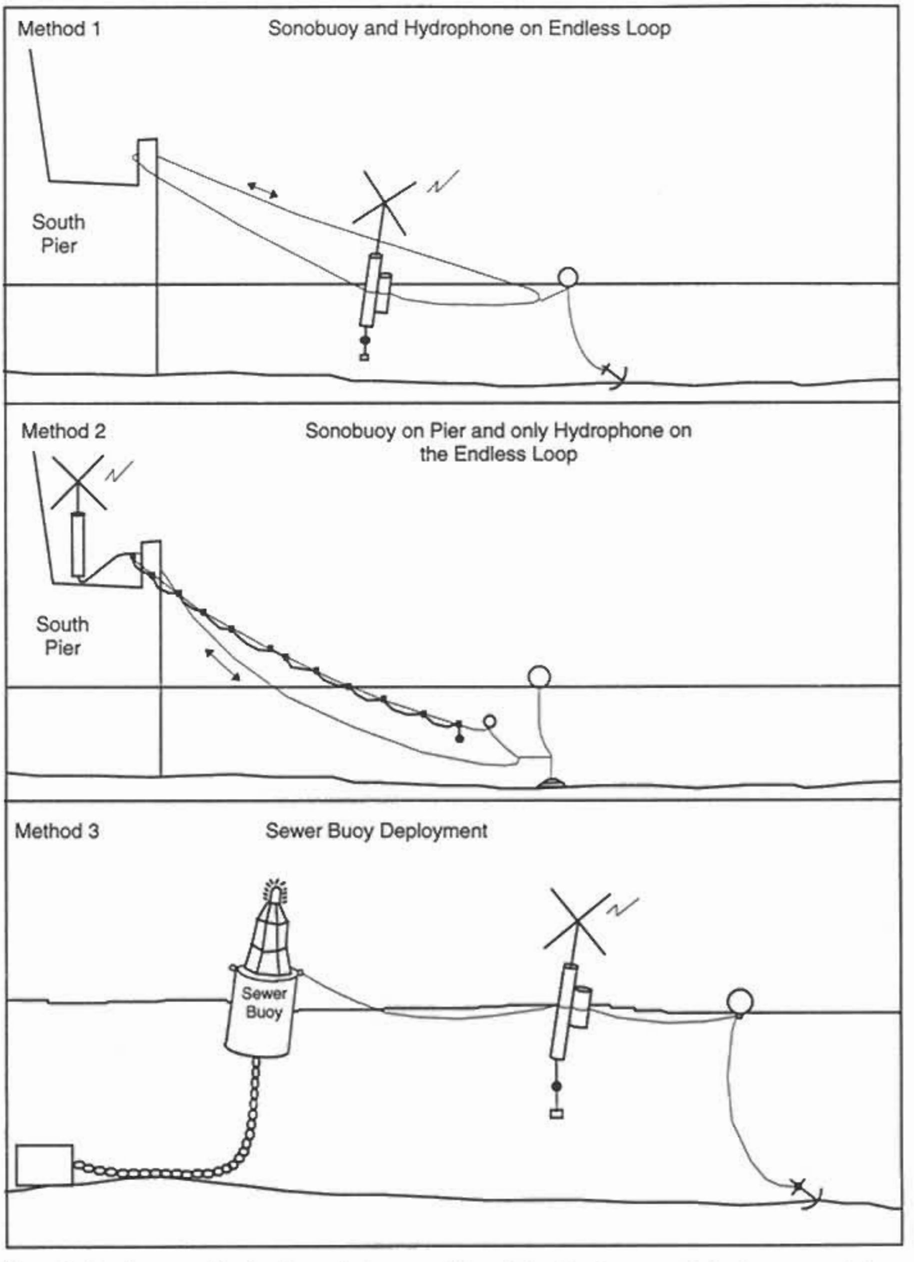


Figure 2. Sonobuoy and hydrophone deployment. The original harbour mouth deployment technique (Method 1), although successful, required periodic recovery of the sonobuoy for battery changes and cable adjustments. Later deployments with the hydrophone cable clipped to the endless loop (Method 2) made battery changes easier and also enabled direct recordings. The hydrophone depth could be varied simply by changing the tension on the endless loop. During the final two watches three hydrophones were deployed in this way on the endless loop. A different technique was required for the sewer buoy area (Method 3), and once deployed this sonobuoy was not regularly serviced, which would have required boat traffic, but allowed to transmit until failure.

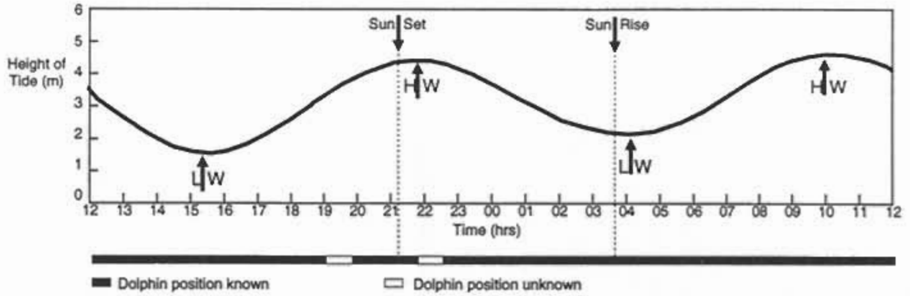


Figure 3. Tidal cycle in the harbour entrance and dolphin position, Summer I (27–28 June 1989).

Base station observers at the landward end of the pier, operated the recording and monitoring and multi-channel recording equipment which could not function for long at the seaward end of the pier. Two or three base station operators, working on a shift system, were adequate. Mains electricity was cabled from a local house to power the base station. The watches were all run from 12.00 to 12.00 GMT.

The objectives of the watches included standardised recording to the dolphin's movements and behaviour through the complete 24 hour cycle. The data could then be compared with other similar formal watches, as well as providing a useful guide to the accuracy of interpretation of informal data (Bloom, 1991, 1992). When conditions allowed, the movements of the dolphin were logged with reference to five areas of his home range (Figure 1). At times when poor light or sea conditions made constant tracking difficult, each individual sighting, position and time was recorded. Although five areas were designated, in practice only four were clearly distinguishable, and determination of the wreck area was by estimation. Environmental data, such as weather, seastate, visibility, and tidal state were logged, as well as boat traffic, swimmer activity and the dolphin's apparent reaction to such events. The 24 hours were analysed as 96 fifteen minute watch periods (WPs). The activities of the dolphin were defined as follows:

Forage/Hunting (F)	Steady to-and-fro patrol swimming activity, and/or steady echolocation click train activity, and/or seen with fish.*
Resting (R)	Long, short, . . . short, long dive pattern (long being greater than 1 minute, and short less than 20 seconds), and/or no echo-location click train activity and no forage or recreational activity
Recreation/Play (P)	Escorting of boats and/or swimmers.**
Unknown (U)	No identifiable activity at any time during a watch period, i.e. dolphin missing or not enough evidence to determine activity.

At Amble (55°22′N), daylight is approximately 10 hours longer during summer. The first watch was scheduled for late June to maximise daylight. A midweek time was chosen to reduce recreational swimmer and boat interference. The second watch was scheduled for mid-winter, to reverse the daylight hour bias. Logistical problems prevented spring and autumn watches. Acoustic monitoring and recording also permitted the collection of data on echolocation behaviour and hunting strategies for more specific research projects (Goodson & Datta, 1992; Goodson, 1990; Goodson, *et al.*, 1994).

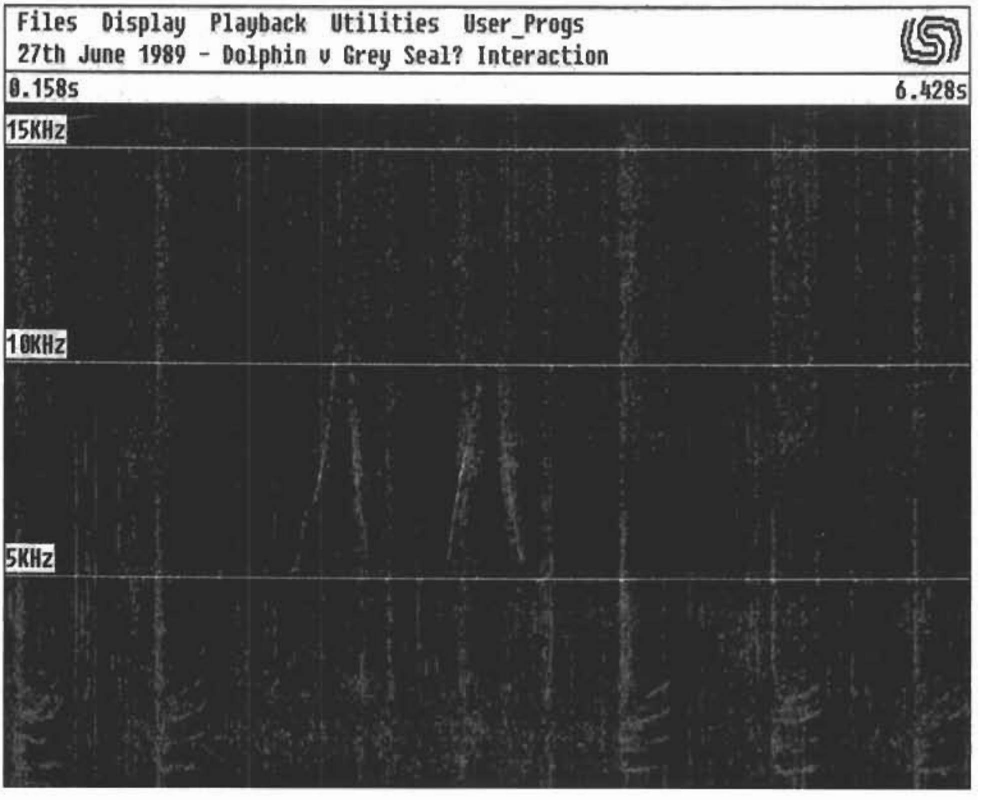
Summary of the six watches

Summer I (27–28 June 1989)

Observation conditions for Summer I (S. I) were fairly miserable at the start of the watch (11.00—rain, wind NW 4–6, seastate 2–4, and swell 1–2). Conditions moderated during the night (wind NW 1–2, sea 0–2, swell 0–1), but deteriorated around 08.00 (more rain, winds NW 2–4, seastate 2–3, swell 1–2). These conditions prevailed for the

*The tossing and carrying of fish could perhaps be a display of recreational or play activity but for the purposes of this study, as the fish first had to be caught, it is classified only as foraging behaviour.

