CHAPTER 4. RESPONSES OF SEA TURTLES TO CAPTURE

4.1 CHAPTER SUMMARY

Trawl-caught sea turtles of three species were monitored post-release using ultrasonic transmitters and Temperature Depth Recorders. Their diving patterns were analysed for signs of modified behaviour in comparison to control sea turtles that had been captured by the rodeo method and not subject to a forced submergence. The work was undertaken because delayed mortality or modified behaviour that increases the risk of secondary mortality of trawl-caught sea turtles has the potential to significantly increase the estimated impact of prawn trawl fisheries on sea turtle populations prior to the mandatory use of TEDs in these fisheries. All sea turtles, regardless of capture method swam rapidly away from the point of release. They displayed a period of frequent surfacing behaviour that was speculated to represent swimming and hyperventilation. The sea turtles then settled into a steady pattern where dive intervals were long and regular. This was speculated to represent recovery behaviour. Normal activity patterns, as documented in the literature, were not apparent in the dive profiles of the trawl-caught sea turtles within the time monitored post-release (i.e., 66 hours). Rodeo-caught sea turtles displayed ‘normal’ activity patterns at about 85 and 111 hours post-release. There was no evidence of delayed post-release mortality from the limited number of trawl-caught sea turtles monitored in this study. However, trawl-caught sea turtles displayed modified diving patterns that would make them more susceptible to secondary mortality such as boat strike. The diving patterns of trawl-caught and rodeo-caught sea turtles suggest that sea turtles are affected by interactions with humans to a much greater extent than previously thought and that the recovery period of such interactions can take several days. This suggests that sea turtles exposed to non-lethal human interactions on a frequent basis should be monitored for chronic impacts on feeding and resting activities.

4.2 INTRODUCTION

4.2.1 Why investigate the response of sea turtles to capture?

Prior to the introduction of TEDs, demersal trawl fisheries caught thousands to tens of thousand of sea turtles each year. Mortality rates of trawl-caught sea turtles varied between fisheries as a consequence of the species caught and the operational characteristics of the fishery (Henwood and Stuntz, 1987; Henwood *et al.* 1992; this thesis, Chapter 3, section 3.4.5, section 3.4.6, section 3.4.7). Estimates of sea turtle by-catch and mortality have been used to assess the impact of trawl fisheries on sea turtle populations (Crouse *et al*. 1987; Crowder *et al.* 1994; Heppell *et al.* 1996) and to simulate the likely population response as a result of management measures e.g., TEDs (Crowder *et al.* 1994; TEWG 2000). Sea turtle population models are highly sensitive to small changes in the mortality rates of sub-adult and adult sea turtles (Crouse *et al*. 1987; Crowder *et al.* 1994; Somers 1994; Heppell *et al.* 1996) and these were the size-classes of sea turtle caught most commonly in trawl fisheries (Poiner and Harris 1996; this thesis Chapter 3, section 3.4.4;).

If a significant proportion of trawl-caught sea turtles that appeared to be active and healthy when released suffered a delayed mortality, then total mortality resulting from trawl captures could have been significantly higher than previously estimated. In addition, if trawl-caught sea turtles displayed modified behaviour that made them more susceptible to a secondary cause of mortality such as boat strike or shark attack, or multiple capture in trawl nets, then trawling could have caused a much higher rate of mortality than previously suspected. Increased estimates of the mortality rates of trawl-caught sea turtles would imply greater impacts by trawl fisheries on sea turtle populations.

4.2.2 Aims of this chapter

In this chapter, I examined evidence for delayed mortality or modified behaviour that may cause secondary mortality by monitoring sea turtle dive profiles for three days following a trawl-capture. This interval was selected as an appropriate period to monitor sea turtles post-release because delayed mortality has been observed within 12 hours of a trawl-capture for nesting *C. caretta* (Limpus and Reimer 1994) and measured lactic acid levels suggest that sea turtles forcibly submerged for 120 minutes in the laboratory (Berkson 1966) or trawl-caught in the wild (Lutz and Dunbar-Cooper 1981) recover within 15 and 24 hours, respectively. Sea turtles were monitored post-release using biotelemetry equipment and archival data recorders. Diving patterns of trawl-caught sea turtles were compared with those of rodeo-caught sea turtles, which had not undergone a forced submergence. Rodeo-caught sea turtles were monitored for six days with the aim of observing ‘normal’ diving patters for sea turtles in Moreton Bay (the study site). Implications of the results are considered in terms of post-trawl mortality and the possible impacts of handling sea turtles.

4.3 MATERIAL AND METHODS

4.3.1 Rationale of method

The behaviour of trawl-caught and rodeo-caught sea turtles was monitored using ultrasonic transmitters and Temperature Depth Recorders (TDRs). This method was selected because biotelemetry equipment has been used to successfully monitor sea turtles and provide relatively precise information on dive profiles (Keinath *et al*. 1995; Williams and Renaud 1998). Studies using biotelemetry equipment and dataloggers are often limited in the number of animals monitored (Brill *et al.* 1995; Keinath *et al.* 1995; van Dam and Diez 1997), and was the case in this study, given the staff resources and budget available (two people and $10,000).

Alternate methods considered

Prior to undertaking the biotelemetry work, I considered a mark-recapture experiment to determine the fate of trawl-caught sea turtles. This would have required a large number of trawl-caught sea turtles to be marked (e.g., with a distinctive painted symbol on the carapace) and then released. Estimates of delayed post-trawl mortality would have been calculated from the ‘recapture’ of marked sea turtles by commercial fishers, and the ‘recapture’ of sea turtle carcasses stranded on coastal foreshores by the general public and Queensland Parks and Wildlife (QPWS) stranding network. The success of the mark-recapture study would have been dependent upon the reporting rate of sea turtle recaptures by commercial fishers as well as the coverage of the QPWS stranding network. The controversial nature of sea turtle by-catch in 1995 did not guarantee the participation of most trawl operators in Moreton Bay. Under-reporting of marked sea turtles (both alive and dead) would have been extremely difficult to quantify and the resulting "error" would have seriously affected the accuracy of survival estimates from the mark-recapture experiment (Pollock 1982; Burnham *et al*. 1987).

4.3.2 The study site

Moreton Bay is a semi-enclosed embayment, located at 27°S, 153°E and is about 26 km wide and 55 km long. It was selected as an appropriate study site because: (i) of the presence of substantial numbers of *C. caretta* and *C. mydas* (Limpus *et al.* 1994a; Limpus *et al*. 1994b); (ii) of the presence of a major prawn trawl fishery (Dredge and Trainor 1994; Robins 1995); (iii) sea turtle catches were a frequent event for commercial trawlers, with an average of one sea turtle caught for every three days trawled (Robins 1995; this thesis Chapter 3, section 3.4.2); (iv) more than 50% of all sea turtles caught annually in the Queensland East Coast Trawl Fishery were estimated to be caught in Moreton Bay (Robins 1995, this thesis Chapter 3, section 3.4.3); (v) preliminary estimates of sea turtle by-catch mortality in Moreton Bay were 0.6% (Robins 1995), which warranted further investigation as additional delayed post-trawl mortality could significantly change current mortality estimates; (vi) 'control' sea turtles could be readily obtained with the cooperation of Queensland Turtle Research Project, that regularly samples sea turtles in the area using the rodeo-capture method; and (vii) the practicalities of this location allowed tagged sea turtles to be monitored from a small vessel under a range of weather conditions.

4.3.3 Sources of sea turtles

Trawl-caught sea turtles were obtained from commercial prawn trawlers operating in Moreton Bay in water depths of 10 to 30 m. Eighteen nights were spent onboard commercial trawlers in order to access seven trawl-caught sea turtles, with an average catch rate of one sea turtle per 2.6 nights fished. Trawl-caught sea turtles landed during standard prawn trawling operations were identified to species, measured for curved carapace length (CCL), tagged and fitted with biotelemetry equipment. All sea turtles were released within 10 minutes of being landed on the vessel. Tracking was undertaken from a 6 m, semi-enclosed vessel, equipped with a 4-element Yagi radio antenna, a directional hydrophone, Interphase Star pilot 6™ GPS, an Echo Depth Sounder and a laptop computer.

Rodeo-caught[8] sea turtles (Limpus and Reed 1985a) were used as 'controls' against which trawl-caught sea turtles were compared. They were caught by the Queensland Turtle Research Project team and transported back to an 18 m research vessel. Sea turtles selected for tracking were caught in waters between 3 and 5 m deep or had a known history (through tag-recapture) of using deep water. Rodeo-caught sea turtles were identified (species and tag number), measured for curved carapace length (CCL), examined externally for disease or damage and fitted with biotelemetry equipment. They were transported by boat to close proximity of their place of capture, before being released at 16:00 hours. Rodeo-caught sea turtles were held out of water for about six hours prior to release, although there was some variation between individuals reflecting their order of capture (i.e., ± one hour).