**In this study all dolphin/boat and dolphin/swimmer interactions are designated as recreational. However, it is possible that territorial defence, dominance behaviour, sexual behaviour, or a combination of these and other unknown factors might have initiated and/or prolonged these encounters.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27th June 1989 - Dolphin v Grey Seal? Interaction
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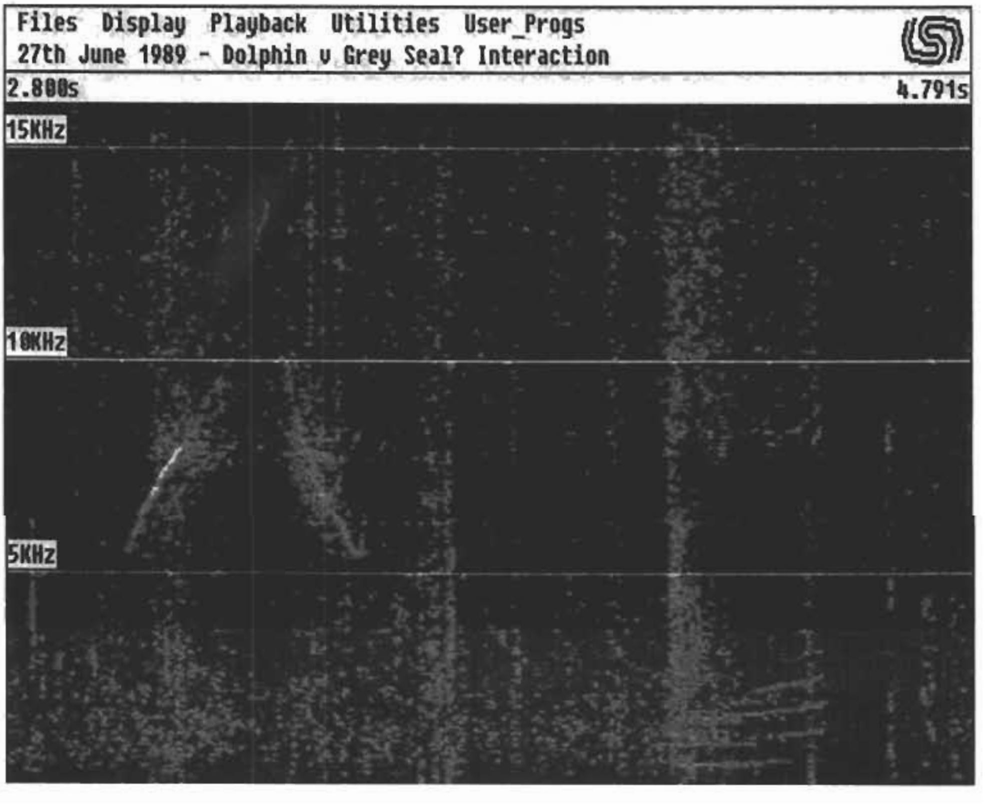
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remainder of the watch (Figure 3). From 11.00–15.00 the dolphin spent most of his time at the sewer buoy. A sonobuoy set in this area operated from 11.00 to 12.30, and although background noises were clear, no echolocation click trains were heard. Despite poor sea conditions at 19.00, a second sonobuoy was deployed but failed to transmit. The third buoy, deployed at 07.15, transmitted successfully for over two hours. In total over three and a half hours of acoustic coverage in the sewer buoy area were achieved during this watch.

The dolphin briefly visited the post area at 12.26, and was observed to jump three times in the same place. Simultaneously, several distinct dolphin signature whistles and a repeated low frequency 'oink' sound were clearly audible above the background noise (Figure 4). The 'oink' sound has been tentatively identified as being from agrey seal (*Halichoerus grypus*). Although no seal was observed at that time, there is a grey seal colony on the seaward side of the nearby Coquet Island. After this event, the dolphin returned to his previous quiet routine around the sewer buoy, and remained there throughout the low water period. At 16.45 the dolphin moved into other areas, with some escorting of boats throughout his home range. Some successful foraging activity was observed in the wreck and post areas, three fish were tossed during the 18.45–19.00 period. The dolphin was unobserved for two short periods (19.00–19.45 and 21.45–22.30). Between these times, during a brief foraging sortie into the harbour mouth, he was observed to panic an eider duck (*Somateria mollissima*) by surfacing underneath it. This and other apparently deliberate acts of duck harassment were informally classified by the watchers as 'duck bashing' episodes.

After dark, at 22.30 the dolphin reappeared in the harbour mouth and settled into a steady to-and-fro patrol forage pattern, which was maintained throughout the ebb tide period. The presence of the dolphin was confirmed by respiratory and other sounds audible to the pier observers. This foraging behaviour continued until just before low water (03.54), when he moved out to the sewer buoy and remained there for the rest of the watch. The sonobuoy failed to detect any echolocation activity between 08.45 and 10.20, although the dolphin was seen to be present for the whole time, and background noises were clear.

Winter I (11–12 January 1990)

Observation conditions for Winter I (W. I) were reasonable (wind W 4–6, offshore, fine, clear weather, seastate 2–3, swell 1–2). A sonobuoy was operational for 19.5 hours at the south pier (Figure 5).

From 12.00–16.00 the dolphin spent most of his time in the harbour mouth. At one point an angler on the pier struck his rod on what he thought was a fish bite; immediately afterwards, the dolphin was seen to leap into the air. It is believed that the dolphin had snagged the line. The dolphin escorted several boats in this period, and settled down into a regular to and fro forage pattern from 15.00. He was observed to catch two fish between 15.00 and 15.30, tentatively identified as one salmonid, and one dogfish (shark) spp.

Foraging continued as the dominant activity until 20.30, with two more fish being tossed in the 16.15-16.30 period (sunset). At 20.30, one hour before low water, the dolphin moved out of the harbour mouth, became silent, and was lost from view. At 23.00 slow repetition rate echolocation clicks (10 to 20 Hz) began, consistent with foraging activity, indicating that the dolphin had returned to the harbour mouth. However, the dolphin was not observed visully until 03.30–03.45. Foraging activity continued as the dominant activity until almost the end of the watch, although the dolphin did move away for a quiet period at the sewer buoy (08.45–10.00) during the first hour of low water slack tide. At 11.30 the dolphin came over to the south pier to interact with swimmers and boats.

During the whole watch, nine fish tossings were observed, eight involving salmonid spp. On one occasion a fish shepherding sequence was observed after a fish chase, which culminated in the tossing of a large salmon in front of the south pier. This fish was thrown and carried out to sea about 100 metres, and then allowed to swim free. The fish then swam slowly back towards the harbour on the surface, apparently unable to dive as its dorsal fins and upper tail were visible above the surface. The dolphin circled and repeatedly surfaced behind and on both sides of the fish until both were in line with the south pier. This shepherding sequence ended abruptly when the dolphin dived and came up to hit the fish from below, but instead of grasping it, the dolphin allowed it to continue upstream into the harbour while he moved away in the other direction towards the north pier.

Summer II (28–29 June 1990)

Observation conditions for Summer II (S. II) were good throughout the watch (fine weather, wind mild SW 1–3, seastate 0–2, swell 0–1). Sonobuoys provided complete 24 hours acoustic coverage at

Figure 4. Spectrogram of dolphin whistles and possible seal 'oink'.

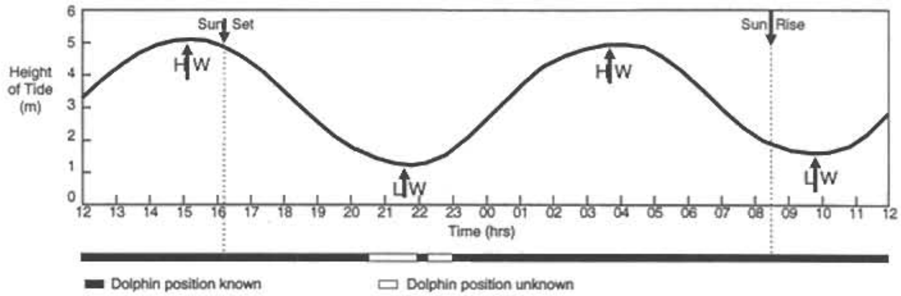


Figure 5. Tidal cycle in the harbour entrance and dolphin position, Winter I (11–12 Jan 1990).

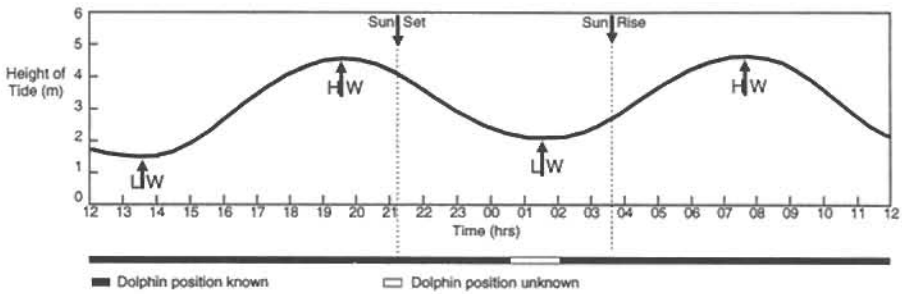


Figure 6. Tidal cycle in the harbour entrance and dolphin position, Summer II (28–29 June 1990).

the sewer buoy and 17+ hours at the south pier (Figure 6). Recreational activity, which was mainly boat related, was common during most of the daylight hours.

Foraging activity was observed from 11.00–11.45, and at least one fish was seen to be caught during this period. A quiet rest period followed (11.45–15.30), with the dolphin at or near the sewer buoy during low water slack tide. During this period there were two grey seal sightings close to the dolphin. There was no apparent interaction during one episode, when the dolphin's resting pattern was unaffected. The other event took place during a break in resting when the dolphin moved inshore to two swimmers in the post area. A grey seal surfaced close to the swimmers, and the dolphin immediately moved towards that position, diving and surfacing several times in the area before rejoining the two swimmers. Unlike the possible interaction of Summer I, however, no sounds were recorded.

Regular foraging began to dominate his activity at 16.30, after an hour spent escorting larger fishing boats from the harbour to the limits of his home range. Foraging continued over the high water slack tide period, through the ebb tide, until the onset of low water slack tide when, at 00.20, he moved out of the harbour mouth and became silent. The dolphin remained unseen and unheard for only 90 minutes, because at 02.00 he was resighted close by the sewer buoy where he stayed until 03.00. Shortly afterwards, a sewer buoy to north pier movement was observed; a distance of approximately 450 metres was transversed in approximately 45 seconds, giving a travel speed of around 10 m/s. Sea state 0 conditions prevailed at this time, and the movement was completed without surfacings.

Foraging activity dominated his observed behaviour from 03.15 until the end of the watch, although recreational activity, usually boat escorting, continued sporadically. Three fish were tossed during this time, making four (all tentatively identified as salmonid spp.) for the whole watch. There was also one incidence of 'duck bashing' during the early morning period.

Winter II (31 January–1 February 1991)

The weather was initially poor for Winter II (W. II), overcast with sleet and rain showers (wind E 3–5, sea 2–4, swell 1–2). From 20.00 onwards the weather improved (wind SE 0–1, sea and swell 0–1) and remained good for the remainder of the watch (Figure 7). Hydrophones were deployed in the harbour entrance from 14.00 onwards, giving 22 hours of coverage in the harbour mouth, but there was no coverage at the sewer buoy.

Foraging, resting, and recreational boat escorting were recorded during the first four hours of the watch, before a prolonged resting period at the sewer buoy (15.30–17.00) coinciding with high water slack tide. As darkness fell and ebb tide began (17.00), the dolphin moved back into the harbour mouth and began foraging. This behaviour was

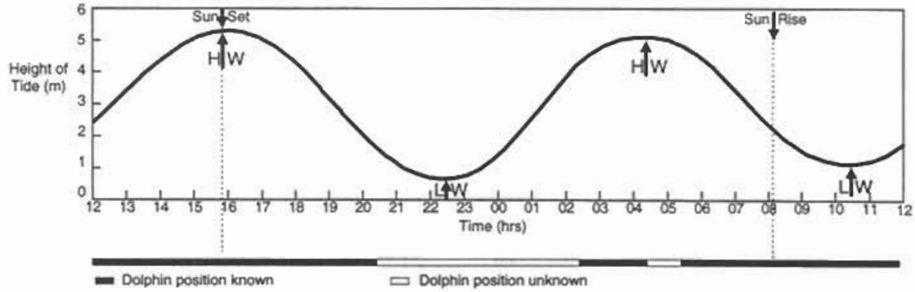


Figure 7. Tidal cycle in the harbour entrance and dolphin position, Winter II (31 Jan–1 Feb 1991).

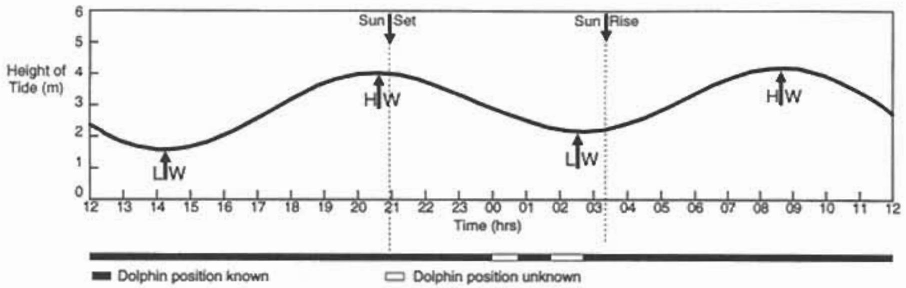


Figure 8. Tidal cycle in the harbour entrance and dolphin position, Summer III (5–6 June 1991).

consistently seen and heard during the ebb tide period until he moved out of the harbour mouth and ceased his steady echolocation emissions during low water slack tide. He remained unobserved from 20.30 to 02.40, when he recommenced foraging in the harbour mouth. Apart from a one hour disappearance (04.15–05.15), foraging activity was constant until 09.20. There were two duck bashing events during this foraging period. The fishing boats leaving harbour just before and after dawn (07.00) were generally ignored and not escorted.

From the onset of low water slack tide (09.30), the dolphin moved further out to the wreck area, where he remained silently until 10.30. He then moved to the sewer buoy and remained in this area for the rest of the watch, with only three brief sorties to other areas (10.45, 11.21, and 11.48). The dolphin was not seen to toss or carry any fish.

Summer III (5–6 June 1991)

Bright, fresh conditions prevailed during the first half of the Summer III (S. III) watch (wind SE 4–6, seastate 2–3, swell 1–2). Wind and sea conditions moderated from 19.00, and by dawn the wind was calm and sea and swell states were 1. Overcast conditions prevailed from dawn until the end of the watch, with rain showers and drizzle during the morning. By 08.00 the wind had strengthened (wind S 4–6, sea state 3, swell 2). The conditions then moderated steadily again and by the end of the watch were wind S 2–3, sea 1–2 and swell 1 (Figure 8). Hydrophones were deployed from the south pier from 13.00, giving 22 hours of coverage, and from the sewer buoy between 21.00 and 07.00.

Foraging activity in the harbour mouth dominated the 11.00–13.30 period, coinciding with ebb tide. This was followed by a resting period at the sewer buoy (13.30–14.45) at the end of the ebb tide and for the first hour of low water slack tide. From 14.45 onwards, recreational activity dominated the remaining low water slack tide and subsequent flood tide periods. The dolphin accompanied one of the regular sightseeing boats with a film crew and swimmers on board, that drifted well to the north of the harbour entrance and well outside his traditional home range. The dolphin only left this boat when it returned to harbour at 16.15. A brief resting period at the sewer buoy from 16.15–17.30 was followed by recreational activity and sporadic foraging for the remainder of the flood tide and the first hour of high water slack tide. He then moved to the sewer buoy for a quiet resting period (21.00–22.00).

With the onset of darkness, and the start of ebb tide (22.00), the dolphin moved back into the harbour mouth, and engaged in foraging (22.00–01.45) with two unobserved periods (00.00–00.25 and 00.30–00.45). At the onset of the low water slack tide the dolphin moved out of the harbour mouth, became silent, and was lost from view. With dawn and improved visibility, the dolphin was relocated escorting a boat out towards the sewer

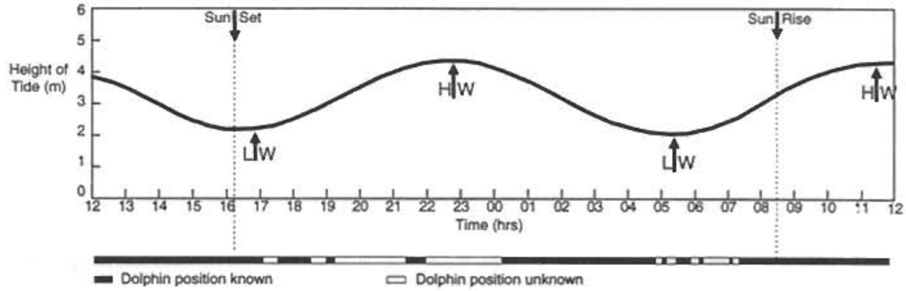


Figure 9. Tidal cycle in the harbour entrance and dolphin position, Winter III (15–16 Jan 1992).

buoy at 02.50. He remained at the sewer buoy until 06.00, with just one excursion (03.15) to escort a fishing boat.

At 06.00 the dolphin left to accompany the same boat and swimmers as on the previous afternoon. He remained in attendance until the party returned to harbour (08.00). Added interest was provided when the skipper's dog fell into the water while barking at the dolphin and the swimmers in the water. From 08.00 to the end of the watch (12.00) foraging activity became more consistent as the high water slack tide ended and the ebb tide began. During this period the dolphin interrupted his foraging activities when one of the many boat or swimmer interaction opportunities arose. During this watch, the dolphin was seen with fish on three occasions at 11.45, 09.08, and 10.29, but species identification was not possible.

Winter III (15–16 January 1992)

Good, calm, bright weather (no wind, seastate 0–1, swell 0–1) prevailed from the beginning of the Winter III (W, III) watch until 07.00, when a breeze developed (W 1–3) for the remainder of the watch (seastate 0–1, swell 1–2). Sonobuoy coverage at the south pier began at 13.00 and continued for 23 hours (Figure 9). There was no deployment at the sewer buoy.

From 12.00–15.00 steady foraging activity was observed on the ebb tide, interrupted during the first hour to escort a sightseeing boat soliciting the dolphin's attention. The dolphin was seen to catch an unidentifiable fish at 14.28. From the onset of low water slack tide, the dolphin moved out to the Pan Bush buoy and remained there until 16.00. The activity of the dolphin was logged as unknown, although with all the recorded surfacings being very close to the buoy itself, the dolphin was perhaps in resting mode. A trawler passing close to this buoy was escorted back to the harbour entrance at 16.10. This boat was unable to enter the harbour due to low water levels and hove to with the dolphin in attendance. As darkness fell and the boat drifted out of visual range, the dolphin was lost from view at 17.00. The dolphin was resighted accompanying a smaller fishing boat into the harbour at 17.40, and almost immediately after this was heard echolocating in a forage pattern.

Foraging continued until 18.25 when the dolphin moved away from the harbour mouth and out of audio and visual range. Apart from two brief sorties back into the harbour (19.00–19.10 and 21.35–21.55), the dolphin was unrecorded through the whole flood tide and the high water slack tide period. At the start of the ebb tide at 00.00, the dolphin returned to the harbour mouth area, and foraging activity was recorded until the beginning of the low water slack tide (04.15). Sightings and echolocation activity consistent with foraging continued sporadically through the low water slack tide. At times the dolphin moved away, only to reappear a few minutes later before disappearing again (04.53–05.10, 05.24–05.30, 05.58–06.15). At 06.20 the dolphin moved out of the harbour mouth, at the beginning of the flood tide, and apart from one brief appearance escorting a boat (07.05), went recorded until improved visibility allowed his position at the sewer buoy to be determined at dawn (07.35).