In this Chapter, trawl-caught sea turtles are distinguished from rodeo-caught sea turtles by prefixing the letter T (=trawl) or R (=rodeo) in front of the individual being referred to e.g., trawl-caught sea turtle number 4 is referred to as T4.

Species of sea turtle monitored

Species selected for monitoring post-release from a trawl capture was opportunistic. *C. caretta*, *C. mydas* and *L. olivacea* were caught by the assisting commercial trawlers, while *C. caretta* were selected for monitoring post-release from rodeo-capture.

4.3.4 Recording of dive profiles and field work

Two dive monitoring systems were used (Table 4.1). Initially, only real-time monitoring of sea turtles using ultrasonic equipment was undertaken because of the unknown probability of equipment retrieval after its timed release. Real-time monitoring involved maintaining constant contact with the ultrasonic signal from the telemetered sea turtle, which was decoded and recorded by a computer onboard the tracking vessel. Real-time monitoring was limited by weather conditions, human endurance and gear reliability

[8] Rodeo-capture involves a human leaping from a speed-boat onto a sea turtle in water <5m deep after a chase that may last from seconds to a few minutes. The sea turtle is held by the anterior and posterior edge of the dorsal carapace and is directed towards the surface. Once at the surface, the speed-boat returns to the human holding the sea turtle. The sea turtle is then lifted into the speed-boat, where it is held in air until the speed boat returned to the mothership.

(e.g., motors, batteries and computers) and provided up to 12 hours of data on the dive profile of sea turtles post-release. Experience in retrieving the real-time monitoring equipment suggested that there was a high probability of equipment retrieval in Moreton Bay, provided the geographic location of the sea turtle was monitored regularly. Therefore, archival Temperature Depth Recorders (TDRs) were used to continuously monitor the dive profile of the telemetered individuals from the time of their release (Table 4.1).

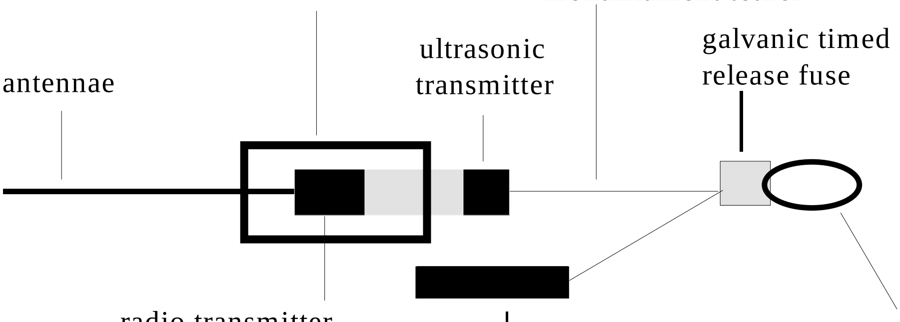
Table 4.1 Specifications of biotelemetry equipment used to monitor sea turtles

System	Manufacturer	Model	Specifications
Radio	Advanced Telemetry Systems	3pn standard transmitter (201) Fieldmaster Receiver 4 element Yagi antenna	60 day life span, weight 12 grams
Ultrasonic	Sonotronics	DT-88 depth tags USR5-W receiver DH-2 directional hydrophone DR-92 data decoder	17 mm x 80 mm, 60 day life span 50 m depth limit, 0.5 m resolution, ±1 m accuracy
TDR	Vemco	MiniLog-TDR MiniLog-PC computer interface	21 mm diam. x 100 mm, 5 year life span, 34 m depth tolerance, 0.2 m resolution ± 1 m accuracy

Real-time monitoring equipment

This system consisted of an ultrasonic transmitter and a radio transmitter sleeved together by a 70 mm x 30 mm (diam.) piece of PVC tubing (Figure 4.1). The transmitters were enclosed within a custom-made float using *Pour-In-Place Syntactic Foam*™ (Flotation Technologies) of slightly positive buoyancy. Floats were a cylindrical, 38 mm in diameter and 115 mm in length. The transmitters were connected to a galvanic timed-release fuse (GTR) via a tether of 0.87 mm monofilament fishing line with a breaking strength 45 kg. The ultrasonic transmitters had a depth resolution of 0.5 m and were calibrated for zero water-depth prior to release of the telemetered sea turtle.

Figure 4.1 Schematic diagram of biotelemetry equipment



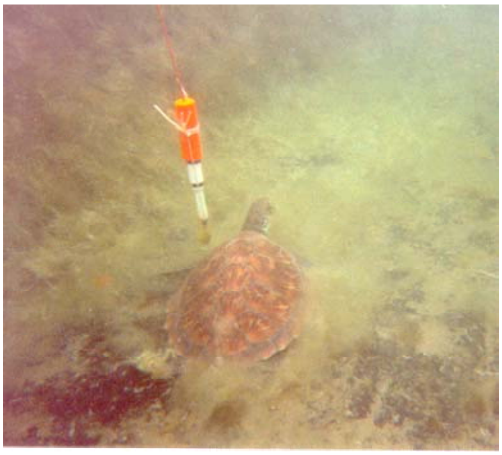
Data-logging equipment

Temperature Depth Recorders (TDRs) were attached to the Galvanic Time Release (GTR) fuse using a second monofilament tether. The custom made float was increased in length to 140 mm to give the combined monitoring equipment slightly positive buoyancy. The TDRs had a memory of 64 Kbytes, allowing 8,128 recordings of temperature (°C) and depth (m). The number of days that a sea turtle could be monitored depended on the time interval between successive data recordings. Temperature and depth of trawl-caught sea turtles was recorded every 35 seconds, recording data 72 hours post-release. Temperature and depth of rodeo-caught sea turtles was recorded every 70 seconds, recording data for 144 hours post-release. The interval between data recordings was doubled for rodeo-caught sea turtles as preliminary data demonstrated that surface intervals could be detected adequately using an interval of around 60 seconds. The TDRs had a sensor depth resolution of 0.2 m and were calibrated for zero depth (i.e., signal at the water's surface) prior to the release of the telemetered sea turtle.

Attachment of tracking equipment to sea turtles

Tracking equipment was attached to the sea turtle via 7 kg breaking-strength cable-tie inserted through a 3 mm hole drilled into the marginal scute adjacent to the post-central scutes. Benzocaine (1/1000 of stock) was applied to the marginal scute before and during drilling to numb the area. Antifungal cream was smeared into the hole before the sea turtle was released. Underwater observations of the tracking equipment suggested that it trailed behind and slightly above when the sea turtle was actively swimming and floated vertically when the sea turtle was stationary (Figure 4.2).

Figure 4.2 Position of biotelemetry equipment when attached to a sea turtle



Monitoring

Telemetered sea turtles were monitored as soon after release as possible. The GPS position of the tracking vessel and water-depth (using a depth sounder) was recorded at 15 minute intervals. The approximate location of the sea turtle was determined by the width of the arc of the ultrasonic signal as detected by the directional hydrophone. During daylight hours, the position of the sea turtle was confirmed by visual sightings as the telemetered sea turtle surfaced to breathe, often within 10 m of the tracking vessel. The time since release of visually confirmed surface events were compared to the depth of the dive profile recorded by ultrasonic tracking equipment and TDRs. Weather permitting, the sea turtle being tracked was relocated each day subsequent to its release until the GTR fuse corroded and the tracking equipment was retreived.

4.3.5 Data analysis

Data recorded by real-time and data logging (i.e., TDRs) equipment were plotted to determine trends in the diving behaviour of sea turtles after their release. Time submerged was calculated as 'the time not at the surface' (van Dam and Diez 1997). The number of surfacing events per hour were calculated and plotted against time post-release and used as an index of capture effect and subsequent recovery. A surface (='near-surface') event was defined as the sea turtle being within 1.0 m of the surface for ultrasonic data and 0.5 m of the surface for TDR data to encompass the resolution of the telemetry equipment[9]. The data were broken into six-hourly intervals post-release to permit summary and analysis (i.e., the calculation of means and standard errors). The following variables were calculated for each interval: (i) number of surface events per hour; and (ii) average bottom interval per hour. Average surface interval per hour was calculated and considered, but the different temporal resolution of ultrasonic and TDR equipment precluded this variable from further consideration.

During real-time monitoring, interference from background noise (e.g., dredging operations) reduced the reliability of the ultrasonic signal and made interpretation of some dive profiles difficult (e.g., T4 between 41 and 44 hours post-release). Periods of unreliable ultrasonic signal were excluded from the analysis.

Dive profiles of trawl-caught and rodeo-caught sea turtles monitored with TDRs were compared for the number of surface events per hour as a function of time since release. Counts of surface events per hour were approximately normalised by the ln(X+0.5) transformation as recommended by Yamamura (1999). The data were analysed in GENSTAT™ (2000) via a Residual Maximum Likelihood Model (REML), with 'sea turtle' being the random term and 'capture method' (i.e., rodeo or trawl) and 'period' (i.e., time since release) as the fixed effects. The bias-corrected back-transformation method was used to estimate the mean surface events per hour post-release for trawl-caught and rodeo-caught sea turtles.

[9] The accuracy of the telemetry equipment (± 1 m) was calibrated for by measuring the reading given when the telemetry equipment was placed on the water surface prior to its deployment. The accuracy of the TDRs was checked by placing TDRs at a known depth (0.5 m to 2.5 m) in a tidal estuary and comparing the relative accuracy of the TDR against the known depth. The depth values fluctuated by 0.16 m, which is within the 0.2 m resolution specified by the manufacturers. The relative accuracy of the TDR was constant over the ~80hrs of deployment. This confirmed that the accuracy of the TDR was constant across several days and could be accounted for by calibrating the TDR at the water surface prior to its deployment.

4.4 RESULTS

In total, twelve sea turtles were captured from a variety of locations within Moreton Bay (Figure 4.3) and were monitored post-release from either a trawl (T) or rodeo (R) capture (Table 4.2). Post-release monitoring was attempted for all twelve sea turtles, but weather conditions, equipment failure and the loss of TDRs resulted in no data being collected for four sea turtles (T7, R3, R4 and R5). Dive profiles collected with real-time ultrasonic monitoring equipment (T1, T2, T3 and T4) were discontinuous because of our inability to locate the sea turtle in question or human fatigue. These dive profiles will be referred to as partial dive profiles. Dive profiles collected with archival TDR monitoring equipment (T5, T6, R1 and R2) were continuous, and will be referred to as continuous dive profiles. Differences between species and size are likely to influence the dive-profiles of the individual sea turtles in this study and were another source of variability in the data.

Results presented in the following sections were based on diving behaviour as monitored by ultrasonic and TDR equipment. The data gathered represent two-dimensional measurements of the position of a sea turtle in the water column (i.e., depth) versus time. No data were collected on the movement of the telemetered sea turtles in three-dimensional space below the surface of the water (Stewart 2002), nor on the aquatic habitat type (i.e., ecological circumstance) encountered by telemetered sea turtles. Therefore, the validity of my inferences about sea turtle behaviour from ultrasonic and TDR equipment is speculative and untested.

Figure 4.3 Moreton Bay including locations (taken with GPS) of trawl-caught and rodeo-caught turtles sighted subsequent to their release.

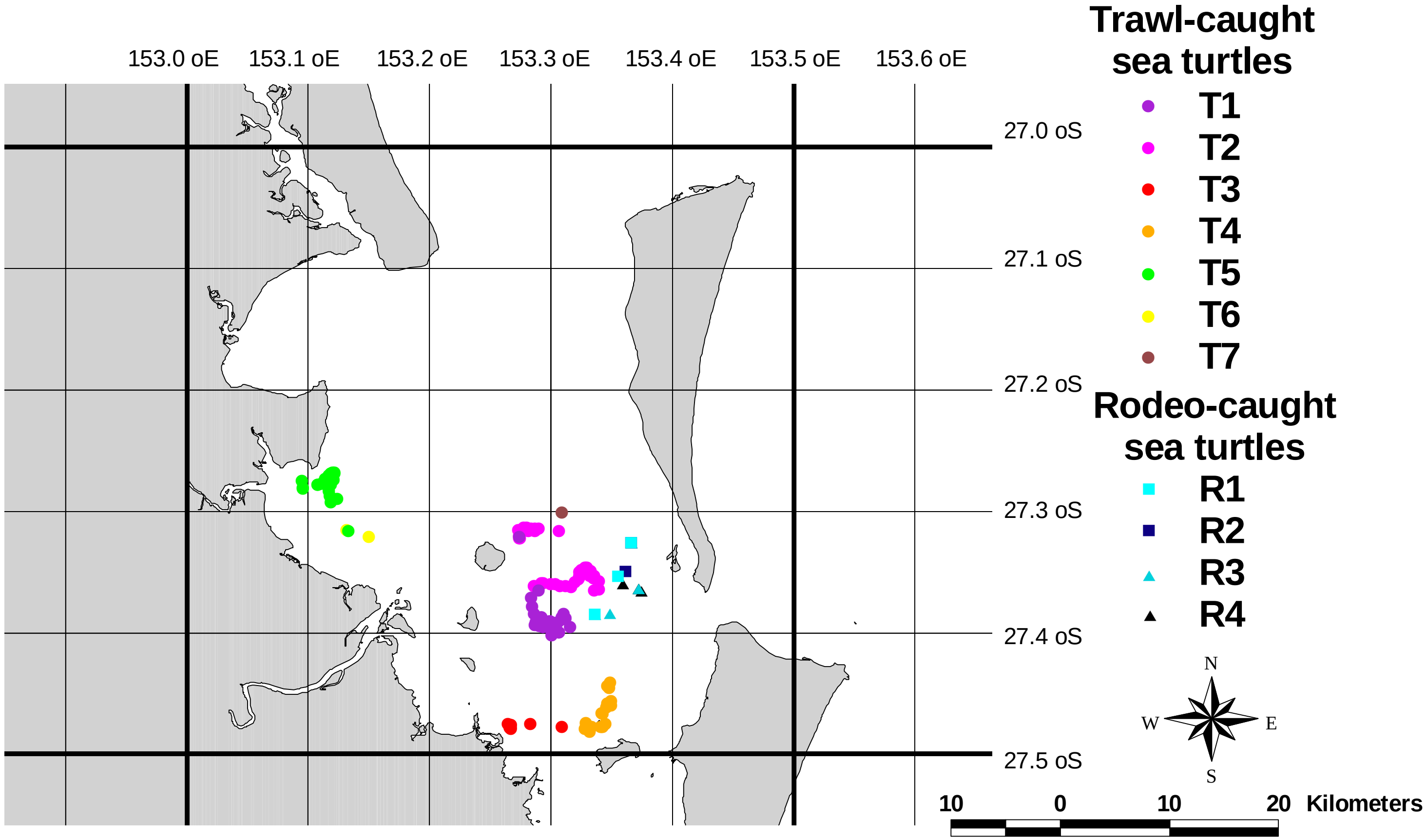


Table 4.2 Details of trawl-caught and rodeo-caught sea turtles that were monitored post-release in Moreton Bay

Identity	Capture method	Date	Species	CCL (cm)	Condition at capture	GTR Fuse	Tracking equipment used to monitor	Recording interval (seconds)	Hours post-release for which data was retrieved	Type of dive profile
T1	Trawl 120 mins duration	Sept. 95	*C. caretta*	87.5	Healthy	3 days	Ultrasonic	1	0 to 1 37 to 42 58 to 64	Partial
T2	Trawl 90 mins duration	Oct. 97	*C. caretta*	83.0	Healthy	6 days	Ultrasonic	1	0 to 8 50 to 55	Partial
T3	Trawl 90 mins duration	Jan. 96	*C. caretta*	Not recorded[1]	Healthy	4 days	Ultrasonic	1	9 to 13 31 to 37	Partial
T4	Trawl 90 mins duration	Feb. 96	*C. mydas*	>95	Sluggish at first	6 days	Ultrasonic	1	0 to 13 35 to 42	Partial
T5	Trawl 90 mins duration	Jan. 97	*C. caretta*	76	Healthy	8 days	Temperature Depth Recorder	35	0 to 54	Continuous
T6	Trawl 90 mins duration	Mar. 97	*L. olivacea*	56	Healthy	8 days	Temperature Depth Recorder	35	0 to 66	Continuous
T7	Trawl 120 mins duration	Nov. 95	*C. caretta*	79.0	Healthy	5 days	Ultrasonic	1	No data retrieved	No dive profile
R1	Rodeo	May 99	*C. caretta*	88.2	Healthy	6 days	Temperature Depth Recorder	70	0 to 162	Continuous
R2	Rodeo	May 99	*C. caretta*	84.3	Healthy	6 days	Temperature Depth Recorder	70	0 to 160	Continuous
R3	Rodeo	May 99	*C. caretta*	96.4	Healthy	na	Temperature Depth Recorder	70	No data retrieved	No dive profile
R4	Rodeo	May 99	*C. caretta*	90.4	Healthy	6 days	Temperature Depth Recorder	70	No data retrieved	No dive profile
R5	Rodeo	May 99	*C. caretta*	86.2	Healthy	6 days	Temperature Depth Recorder	70	No data retrieved	No dive profile

[1] CCL for T3 was not recorded as a consequence of rough weather conditions; na = Not applicable

4.4.1 Post-release behaviour of sea turtles

All sea turtles displayed a distinctive escape response upon release from the trawler or the research boat, swimming rapidly away from the boat, often undertaking numerous short shallow dives. It is difficult to generalise about the dive profiles, as the telemetered sea turtles varied in their behaviour. However, the sea turtles in this study displayed the following dive types, although the timing, frequency and duration of these dive types varied between sea turtles.

Erratic short dive intervals

This dive pattern consisted of the sea turtle diving to various depths, but immediately returning to surface (or near surface) waters (Figure 4.4). This pattern of diving was observed for all sea turtles monitored immediately upon release and was associated with the initial escape response of the sea turtles swimming rapidly away from the trawler.