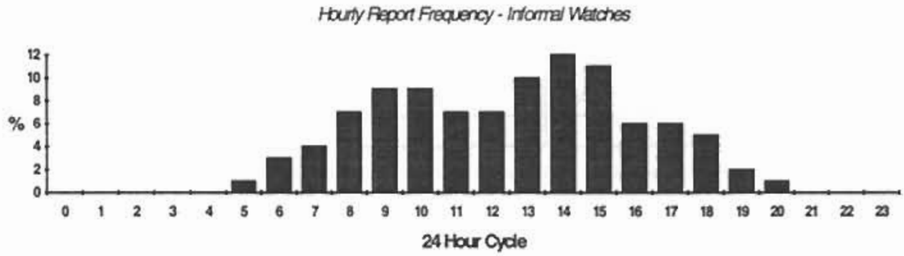
The dolphin remained resting at the sewer buoy until a passing fishing boat was escorted back into the harbour mouth (09.25). A short period of foraging activity followed (09.30–10.15), before he moved back to the sewer buoy. At 11.45 the dolphin reappeared in the harbour mouth for the final minutes of the watch, and the subsequent foraging continued after the formal watch ended at 12.00.

Results

1. Observer biases

Data have been collected on this dolphin since 1988 (Bloom, 1991), the vast majority as a result of informal watch reports from many sources. These reports varied due to observer habits, duration of watch, time of day, time of year, year of observation, weather and seastate conditions. The position and activity of the observer (e.g. standing on

Time	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Informal (Hrs)		Formal (.25 Hrs)	
													Total	%	Total	%
0	0.5												0.5	0	15.0	3
1	0.5												0.5	0	15.0	3
2													0.0	0	19.0	4
3							0.5						0.5	0	24.0	5
4				0.5	1.5		2	1	0.5				5.5	0	22.0	4
5			1	2	4	4	6	2	2				21.0	1	22.0	4
6				10.5	12	5	11	8.5	5.5	2.5			55.0	3	21.0	4
7	2	4.5	7	10	10	10	7.5	6	9	4.5	0.5	1.5	72.5	4	23.0	5
8	14.5	7	12	15.5	10	10	19.5	10	13	9.5	2	7.5	130.5	7	24.0	5
9	19	16	13.5	13	11	18.5	15	10.5	20	15	10	13	174.5	9	24.0	5
10	17.5	19	11	8.5	10	11	11	14	16	18	17.5	16	169.5	9	24.0	5
11	12	10	13	5.5	10.5	4	9	15.5	15.5	11	10.5	14.5	131.0	7	24.0	5
12	11	12	12	9.5	12.5	4.5	13.5	8	15	14	10.5	8.5	131.0	7	24.0	5
13	14.5	18	14.5	16.5	19.5	14.5	22	17	17.5	18	8.5	15	195.5	10	24.0	5
14	22.5	28	27.5	13	17	11.5	21	23.5	20.5	28	12	19.5	244.0	12	24.0	5
15	20	26.5	14	12	16.5	14.5	21	20.5	23	26.5	15	13.5	223.0	11	24.0	5
16	4	7	13.5	8.5	11	11	8.5	22	15.5	14.5	4.5	3.5	123.5	6	24.0	5
17		2	8	10.5	13.5	10	19.5	23	20	5.5	1	0.5	113.5	6	22.0	4
18			5	8.5	22.5	10	19.5	14.5	11	2			93.0	5	22.0	4
19				4	11.5	15	9.5	6.5	2				48.5	2	18.0	4
20					6	2	7.5	3.5					19.0	1	17.0	3
21						0.5	3.5						4.0	0	13.0	3
22									0.5				0.5	0	11.0	2
23									0.5				0.5	0	16.0	3
Total	138	150	152	148	199	156	227	206	207	169	92	113	1957.0	100	496.0	100



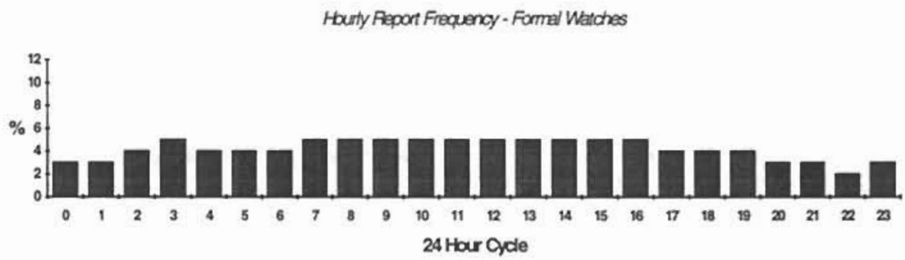


Figure 10. Informal and formal 24 hr watch hourly distribution, showing the time of day and monthly distribution of the hourly informal diary sheet reports from 1988–92. (All times corrected to GMT). The shaded boxes represent the approximate sunrise and sunset times, indicating very few informal nocturnal reports. The six formal watches, which were recorded as fifteen minute periods (24 representing total coverage), show a much more even report frequency. This result is represented graphically, below the table, in the separate informal and formal bar charts.

the pier, swimming, or watching from a boat), distance from the dolphin, as well as variation in the visibility of the dolphin's activity, tend to bias these reports towards high activity close inshore activities (e.g. swimmer interactions in the harbour mouth) and against less obvious, more distant, activities (e.g. resting quietly at the sewer buoy).

To explore these unavoidable informal observer biases, the formal 24 hour watches employed the same nucleus of experienced researchers and similar recording protocols over the same time period (Figure 10). The dolphin's activities observed and recorded during the informal watch time from 1988–92 are, in some cases, markedly different to those recorded during the six formal watches conducted during 1989–1992. Informal reporting of each activity varied significantly between the five years for which data were recorded (Figure 11). Activity information was logged for contiguous 15 minute periods on formal watches, but in one hour periods on informal watches. In order to calculate the effects of observer bias between these two

YEAR	Forage		Resting		Recreation		TOTAL PERIODS
	No.	%	No.	%	No.	%	
1988	64	49	75	58	55	42	130
1989	298	52	140	25	388	68	569
1990	467	69	47	7	531	79	674
1991	240	51	24	5	362	78	467
1992	64	55	23	20	46	39	117
TOTAL	1133		309		1382		1957
χ^2 (df. 4)	55.60		285.48		139.45		18.47

Figure 11. Annual informal reporting of dolphin activity. No.=number of hourly periods when the indicated behaviour was recorded. %=percentage of total periods recorded for that year. There were significant statistical differences, at the 0.1% level, between the annual reporting of all dolphin activities. The informal reporting system was initiated during 1988, and the dolphin left the area in 1992, so the figures for these years are lower.

ACTIVITY	INFORMAL Time (1 Hr)		FORMAL Time (15 min)		FORMAL Time (1 Hr)		χ^2 (df. 1)
Forage	1133	58%	293	59%	98	74%	12.98
Resting	309	16%	129	26%	42	32%	21.595
Recreation	1382	70%	129	26%	59	26%	37.629
TOTAL	1957		478		132		

Figure 12. Comparison of informal and formal watch data. The percentages represent the watch periods in which *one or more* of the three activities was reported to occur and as such the columns will not add up to 100%. The informal data were collected between 1988 and 1992. The formal data are derived from the 478 quarter hourly watch periods in which the dolphin was actually monitored during the six watches. The formal 15 minute watch periods were collected into 1 hour combined watch periods to compare formal and informal reporting. One or more dolphin activities were recorded in 132 out of the possible 144 one hour formal combined watch periods.

types of watches, the data for formal watches were gathered into hourly figures (Figure 12).

The more obvious activities classified as recreation were reported to occur much more often during informal time (70%) than formal time (26%) and this was significant statistically at the 0.1% level, $\chi^2=37.629$ with one degree of freedom (df. 1). Conversely resting was reported more during the formal watch (32%) than during informal time (16%) and this difference was also significant statistically ($\chi^2=21.595$, df. 1) at the 0.1% level. The reporting of forage activity showed the smallest difference between the two sample methods (formal time 74% and informal time 58%), but this was still statistically significant ($\chi^2=12.98$, df. 1) at the 0.1% level. These figures are perhaps to be expected, given that the primary foraging area is close to the south pier, which was the most favoured observer location. With resting occurring well away from the pier, the converse is true. Many of the regular informal reporters were actually involved in recreational activity, whereas formal watches were deliberately devised and scheduled to try and minimise the opportunity of boat and swimmer interaction. It is therefore to be expected that there would be differences in the reporting of recreational activities.

2. Home range use

2.1 General home range use. For summer watches, with only six and a half hours between sunset and sunrise, and visibility at those times often good enough to see the harbour entrance clearly, the dolphin's activity was recorded as unknown for only 90 minutes during S. I and S. II and for 114 minutes during S. III.

On the winter watches, with over 16 hours of darkness between sunset and sunrise, the dolphin's activity was unknown for longer periods. During all three winter watches the dolphin moved out of the harbour at low water slack tide and was unobservable. On W. I the dolphin returned two hours later and was monitored, mainly acoustically, for the remainder of the night. During W. II the dolphin did not return until the following high water slack tide period, approximately six hours later. On W. III the dolphin did not return until the beginning of the ebb tide approximately seven hours later, however unlike the previous two winter watches, the dolphin did make several brief visits to the harbour entrance during this long 'absent' period. Much of this missing time was almost certainly spent at the sewer buoy but, with no daylight to see or echolocation activity to hear, this would be difficult to prove without potentially disturbing the animal by putting a boat in that area.

Analysis revealed that the dolphin spent nearly half his time (Figure 13) in the harbour mouth (49.00% s.d. 17.25). He spent significantly more time here during winter (56.75% s.d. 16.50), than in summer (41.25% s.d. 14.00; $\chi^2=205.4$, df. 1). The next most frequented area was the sewer buoy (23.25% s.d. 13.75) where he was recorded significantly more in summer (33.25% s.d. 12.25) than in winter (13.25% s.d. 4.25; $\chi^2=486.7$, df. 1). This is to be expected given this area's distance from the south pier observation point, and the much shorter daylight period in the winter watches.

The other defined areas within his home range (wreck, Pan Bush, and post areas) were not heavily frequented during any of the six watches (11.75% of the overall time).

The dolphin's activity was unknown for only 15.75% of the total 144 hours, with significantly less unknown time in summer (6.75% s.d. 0.75) than in winter (24.50% s.d. 11.50; $\chi^2=512.5$, df. 1). Much of the missing winter time was probably spent quietly at the sewer buoy. If this is so, it would raise the winter sewer buoy time budget towards the summer level.