Regular long dive intervals

This dive pattern consisted of the sea turtle spending most of its time at a consistent depth, interspersed with direct vertical movement to surface (or near surface) waters (Figure 4.4). The duration of the time at depth was variable, but in general was >25 minutes. Time at the surface ranged from 12 seconds to 123 seconds (T1), as recorded at one-second intervals by ultrasonic equipment.

Mixed dive intervals

At other times, the diving pattern was not either of the above dive patterns, but contained elements of each (Figure 4.4).

'Normal' activity patterns

The rodeo-caught sea turtles were monitored for 162 hours post-release. Both R1 and R2 showed a significance change in diving behaviour from a continuous period of long regular dive intervals to diurnal patterns of activity where mixed dive intervals were displayed during daylight and long regular dive intervals were displayed during the night (Figure 4.4). This diving behaviour is consistent with 'normal' activity patterns reported by Dodd (1988) and van Dam and Diez (1997).

For context, the individual dive profiles of each trawl-caught and rodeo-caught sea turtle are presented in Figures 4.5 to 4.12.

Figure 4.4 General dive patterns of trawl-caught and rodeo-caught sea turtles

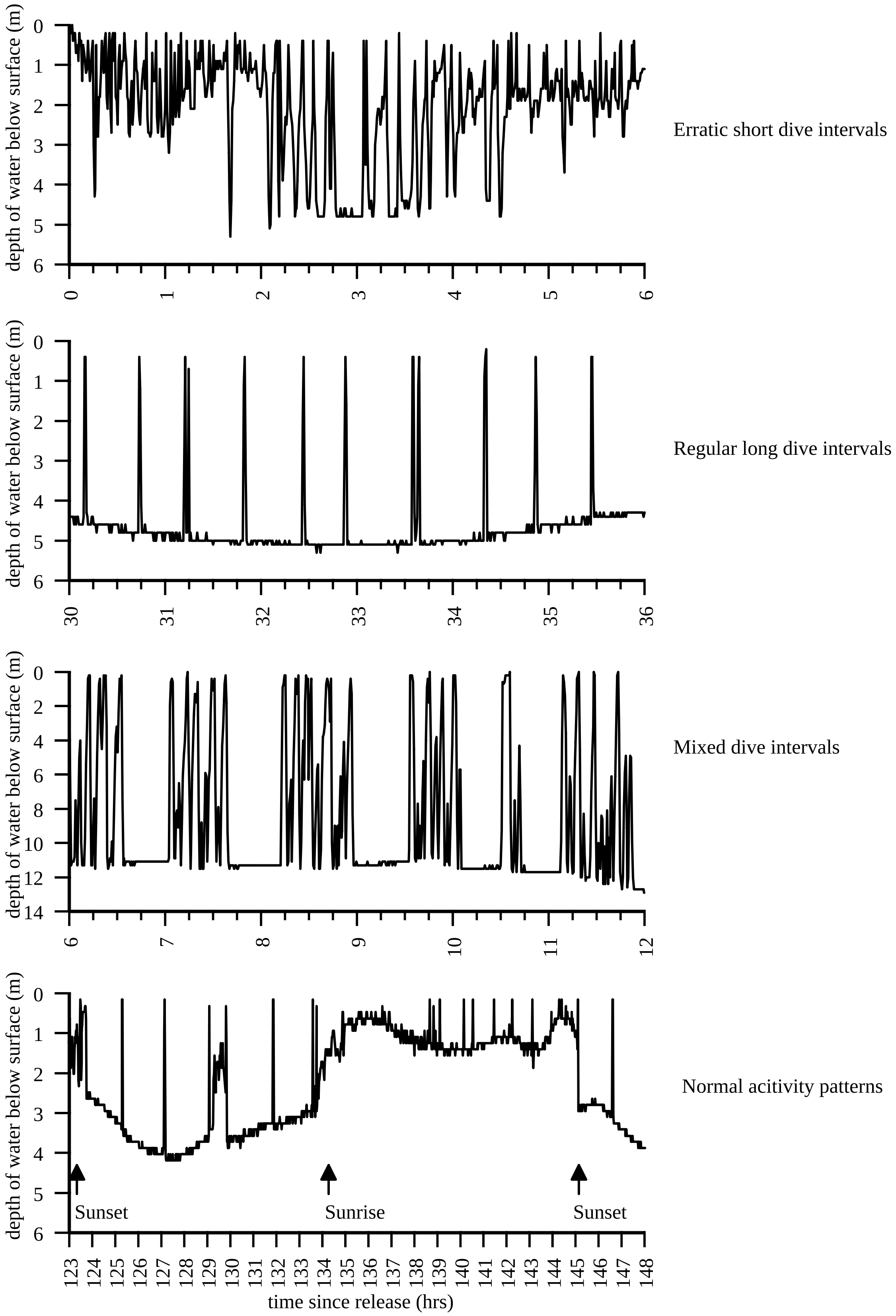


Figure 4.5 Partial dive profile of trawl-caught sea turtle T1 monitored using real-time ultrasonic tracking equipment

Context: T1 was an 87.5 cm CCL *Caretta caretta* caught at 18:30 in Moreton Bay during a trawl of 120 minutes duration on the 26/09/1995. T1 was located immediately after release and monitored using ultrasonic equipment (one second recording interval) for about 20 minutes before the signal was lost. Tracking was then abandoned due to 25 knots winds and 2m seas. Tracking was resumed ~36 hours later. T1 was tracked for the next six hours. Tracking stopped but resumed ~58 hours after release.

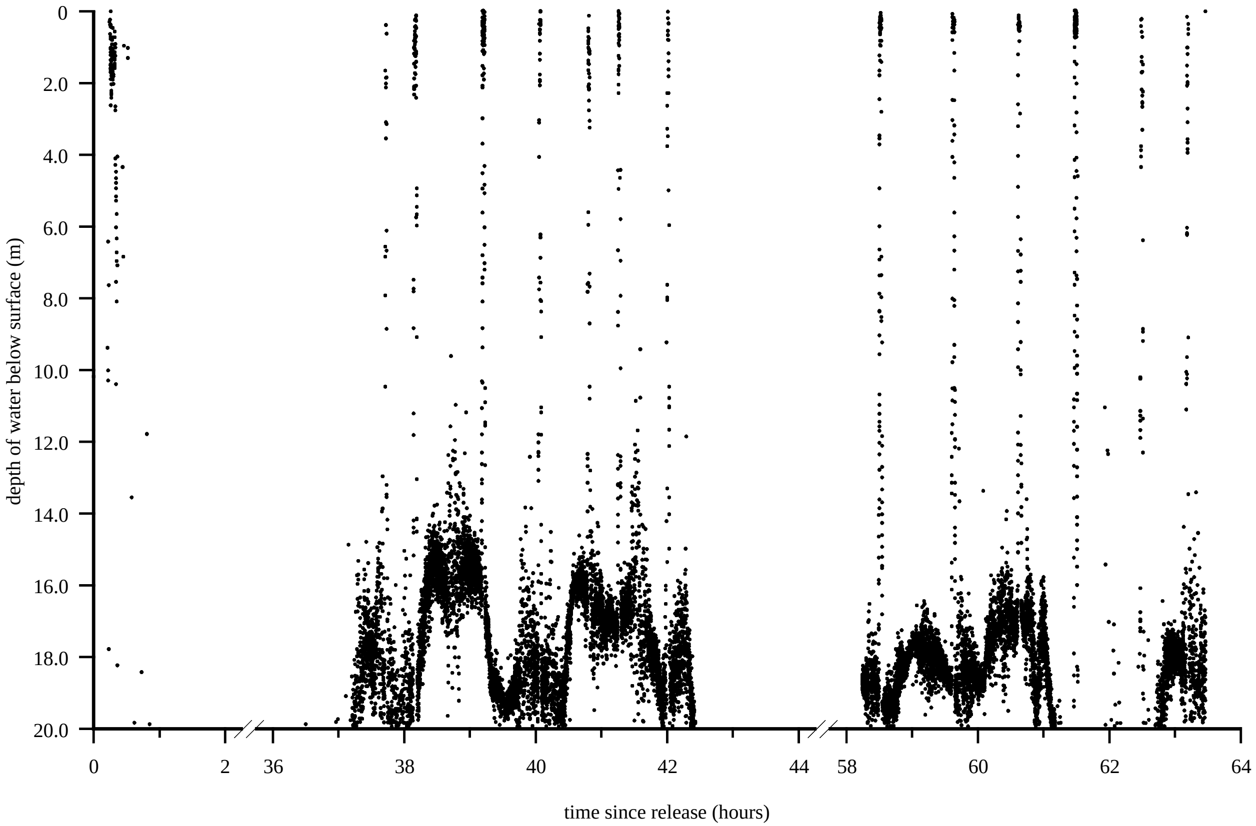


Figure 4.6 Partial dive profile of trawl-caught sea turtle T2 monitored using real-time ultrasonic tracking equipment

Context: T2 was an 83.0 cm CCL *Caretta caretta* caught in Moreton Bay at 04:00 in a trawl of 90 minutes duration on the 17/10/1995. T2 was located immediately upon release and monitored continuously for the next eight hours using ultrasonic equipment (one second recording interval). Tracking was unsuccessfully attempted (i.e., could not locate T2) at ~12½ and ~24 hours after release. T2 was relocated at ~50 hours after release, having moved two nautical miles from its last known position and was tracked for the next six hours.

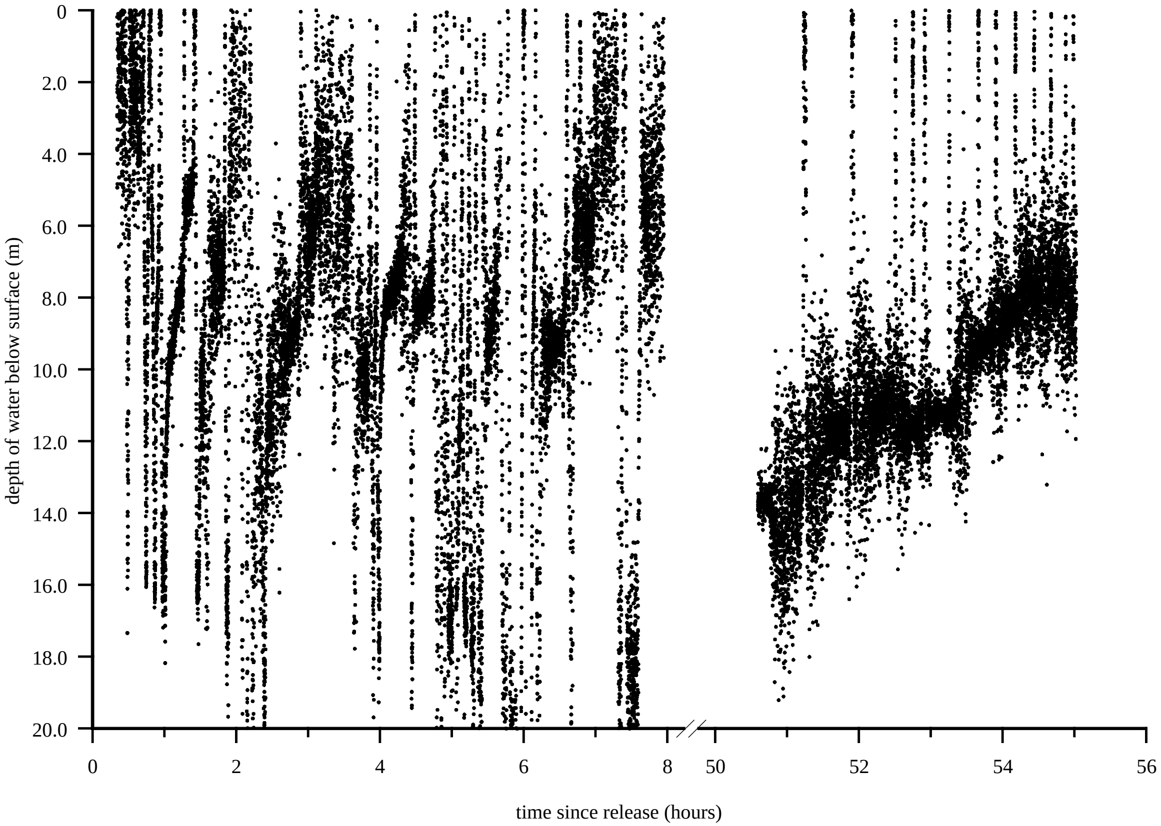


Figure 4.7 Partial dive profile of trawl-caught sea turtle T3 monitored using real-time ultrasonic tracking equipment

Context: T3 was a *Caretta caretta* caught in Moreton Bay at 00:21 in a trawl of 90 minutes duration on the 21/01/1996. T3 was not located until ~8½ hours after release, and was then monitored for four hours using ultrasonic equipment (one second recording interval). Tracking of T3 recommenced at ~31 hours after release and continued until equipment failure at 36 hours after-release. Poor weather prevented further tracking.

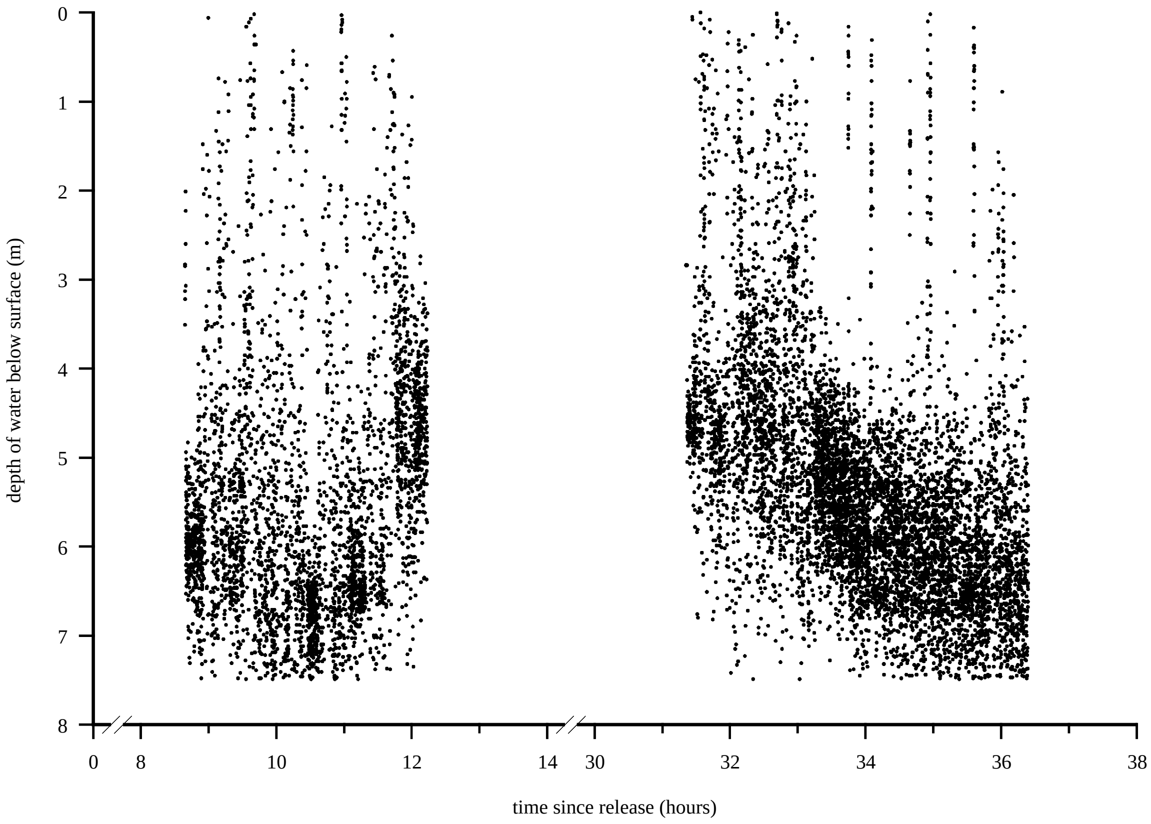


Figure 4.8 Partial dive profile of trawl-caught sea turtle T4 monitored using real-time ultrasonic tracking equipment

Context: T4 was a *Chelonia mydas* caught in Moreton Bay at 01:30 in a trawl of 90 minutes duration on the 05/02/1996. T4 did not move when initially landed on the trawler then deeply inhaled within five minutes of being on the trawler. T4 was considered to be in the most ‘sluggish’ condition of all the trawl-caught sea turtles observed. T4 was released and monitored using ultrasonic equipment (one second recording interval) for the next 12 hours. Tracking recommenced at ~36 hours after release for eight hours but poor weather prevented further tracking.