There were only two recorded excursions by the dolphin outside the home range. The first lasted for four minutes (W. I), the second for 40 minutes (S. III); both were the result of boat escorting.

2.2 Tidal relationship with home range use

The four distinct tidal phases (ebb, low, flood and high tide periods) had an apparent influence on home range use (Figures 14a and 14b). During ebb tide the dolphin showed a strong preference for the harbour mouth, 81.0%, s.d. 16.5 of all ebb tide time was spent here, with little apparent variation between the six individual watches. However, significantly more time was spent in the harbour entrance during winter (89.0%, s.d. 4.5) than in summer (72.5%, s.d. 14.0; $\chi^2=6.35$, df. 1 at the 5% level).

During flood tide the dolphin was likely to be found at the harbour mouth (36.0%, s.d. 28.0) or the sewer buoy (30.0%, s.d. 19.0). Missing time varied significantly ($\chi^2=27.12$, df. 1 at the 0.1% level) between summer (3.0%, s.d. 4.0) and winter (34.5%, s.d. 23.0), perhaps resulting from an underestimation of sewer buoy time during winter. The significant seasonal bias, with the dolphin apparently spending more time in the harbour mouth during winter (45.0%, s.d. 30.5%) than summer (28.0% s.d. 24.5%; $\chi^2=4.99$, df. 1, at the 5% level) may therefore be an artefact.

The high tide summary indicates an overall preference for the harbour mouth (43.5%, s.d. 31.0), with much of the rest of the time at the sewer buoy (28.0%, s.d. 12.0). This was not consistent through all six watches. W. III had a significant missing component, perhaps masking another underestimation of sewer buoy time. The dolphin was most often found close to the sewer buoy at low tide. The overall figure of 33.0% (s.d. 21.0) is probably similarly seriously underestimated.

The results of this analysis suggested that the best time to observe the dolphin close inshore near the pier was during an ebb tide, the worst time during low tide, with the remaining two tidal phases less predictable.

3. Dolphin activity

A single 15 minute watch period could contain one or more recorded activities. For example, the dolphin was quietly resting close to the sewer buoy and then accompanied a returning fishing boat before beginning a steady echolocation search pattern in the harbour mouth. All three defined activities were thus recorded in a single WP. The figures discussed in this section are WPs in which activities were recorded, and not percentages of real time (as in Sections 2.1–2.2). The percentages therefore do not total 100.

Comparing activities from watch to watch poses problems because different watches, although all comprising 96 WP, contained differing numbers of WPs when activities were monitorable, so different percentage ratios can be derived. The percentages shown in Figure 15b are derived using the maximum 96 WPs possible in the watches. Figure 15c perhaps the most representative for foraging because this activity's detectable acoustic component makes non-visual monitoring possible. These data are derived from the WPs in which the dolphin's activities were determinable. Figure 15d is derived from daylight WPs only, and as resting and recreational activities were only positively identified visually, this daylight ratio is perhaps the most representative for these two activities.

3.1 Foraging. Foraging activity was most often observed in the harbour mouth, especially towards the north pier (Figure 1). During this activity the dolphin swam in a regular pattern with medium length dives (20 to 60 seconds) recorded more often than long dives (more than 1 minute). This regular patrolling could be across the harbour entrance or up and down within the entrance. The swimming area could also be just outside the line of the north pier, where the dolphin appeared to be working the eddy currents created along the freshwater/seawater margin.

	Summer			Winter			Total		
Area	Total	Mean	%	Total	Mean	%	Total	Mean	%
Harbour	1781	594	41.25	2448	816	56.75	4229	705	49.00
s.d		203	14.00		238	16.50		248	17.25
Wreck	386	129	9.00	161	54	3.75	547	91	6.25
s.d		23	1.75		25	1.75		45	3.25
Pan Bush	124	41	2.75	65	22	1.50	189	31	2.25
s.d		39	2.75		20	1.50		33	2.25
Sewer	1437	479	33.25	570	190	13.25	2007	335	23.25
s.d		178	12.25		63	4.25		197	13.75
Post	258	86	6.00	12	4	0.25	270	45	3.00
s.d		17	1.25		3	0.25		43	3.00
Other	40	13	1.00	4	1	0.00	44	7	0.50
s.d		18	1.25		2	0.25		15	1.00
Unknown	294	98	6.75	1060	353	24.50	1354	226	15.75
s.d		11	0.75		165	11.50		173	12.00
	4320	1440	100	4320	1440	100	8640	1440	100

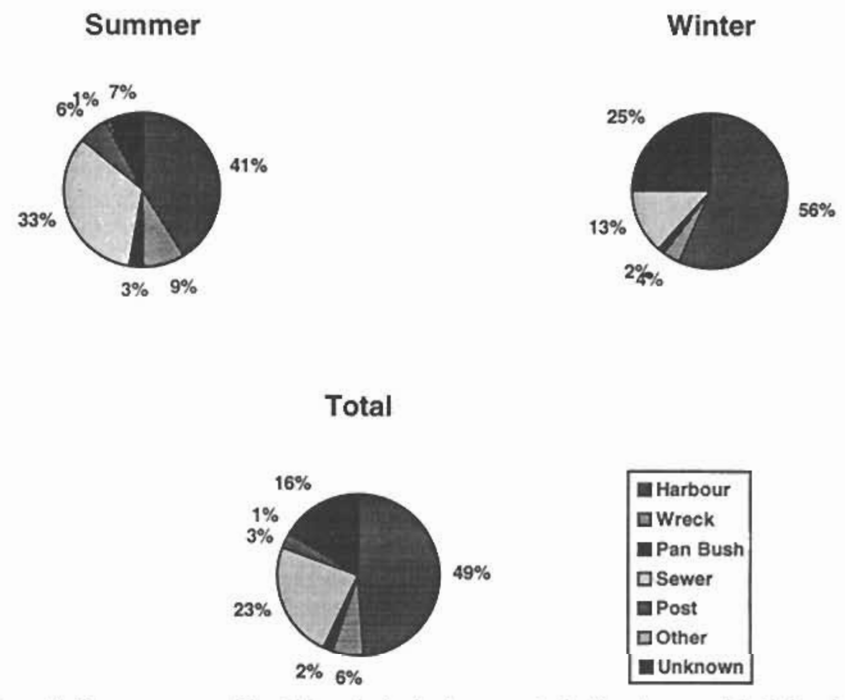


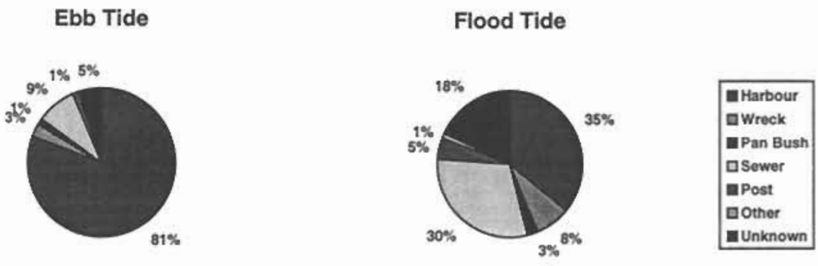
Figure 13. Home range use. The table and pie charts represent the time (expressed both in minutes and as a percentage), and standard deviation (s.d.) that the dolphin was recorded in the five defined areas of his home range (Harbour mouth, Wreck, Pan Bush, Sewer buoy, Post), outside the home range (Other), and the time when he was not monitorable (Unknown).

Ebb Tide

	Harbour		Wreck		Pan Bush		Sewer		Post		Other		Unknown		Total
Summer	311	72.5%	14	3.5%	0	0%	77	18%	10	2%	0	0%	18	4%	430
s.d	±61	±14%	±16	±4%	±0	±0%	±90	±21%	±10	±2%	±0	±0%	±25	±5.5%	
Winter	435	89%	11	2.5%	12	2.5%	3	0.5%	1	0%	0	0%	28	5.5%	490
s.d	±22	±4.5%	±3	±0.5%	±12	±2.5%	±3	±0.5%	±1	±0%	±0	±0%	±29	±6%	
Total	746	81%	25	3%	12	1.5%	80	8.5%	11	1%	0	0%	46	5%	920

Flood Tide

	Harbour		Wreck		Pan Bush		Sewer		Post		Other		Unknown		Total
Summer	130	28%	63	13.5%	23	5%	184	39.5%	42	9%	8	2%	15	3%	465
s.d	±114	±24%	±6	±1.5%	±15	±3.5%	±75	±16%	±31	±6.5%	±12	±3%	±21	±4%	
Winter	189	45%	5	1%	0	0%	80	19%	1	0%	1	0.5%	144	34.5%	420
s.d	±128	±30%	±4	±1%	±0	±0%	±51	±12%	±1	±0%	±2	±0.5%	±95	±23%	
Total	319	36%	68	7.5%	23	2.5%	264	30%	43	5%	9	1%	159	18%	885



Low Tide

	Harbour		Wreck		Pan Bush		Sewer		Post		Other		Unknown		Total
Summer	46	16.5%	20	7%	2	0.5%	144	51.5%	13	4.5%	5	2%	50	18%	280
s.d.	±29	±10%	±5	±2%	±2	±0.5%	±22	±8%	±11	±3.5%	±7	±3%	±37	±13%	
Winter	68	24.5%	37	13.5%	9	3%	39	14.5%	2	0.5%	0	0%	120	44%	275
s.d.	±52	±19%	±28	±10%	±9	±3%	±30	±11%	±2	±0.5%	±0	±0%	±24	±8.5%	
Total	114	20.5%	57	10%	11	2%	183	33%	15	2.5%	5	1%	170	31%	555

High Tide

	Harbour		Wreck		Pan Bush		Sewer		Post		Other		Unknown		Total
Summer	107	40.5%	32	12%	16	6%	79	30%	16	6%	0	0%	15	5.5%	265
s.d.	±66	±25%	±14	±5%	±22	±8%	±32	±12%	±15	±6%	±0	±0%	±21	±8%	
Winter	119	47%	1	0.5%	1	0.5%	67	26%	1	0.5%	0	0%	66	22.5%	255
s.d.	±92	±36%	±1	±0.5%	±1	±0.5%	±31	±12%	±1	±0.5%	±0	±0%	±51	±20%	
Total	226	43.5%	33	6.5%	17	3.5%	146	28%	17	3%	0	0%	81	15.5%	520

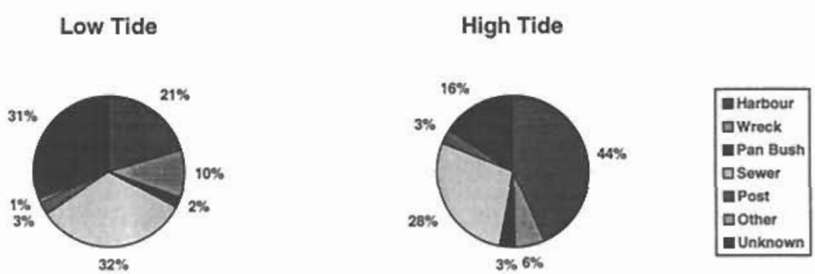


Figure 14. (a) Time budget (in minutes) during ebb and flood tides. For further explanation see Figures 12 and 13. (b) Time budget (in minutes) during low and high tides. For further explanation see Figures 12 and 13.