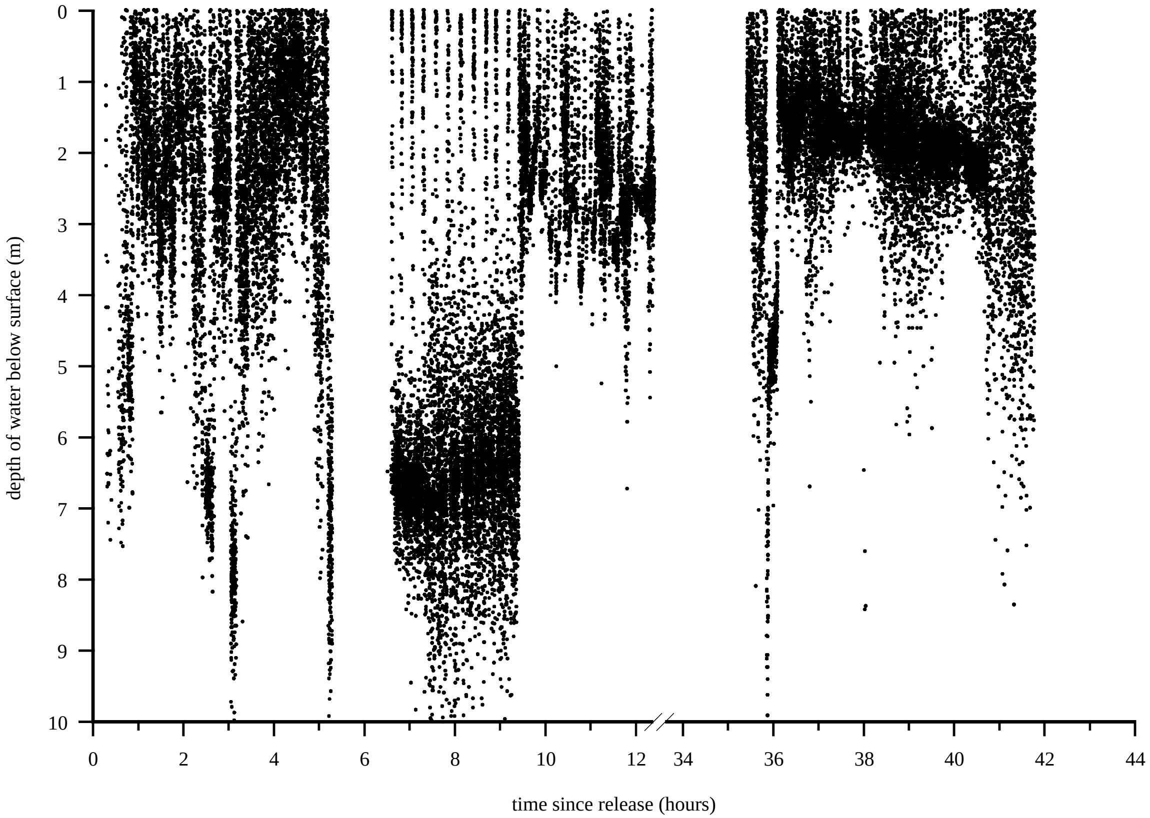


Figure 4.9 Continuous dive profile of trawl-caught sea turtle T5 monitored using TDRs

Context: T5 was a 76.0 cm *Caretta caretta* caught in Moreton Bay at 12:40 in a trawl of 90 minutes duration on the 22/01/1997. T5 was released and located using ultrasonic and TDR equipment for the next six hours. For the last three hours of this tracking session, T5 remained near a sub-surface rock formation in Moreton Bay (Otter Rock) around which 14 trawlers were trawling intensively. T5 was relocated on each of the following two days. The dive profile of T5 was monitored mostly using a TDR (35 second recording interval) that recorded continuously for 54 hours after release. Note the presence of the tidal cycle within the dive profile. This suggests that T5 spent most its time at a particular depth (e.g., the sea floor), with water depth changing by about two metres as a result of the flood and ebb of the tide.

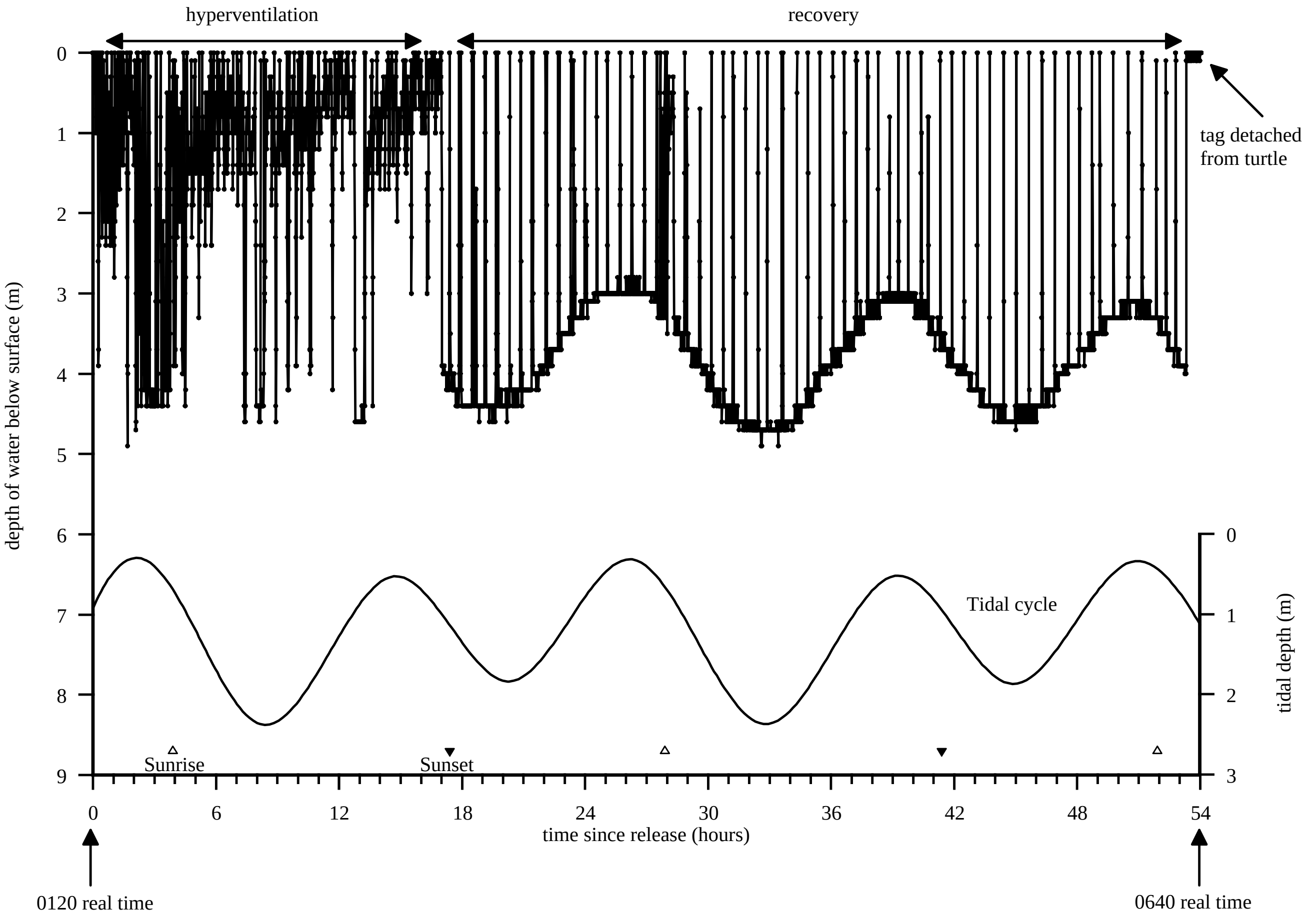


Figure 4.10 Continuous dive profile of trawl-caught sea turtle T6 monitored using TDRs

Context: T6 was a 56.0cm *Lepidochelys olivacea* caught in Moreton Bay at 02:00 in a trawl of 90 minutes duration on the 19/03/1997. T6 was released and located using ultrasonic equipment but interference from dredging operations on frequency of the ultrasonic tag (40 kHz) prevented real-time tracking. The dive profile of T6 was recorded continuously for ~66 hours after release using a TDR (35 second recording interval). The tidal cycle can also be seen in this dive profile.