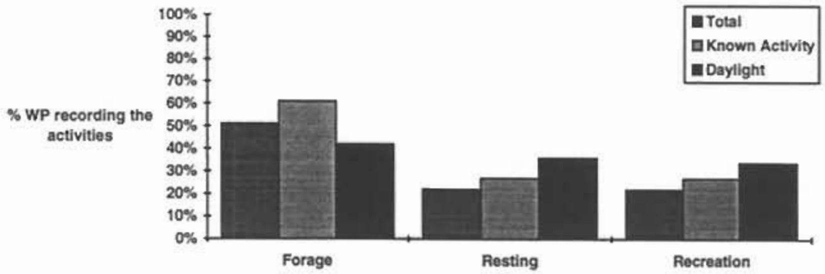


Figure 15a. Summary of dolphin activity using three different methods of deriving WPs (Figures 15b-d) See text for further explanation.

	S. I		S. II		S. III		W. I		W. II		W. III		Total	
WPs with:	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Forage	29	30%	59	61%	43	45%	70	73%	44	46%	48	50%	293	51%
Resting	48	50%	17	18%	27	28%	5	5%	18	19%	14	15%	129	22%
Recreation	8	8%	44	46%	41	43%	14	15%	7	7%	15	16%	129	22%
Total WPs	96		96		96		96		96		96		576	

Figure 15b. Total WP and occurrence of dolphin activities

	S. I		S. II		S. III		W. I		W. II		W. III		Total	
WPs with:	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Forage	29	35%	59	66%	43	48%	70	81%	44	70%	48	72%	293	61%
Resting	48	57%	17	19%	27	30%	5	6%	18	29%	14	21%	129	27%
Recreation	8	10%	44	49%	41	46%	14	16%	7	11%	15	22%	129	27%
Total WPs	84		89		89		86		63		67		478	

Figure 15c. Known WP and occurrence of dolphin activities

	S. I		S. II		S. III		W. I		W. II		W. III		Total	
WPs with:	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Forage	15	19%	47	60%	30	38%	23	56%	17	43%	17	44%	149	42%
Resting	48	61%	17	22%	27	34%	5	12%	18	45%	14	36%	129	36%
Recreation	8	10%	44	56%	38	48%	13	32%	7	18%	11	28%	121	34%
Total WPs	79		78		79		41		40		39		356	

Figure 15d. Daylight WP and occurrence of dolphin activities

Figure 15. (a) Summary of dolphin activity using three different methods of deriving WPs (Figures 15b-d) See text for further explanation. (b) Total WP and occurrence of dolphin activities. (c) Known WP and occurrence of dolphin activities. (d) Daylight WP and occurrence of dolphin activities.

Foraging was recorded in 293 WPs out of a total of 576 WPs, suggesting that just over half of this dolphin's time (51%) was spent foraging (Figure 15b). However, this value does not take into account the 96 WPs in which the dolphin was unseen or his activity could not be defined, so it may well be an underestimate. A 'determinable' activity WP total (478) increases the forage activity percentage to 61% (Figure 15c). These two activity figures were significantly different ($\chi^2=11.1$, df. 1, at the 5% level). The frequency of recorded forage activity varied greatly between the six watches, ranging from 29 WPs (S. I) to 70 WPs (W. I). These variations were significant at the 0.1% level for both total WPs ($\chi^2=41.81$, df. 5) and 'determinable' WPs ($\chi^2=52.24$, df. 5).

In order to exploit the acoustic nature of foraging activity, hydrophone coverage of the harbour mouth was attempted and achieved on five of the six watches, and echolocation click trains were recorded in 232 WPs. The echolocation search pattern of this dolphin was dominated by a very slow, and relatively loud, click emission typically at a pulse repetition frequency (PRF) varying between 12 and 16 Hz. From time to time, presumably on detection of an 'interesting' target echo, the PRF increased audibly, giving a rising pitch mewing (Goodson, 1990; Goodson *et al.*, 1994). This

WPs with:	S. II	S. III	W. I	W. II	W. III	Total
Echolocation click trains heard	52	35	63	38	44	232
Patrol pattern seen (with hydrophone coverage)	49	29	43	37	16	174
Click trains heard and patrol pattern observed	49	29	43	35	16	172

Figure 16. Simultaneous visual and acoustic monitoring of forage effort and activity. Note: no S. I data because no hydrophone coverage at the harbour entrance; during W. III night visibility was very limited.

WPs with:	S. II	S. III	W. I	W. II	W. III	Total
Echolocation mewing heard	19	10	20	10	24	83
Echolocation click trains heard	52	35	63	38	44	232
WP Forage/Hunt Ratio	2.7	3.5	3.2	3.8	1.8	2.8

Figure 17. Hunting Events monitored acoustically. Note: no S. I data because no hydrophone coverage at the harbour entrance.

WPs with:	S. I	S. II	S. III	W. I	W. II	W. III	Total
Patrol pattern seen	29	56	37	50	41	20	233
Fish seen or high activity	1	12	4	19	1	6	43
WP Forage/Hunt Ratio	29.0	4.7	9.3	2.6	41.0	3.3	5.4

Figure 18. Hunting Events monitored visually.

WPs with:	S. II	S. III	W. I	W. II	W. III	Total
Fish or high activity	10	1	12	1	6	30
Simultaneous 'mewing'	9	1	12	1	6	29
Ratio	0.9	1.0	1.0	1.0	1.0	0.97

Figure 19. Simultaneous visual and acoustic recording of hunting. Note: no S. I data because no hydrophone coverage at the harbour entrance.

acoustic behaviour appears to coincide with fish detection and interception, although the success of these chases was difficult to judge accurately unless the fish was brought to the surface. A total of 20 fish were seen, of these 12 were salmonid in appearance, another tentatively identified as dogfish spp., and the remainder were unidentifiable.

When the dolphin could be both easily watched and hydrophones were in the water, to and fro patrolling was observed in 174 WPs. In 172 of these WPs, both visual and acoustic forage indicators coincided (Figure 16), suggesting that echolocation scanning on a regular patrol pattern was the principal fishing strategy employed.

Attempts were also made to monitor hunting sequences in more detail. When mewing echolocation activity was used to indicate hunting events, the overall forage time to hunting event ratio was calculated as 2.8 WPs (Figure 17). This ratio varied from 1.8 (W. III) to 3.5 (S. III and W. II) but the differences were not significant ($\chi^2=8.73$, df. 4, NS), suggesting little change in the forage/hunt ratio across all the watches.

When visual observations alone were used to indicate hunting events (when the dolphin was seen with fish or displaying high activity during patrolling—swirling tail washes, porpoising repeatedly in the same position, fast straight line tail 'footprints'), this gave a higher forage/hunt ratio of 5.4 WPs. This ratio varied from 2.6 (W. I) to 41 (W. II), suggesting little consistency ($\chi^2=27.56$, df. 5, significant at the 0.1% level), in contrast with the results from acoustic monitoring.

During WPs that had simultaneous visual and acoustic coverage, there were 30 WPs in which high activity or fish tossing was observed (Figure 19). In 29 (96.7%) of these WPs, high PRF echolocation mewing activity was also recorded. By combining the totals of Figure 19 for summer and winter, a χ^2 value of 0.009 (df. 1) was calculated. This result suggests that the visual observation of fish or high activity events was related to mewing activity at the 92.3% confidence level. One possible reason for the S. II quiet hunting sequence is that the initial fish detection and chase episode actually began behind the north pier, where echolocation activity would have been masked from the hydrophones.

The comparison of data derived purely from visual or acoustic monitoring techniques has produced widely differing results in this study. This

WPs when:	Summer		Winter		χ^2 (df. 1)
	No.	%	No.	%	
Forage activity recorded	131		162		
Dolphin activity monitorable	262	50.0	216	75.0	30.1 (0.1%)
Total WPs (96 x 3)	288	45.5	288	56.5	6.25 (1.0%)

Figure 20. Seasonality of forage activity. Significance levels in brackets.

	WPs	Ebb	Low	Flood	High	Total	χ^2 (df. 3) *
Summer	Forage WPs	66/86	9/56	31/93	25/53	131/288	59.0 (0.1%)
		77%	16%	33%	47%		
Winter	Forage WPs	92/98	15/55	34/84	21/51	162/288	88.4 (0.1%)
		94%	27%	41%	41%		
	χ^2 (df. 1) **	9.71 (5%)	1.45 (NS)	0.69 (NS)	0.174 (NS)		
Total	Forage WPs	158/184	24/111	65/177	46/104	293/576	144.2 (0.1%)
		(86)	(22)	(37)	(44)		

Figure 21. Forage activity in relation to tides. Significance levels in brackets. *Overall tidal differences within one season. **Overall seasonal differences for each tidal state.

suggests that although the sole use of visual observations may accurately monitor forage activity and effort, it is a much poorer indicator of actual hunting events. Acoustic monitoring alone produced more consistent results from watch to watch, and appeared a better indicator of both forage activity and hunting events. Rare forage activity and hunting events occurred which were not detected acoustically, suggesting that a combination of both is required.

3.1.1 Seasonality of forage behaviour. During the summer watches the dolphin was recorded foraging during 131 WPs, whereas during winter watches foraging activity was recorded in 162 WPs (Figure 20). Whether this figure is derived from total WPs (Figure 15b) or from determinable activity WPs (Figure 15c), in both cases there is a statistically significant seasonal difference in foraging frequency at the 1.0 and 0.1% levels respectively (total WPs $\chi^2=6.25$, df. 1; known WPs $\chi^2=30.1$, df. 1).

3.1.2 Forage activity in relation to tides. Tidal state has been shown to be significantly related to the movements and time spent by the dolphin in different areas of the home range (Section 2.2 and Figure 14), so it is not surprising that there is also a relationship with foraging behaviour (Figure 21, right hand column, $\chi^2=144$, df. 3, significant at the 0.1% level) in both summer ($\chi^2=59.0$, df. 3) and winter ($\chi^2=88.4$, df. 3). Forage activity was recorded in flood and high tide phases, but with totals of 37% and 44% respectively, foraging was less predictable here than during ebb and low tides. Foraging was at its lowest during the low water slack tide phase with activity in only 22% of WPs.

Foraging was most often recorded during ebb tide (86%) and significantly more often during winter ($\chi^2=9.71$, df. 1, significant at the 5% level). However, the average time spent foraging increased by 19% ($162 \div 131 \times 100 = 119\%$) from summer to winter, so the expected foraging activity in winter at each tidal state due solely to this seasonal increase can be calculated (ebb=89.5/98, low=10.5/55, flood=33.3/84, high=28.6/51 WPs). By comparing these expected values to the total number of winter WPs in which foraging was observed for each tidal state, it was found that there was no statistically significant change in the proportion of the dolphin's time spent foraging in winter for any of the four tidal states beyond that attributable to the overall seasonal increase ($\chi^2=0.168$ ebb, $\chi^2=0.625$ low, $\chi^2=0.002$ flood, $\chi^2=1.710$ high, all df. 1). On the contrary, the observed flood tide WPs spent foraging during winter matched those predicted from the summer observations at the 95% confidence level.

Tidal influence may operate at various levels. For example: at low water, depths of less than 1.5 m in the harbour entrance are common and the increased acoustic reverberation reduced the target detection range. In addition, turbulence and breaking wave action filled the shallow water column with air bubbles (Fasick, 1992; Lamarre and Melville, 1991), seriously affecting the echolocation ability of the dolphin. Tidal state may also have an effect on salmonid prey species. Potter *et al.* (1992), in a study of Atlantic salmon estuarine movements,

	SUMMER		WINTER		TOTAL		χ^2 (df.1)
	WPs	%	WPs	%	WPs	%	
Day	92/236	39%	57/120	48%	149/356	42%	2.03 (NS)
Night	39/52	75%	105/168	62%	144/220	66%	2.22 (NS)
χ^2 (df. 1)	20.86 (0.1%)		5.81 (5%)		29.37 (0.1%)		

Figure 22. Diurnal and nocturnal forage activity. Significance levels in brackets.

found that these fish may enter an estuary during any tidal state but tended to congregate in the entrance during the ebb tide, moving into the river during the following flood tide. Such a migration pattern through the narrow harbour entrance might have concentrated fish during the ebb, facilitating hunting.

3.1.3 Diurnal and nocturnal forage activity. For the purposes of this analysis, night WPs were determined (by the observers at the end of the pier at the time) as those between sunset and sunrise when it was too dark to see the whole of the dolphin's home range. Depending on weather and cloud conditions, darkness did not usually begin until two to three WPs after sunset and ended five to six WPs before sunrise.

Forage activity was recorded in 144 of 220 nocturnal WPs (66%) (Figure 22). A similar number of WPs was also recorded for forage activity during daylight (149). However, there were more daylight WPs (356), and consequently the percentage figure for daylight was significantly lower (42%) (χ^2=29.37, df. 1, at the 0.1% level). This variation was most evident during summer watches (χ^2=20.86) with their large daylight to darkness difference (236 versus 52). During winter watches, when dark WPs (168) outnumbered daylight WPs (120), the day/night difference in forage activity frequency was not as significant (χ^2=5.81, df. 1, at the 5% level). In contrast, there was no significant seasonal effect on day or night forage frequency despite the widely differing WP totals involved (χ^2=2.03 for day WPs, χ^2=2.22 for night WPs).

3.1.4 Forage activity in other areas. Although the harbour mouth was the primary hunting area, fish tossing was occasionally seen in the post and wreck areas. Because the dolphin spent little time in these areas (Section 2.1), the limited hydrophone resources were concentrated elsewhere. There is thus no acoustic data to back up these visual records.

3.2 Resting

Resting behaviour was most evident at the sewer outfall buoy. It was not only characterized by the regular dive pattern described above (see Materials and methods), but also by almost complete silence, with no echolocation click trains or whistles. On many occasions during the resting dive pattern the dolphin would track due north, in a straight line, during the short dive sequences before reappearing very close to the buoy again after the long dive, as if moving in an associated regular and complimentary underwater swimming pattern.

Some sonobuoy coverage at the sewer buoy was achieved on all three summer watches (Figure 2), a total of 151 WPs (approximately 37.75 hours), including complete 24 hour coverage of S. II. The dolphin was visually observed to be in the area and resting in 43 of these WPs (approximately 10.75 hours). Only a very occasionally loud click, that may tentatively be classified as bioacoustic, was registered by the hydrophones. Wave action generated an irregular, but frequent, metallic clinking sound from the buoy anchor chain. This may have provided the dolphin with an acoustic reference point in much the same way as it reassured us that the hydrophone was still functioning.

Unlike foraging (with its positive acoustic component), resting behaviour could only be confirmed visually. Since resting normally occurred close to the sewer buoy, some 500 metres distant from the observation point, it could therefore only be recorded with confidence during daylight. The data in this section relates only to diurnal WPs (Figure 22) and no daylight/darkness comparison was possible.

The amount of diurnal resting recorded varied considerably from watch to watch (Figure 23) ranging from 61% (48 WPs in S. I) to 12% (5 WPs in W. I). This resulted in a mean resting value for the six watches of 36%. The difference between individual watch resting totals was significant statistically (χ^2=39.95, df. 5, at the 0.1% level).

3.2.1 Seasonal resting activity

The data in Figure 24 suggest a small difference in the frequency of resting behaviour between summer (39%) and winter (31%). However there were more daylight WPs during the summer watches (236) than during the winter (120), and the apparent difference was not statistically significant (χ^2=1.948, df. 1, NS).

	S. I	S. II	S. III	W. I	W. II	W. III	Total
Resting WPs	48	17	27	5	18	14	129
Diurnal WPs	79	78	79	41	40	39	356
% Ratio	61%	22%	34%	12%	45%	36%	36%

Figure 23. Resting activity during diurnal WPs.

	Summer	Winter
Day WPs with resting	92	37
Total day WPs	236	120
% ratio	39%	31%

Figure 24. Seasonal resting activity.

3.2.2 Tides and resting activity

There was a significant statistical relationship ($\chi^2=24.1$, df. 3 at the 5% level) between tide state and observed resting behaviour (Figure 25). Resting was the dominant observed activity during daylight low water slack tide WPs (58%). This behaviour was also recorded regularly during both flood tide (37%) and high water tide (33%) WPs, while for the ebb tide phase, resting behaviour was only observed during 20% of the WPs.

There were apparent seasonal relationships, but these were only statistically significant for two of the four tidal states. During the ebb phase ($\chi^2=13.52$, df. 1) no resting was recorded at all during winter watches. For low tide ($\chi^2=3.93$, df. 1, significant at the 5% level), resting was recorded more frequently in summer. During high tide, resting activity was recorded equally in winter and summer (12 WPs each). Although twice as many WPs were monitored during summer, there was no significant difference in resting between summer and winter watches ($\chi^2=3.445$, df. 1). The flow tide phase also showed no statistically significant seasonal differences ($\chi^2=0.548$, df. 1, NS at the 5% level), with resting behaviour recorded for 34% of summer and 43% of winter WPs.

3.2.3 Resting activity in other areas. Of the 129 WPs where resting behaviour was recorded, 124 were for the sewer buoy area. The remaining five were recorded in the adjoining post area (two WPs recorded in S. I and three WPs in S. II). During W. III the dolphin was possibly resting close to the Pan Bush buoy for three WPs but prevailing sea and swell state conditions at the time made confirmation impossible. These periods were logged as 'unknown' activity WPs.

3.3. Recreation

The dolphin frequently associated with both boats and swimmers, expending much time and energy escorting craft of all kinds, as well as interacting with swimmers and divers (Bloom, 1991). Even when resting or foraging, the dolphin would often break from these activities to investigate a boat or swimmer. In some cases recreational activity developed, while in others the dolphin returned to his previous activity. During the six watches, no identifiable dolphin sounds were heard while he was engaged in boat-escorting and swimmer interactions. Divers have, however, reported audible vocal activity on occasion, including clicks and whistles, as well as bubble blowing. This was especially true during periods of high activity and excitement (Bloom, 1991). The monitoring of recreational activity could thus only be confirmed visually. Although it was occasionally possible to record escorting at night (8 WPs from 28 WPs offering recreational opportunity) only daylight WPs provided a realistic opportunity to accurately record such events.

Recreational activity was recorded in 129 WPs (Figure 15) giving ratios of 22% and 27% for total and known totals respectively. However, during the 356 daylight WPs, recreational activity was recorded in 121 WPs (34%), perhaps the most accurate representation (Figure 26). The frequency varied significantly from watch to watch ($\chi^2=35.22$, df. 5, 0.1% significance level) with a range from 8 WPs (S. I) to 44 WPs (S. II). Opportunities for recreational activity required the presence of boats or swimmers in the home range area and these opportunities varied considerably from 19 WPs (W. II) to 59 WPs (S. III).

There does not appear to be any particular seasonal or temporal pattern to the acceptance or rejection of recreational opportunities. It is, however, clear that the animal did not necessarily react to every event, as might be the case if this behaviour contained, for example, a strong component of territorial defence. This apparent degree of choice should also mean that the animal was able to prevent visitors dictating its entire pattern of behaviour.

3.3.1 Seasonality of recreational activity. Recreational activity was recorded more often in summer (90 WPs) than in winter (31 WPs). There were, however, more recreational opportunities during summer (135 WPs) than winter (31 WPs) (Figure 27). The acceptance rates were 67% and 53% for summer and winter respectively, but this difference was not statistically significant ($\chi^2=2.91$, df. 1, NS).