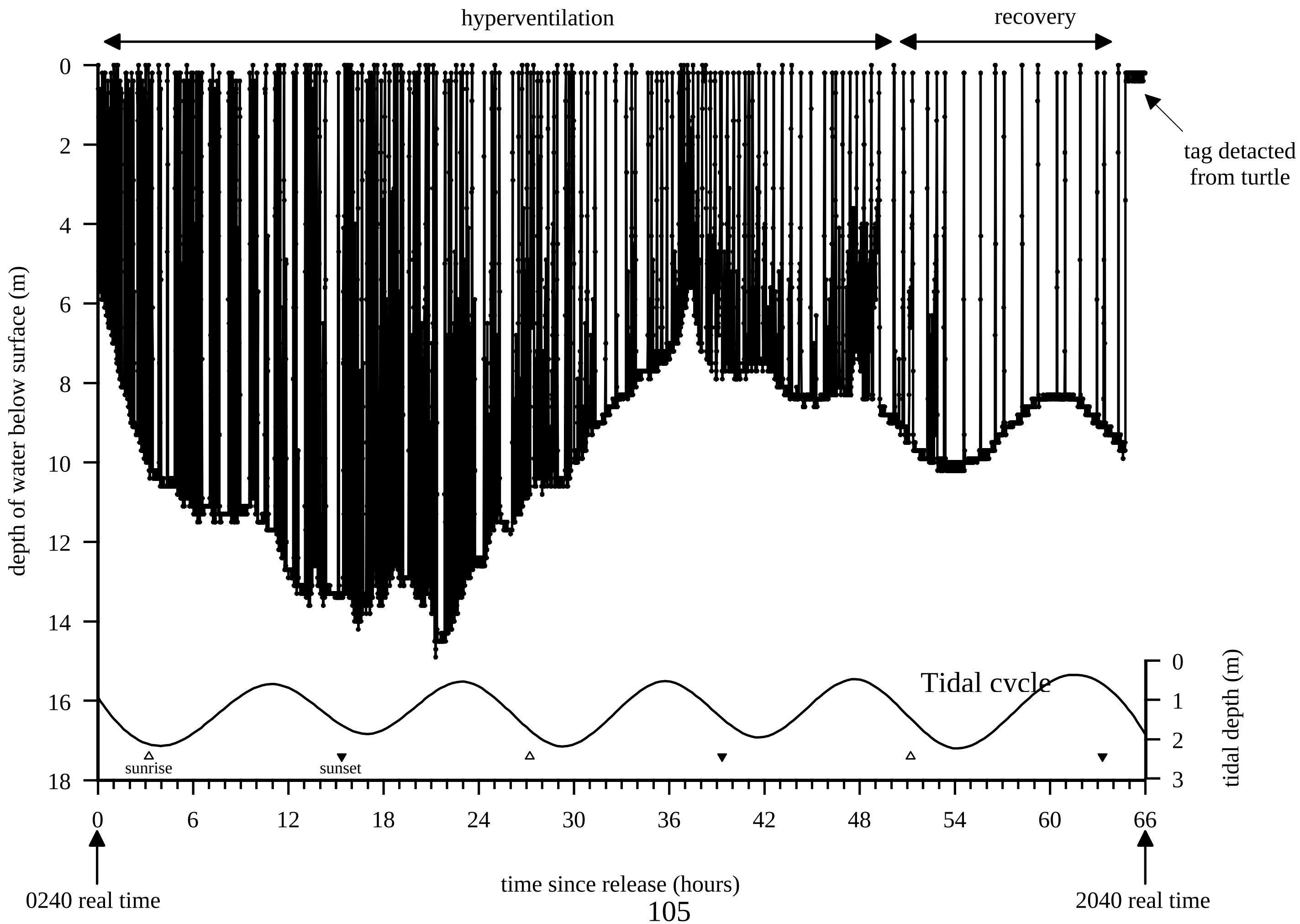


Figure 4.11 Continuous dive profile of rodeo-caught sea turtle R1 monitored using TDRs

Context: R1 was an 88.2cm *Caretta caretta* was a rodeo-caught turtle caught and released in Moreton Bay on the 12/05/1999, after about six hours of being held out of water. The dive profile of R1 was monitored using a TDR (70 second recording interval).

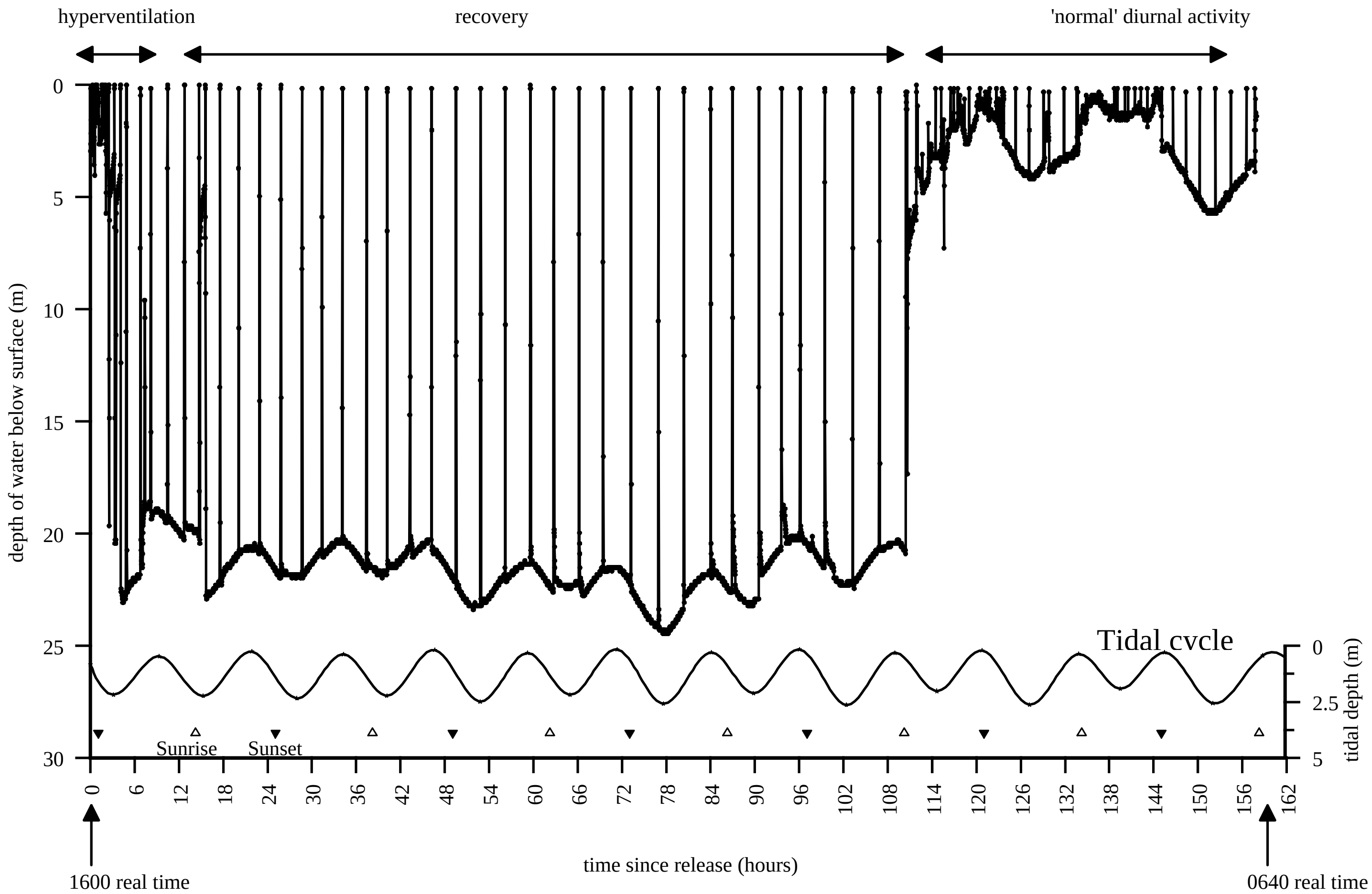
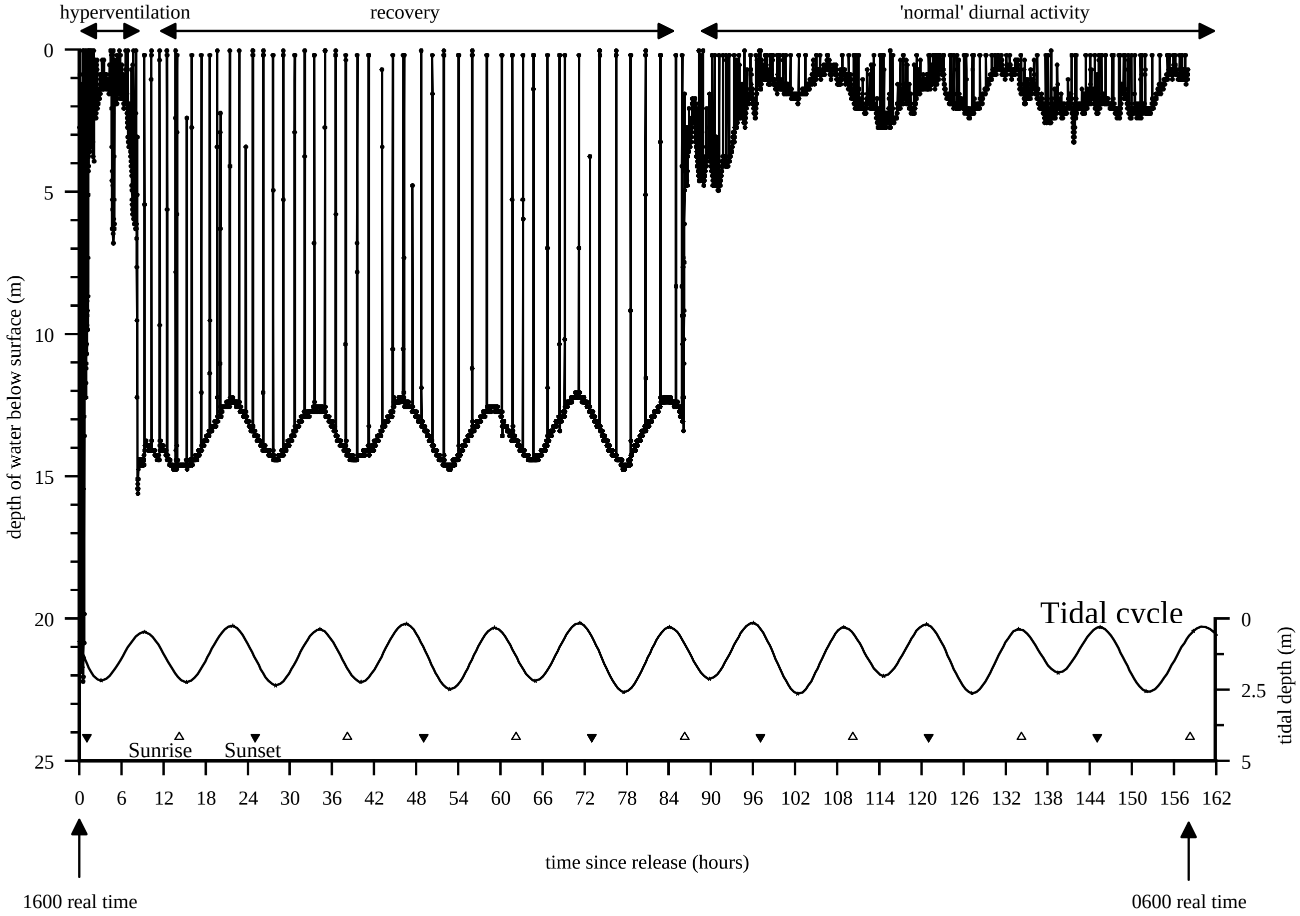