	WPs with:	Ebb	Low	Flood	High	Total
Summer	Resting	17/49	31/46	32/93	12/48	92/236
	% ratio	35%	67%	34%	25%	39%
Winter	Resting	0/36	9/23	16/37	12/24	37/120
	% ratio	0%	39%	43%	50%	31%
	* χ^2 (df. 1)	13.52 (0.1%)	3.93 (5%)	0.548 (NS)	3.445 (NS)	
Total	Resting	17/85	40/69	48/130	24/72	129/356
	% ratio	20%	58%	37%	33%	36%
		** χ^2 (df. 3) = 24.10, significant at the 0.1% level				

Figure 25. Tides and diurnal resting activity. *Overall seasonal differences for each tidal state. **Overall tidal differences.

WPs with:	S. I	S. II	S. III	W. I	W. II	W. III	Total
Recreational activity	8	44	38	13	7	11	121
Recreational opportunity	30	53	52	18	15	26	194
Acceptance rate	27%	83%	73%	72%	47%	42%	62%
	χ^2 = 35.22 df. 5, significant at the 0.1% level.						

Figure 26. Daylight occurrence of recreational opportunity and activity.

WPs with:	Summer	Winter	Total
Recreational activity	90	31	121
Recreational opportunity	135	59	194
Acceptance rate	67%	53%	62%
	χ^2 (df. 1) = 2.91, NS		

Figure 27. Seasonality of recreational activity.

WPs with:	Ebb	Low	Flood	High
Recreational activity	22	15	54	30
Recreational opportunity	44	25	81	44
Acceptance rate	50%	60%	67%	68%
	χ^2 (df. 3) = 4.21, NS			

Figure 28. Tides and recreational activity.

3.3.2 Tides and recreational activity. Opportunities for recreational activity involving swimmers and boat traffic were mainly concentrated during flood tides. Recreational activity was observed in 54 of the 81 daylight flood tide WPs, giving an acceptance rate of 67% (Figure 28). Recreational opportunities occurred in 44 WPs during high water, and activity developed in 30 of these cases, giving a similar acceptance rate of 68%. Recreational possibilities occurred in a similar number of periods during the ebb tides (44 WPs) as for the high water periods, but only half of these developed into recreational activity. Finally the low water period, which severely restricts boat traffic in and out of the harbour, offered least opportunity for recreation (25 WPs) and recreational activity developed in 15 WPs (60%). Statistical analysis shows, however, that there was no significant relationship between tidal phase and recreational activity developing (χ^2=4.21, df. 3, NS).

3.4 Unknown

It was not possible to record any defined dolphin activity in 98 of the 576 WPs (17%) (Figure 29). Most of these occurred during the long winter nights (72 WPs, 74% of the total lost). The majority of unknown activity WPs was recorded during W. II and W. III, when the dolphin moved away from

Unknown WPs	S. I	S. II	S. III	S. Tot.	W. I	W. II	W. III	W. Tot.	Total
Day:	9	1	3	13	0	4	4	8	21
Night:	3	6	4	13	10	29	25	64	77
Total:	12	7	7	26	10	33	29	72	98
% (576 WPs)	13%	7%	7%	9%	10%	34%	30%	25%	70%

Figure 29. Distribution of unknown activity WPs.

	S. I	S. II	S. III	S. Tot.	W. I	W. II	W. III	W. Tot.	Total
Inter-area movement	28	36	38	102	16	14	10	40	142
Recreational motivation	8	34	30	72	7	5	4	16	88
% ratio	29%	94%	79%	71%	44%	36%	40%	40%	62%

Figure 30. Dolphin movements during the six 24 hour watches.

the harbour entrance for long periods; conversely the short winter days accounted for the lowest number of unknown activity WPs (8). During the three summer watches, the numbers of unknown WPs in daylight and darkness were equal, although there were many more daylight WPs during the summer (236 versus 52 WPs).

3.5. Travel around the home range

One activity often noted in behavioural studies of dolphins is 'travel'. However, in the case of Freddy, the range was so small it was sometimes traversed in one or two minutes. The apparent motive for such movements was often in response to recreational opportunities. There were only two excursions outside the home range during the six watches (W. I and S. III), and in both cases these were the result of recreational activity.

The most common non-recreation related movement was traversing the 500 metres between the sewer buoy and the harbour entrance. The dolphin was observed on one occasion to cover 450 metres of this distance in 45 seconds, giving a travelling speed of 10 m/s (36 km/h). Sonobuoys deployed at both positions each had the sensitivity to cover this range acoustically, and yet echolocation signals were rarely evident during such travel. This suggests that passive sonar or other nonacoustic sensory abilities were being employed as navigational aids during movement around the dolphin's home range (Klinowska, 1990; Goodson, 1990). The journey was usually completed at a more leisurely pace (over two to three minutes) at speeds of 3–4 m/s, i.e. falling within ranges reported by Morris & Lockyer (1987) for the solitary dolphin Simo.

During the 356 daylight WPs the dolphin remained within one of the five defined areas of his home range for the whole of 214 WPs (60%). Of the 142 WPs in which the dolphin moved from one area to another, 88 WPs (62%) were recreationally oriented (Figure 30). Similar recreationally motivated movement ratios were recorded for the winter watches, with a mean of 40%, but the ratio varied widely during the summer watches (29% to 94%) suggesting little consistency.

Summary

This dolphin's small home range, conservative movements and activity patterns provided a unique opportunity for the study of a solitary *Tursiops* through complete 24 hour cycles. During the six watches conducted the dolphin spent approximately half of his time in the harbour mouth (49%), just under a quarter of his time at the sewer outfall buoy (23%) (500 metres seaward of the harbour entrance), and a further 12% in the other areas of his home range. For the remaining 16% of the total 144 hours the dolphin was neither visually nor acoustically monitored. Most of this lost time occurred in the long winter nights when the dolphin moved away from the harbour mouth.

Tidal rhythms appeared to be the major influence on the dolphin, possibly through water depth variations and/or effects on prey behaviour. A very strong preference was shown for the harbour mouth during the ebb tide phase (81%), although time was also spent in the harbour mouth during flood (36%) and high water (43%). However, as the dolphin was also recorded regularly at the sewer buoy during flood (30%) and high water slack tide (28%), his location during these phases was less predictable. During low water slack tide, when water levels in the harbour entrance were often less than 1.5 metres, the dolphin was most often recorded in the sewer outfall buoy area (33%). During summer watches (with their much longer day lengths) sewer buoy residency accounted for 51% of low water slack tide time, so the total figure of 33% is an underestimate, due to lost time in the long winter nights when the sewer buoy was not visible.

For analysis of dolphin activity the 24 hour days were split into 96 fifteen minute watch periods

(WPs) and the defined activities of forage, resting and recreation recorded. Foraging, unlike the other defined activities, was monitorable at night because of its distinctive acoustic characteristics and was recorded in 293 WPs. With 576 WPs in total, this represented a foraging ratio of 51%. Alternatively, if only WPs with known dolphin location and determinable activity (478 WPs) are considered, then the foraging ratio is increased to 61%, and for daylight only, the ratio falls to 42% (149 of 356 daylight WPs). Forage activity was most often associated with the harbour mouth area, especially at night, and during the ebb tide phase. There was also more forage activity recorded during the winter watches.

The defined activity of resting was recorded in 129 WPs which gave ratios of 22% for total WPs and 27% for determinable activity WPs. This behaviour was only monitorable visually, suggesting that the daylight WP ratio (36%) was the most representative indicator of the frequency of occurrence of this activity. Resting most often occurred within the sewer buoy area, during the low water tidal phase. There was no apparent seasonal change in this activity.

Close association with boats and swimmers was defined for the purposes of this study as recreational activity. There were 129 WPs in which recreational activity was recorded, giving ratios of 22% for total WPs and 27% for determinable activity WPs. Recreational activity was dependent on opportunity, and of 194 WPs offering boat and swimmer events, the activity actually developed in 121 (62%). Recreational activity was occasionally recorded during nocturnal WPs (8) but only if the event took place close to the observer position on the pier. This suggests recreation, along with resting activity, is best represented as the daylight ratio of 34% (121 of 356 daylight WPs). Recreational activity could draw the dolphin to any part of his home range, and on two occasions during the six watches actually outside this area.

On several occasions during the watches the dolphin was observed to harass and panic eider ducks that were resting on the water in the harbour entrance. On another occasion the dolphin was observed to 'shepherd' a salmonid fish into the harbour entrance and then allow it to swim onwards upriver.

During the 356 diurnal WPs when the dolphin's movements from one area to another could accurately be monitored, most (62%) appeared to be recreationally associated. During one non-boat related movement the dolphin was observed to travel a distance of approximately 450 metres, from sewer buoy to harbour mouth area, in 45 seconds giving an average travelling speed of 10 m/s.

Conclusions

With only six watches it is difficult to draw any final conclusions. Nevertheless, this dolphin provided an interesting insight into the time budget and activities of a wild dolphin throughout complete 24 hour cycles.

Foraging, the dominant activity, was recorded in over half the total watch periods. However, comparison of forage data, derived purely from visual or acoustic monitoring techniques, suggests that although the sole use of visual observations may accurately monitor forage activity, it is a much poorer indicator of actual hunting events. Ideally a combination of both methods should be used to complement each other. This study also suggests that purely daylight watches may significantly underestimate the amount of time and effort devoted to forage activity.

Steady echolocation click train activity was the principal fish detection and hunting tool, most commonly used in conjunction with a regular patrol pattern. Conversely, when travelling between different areas of his home range, echolocation activity does not appear to play a major role in navigation of known territory. Prolonged acoustical coverage in the dolphin's principal resting area at the sewer buoy indicated that this was essentially a silent behaviour.

There were significant differences in the acceptance rate of recreational opportunities between the six watches, but with no seasonal or temporal pattern. This suggests that the dolphin was able to choose whether or not to participate, and was not compelled to do so by possible motives of territorial defence, curiosity, etc.

An earlier paper (Bloom, 1991) reviewed the apparent habits and behaviour of this dolphin, based on informal reports. It is now clear that the informal watchers significantly over-reported recreational activity and under-reported resting, in comparison with the formal watchers. Reports of foraging activity were less biased, but still under-represented. These differences appear to reflect the different interests and opportunities of the informal and formal watchers.

Finally, six weeks after the last winter watch included in this paper (15th–16th January 1992), the dolphin left this home range. During the following weeks there were occasional sightings up and down the coast to the south before the final confirmed sighting near Roker pier, Sunderland on 26th April 1992 (Bloom, 1992).

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