Figure 4.12 Continuous dive profile of rodeo-caught sea turtle R2 monitored using TDRs

Context: R2 was an 84.3cm *Caretta caretta* was a rodeo-caught turtle caught and released in Moreton Bay on the 12/05/1999, after about six hours of being held out of water. The dive profile of R2 was monitored using a TDR (70 second recording interval).



4.4.2 Differences in the post-release dive profiles between trawl-caught and rodeo-caught sea turtles

The current study aimed to examine evidence for differences in the dive profiles of trawl-caught and rodeo-caught sea turtles that might indicate changes in behaviour that could be considered a consequence of the trawl-capture. The partial dive profiles provided fine scale temporal resolution of the diving behaviour of the trawl-caught sea turtles because the ultrasonic recording interval was one second (Figures 4.4 to 4.8). The requirement for real-time data collection of the ultrasonic signal provided a spatial context in which to interpret the dive profiles (i.e., visually confirm surface events and ascertain the location and water-depth that the telemetered sea turtle was occupying). However, the partial dive profiles were difficult to interpret because of temporal context of the dive profile was unknown i.e., what was the dive profile of the sea turtle prior and post the data-recording interval? The continuous dive profiles (recorded at 35 and 70 second intervals) had less temporal resolution than the ultrasonic dive profiles (Figures 4.9 to 4.12). Therefore, fine scale changes in dive profile were not recorded. However, the continuous dive profiles were more readily interpreted because of the extended time over which changes dive patterns could be assessed.

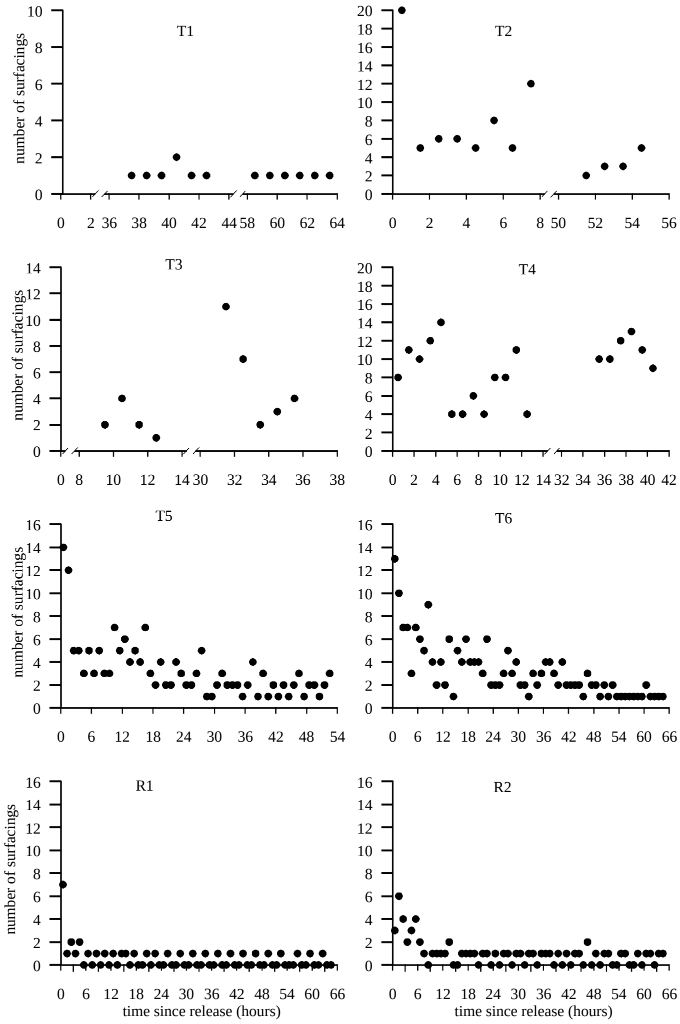
The dive profiles of the trawl-caught and rodeo-caught sea turtles as measured by the TDRs were qualitatively different (Figures 4.9 to 4.12). The measures of the dive behaviour (i.e., surface events per hour, surface intervals, dive intervals) were inherently correlated, and offered different insights into the possible response to capture as well as being limited by different assumptions.

Surfacing events – number per hour

A surface event was defined as the movement of a sea turtle into waters <1.25 m deep. In general, the number of surface events per hour was inversely related to time since release, being highest during the first six hours, then decreasing at varying rates to stabilise at a lower level (Figure 4.13). Surface events per hour decreased when sea turtles settled into the ‘regular long dive interval’ diving pattern. Rodeo-caught sea turtles (R1, R2) settled into this diving more quickly than the trawl-caught sea turtles (Figure 4.13).

Figure 4.13 Surface events per hour of trawl-caught and rodeo-caught sea turtles

(Note the variation in the scales along the x-axis and y-axis)



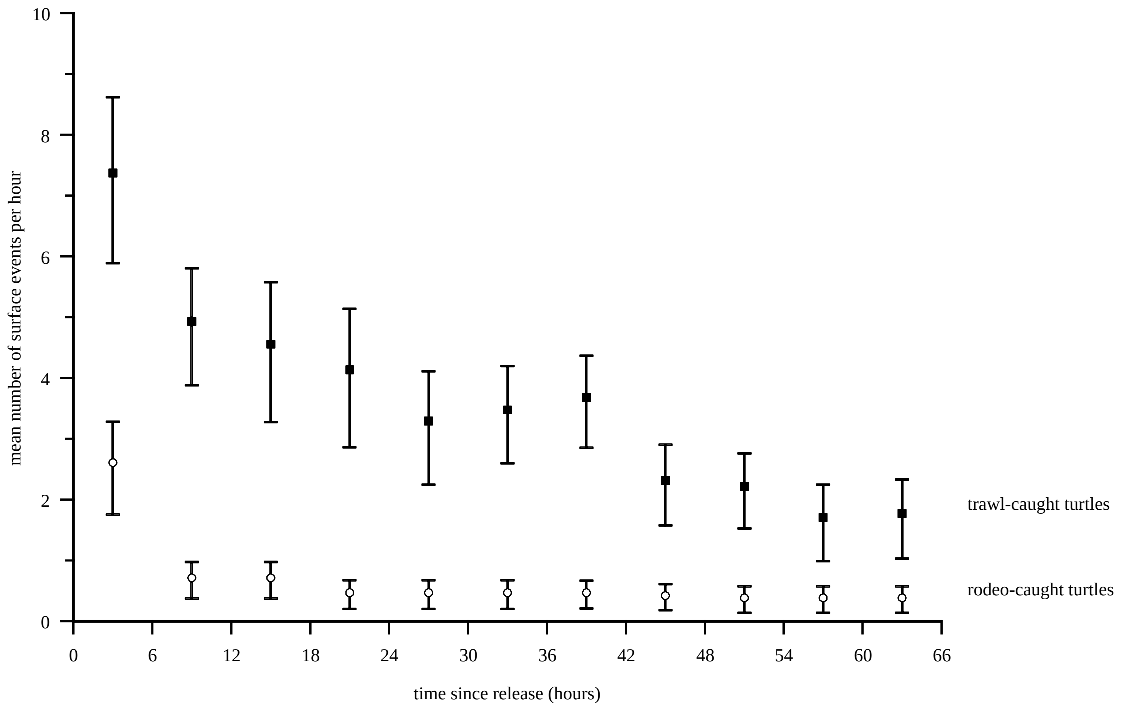
The number of surface events per hour was significantly different between trawl-caught and rodeo-caught sea turtles, based on TDR data only (Table 4.3). The auto-regressive term (of order one) in the mixed model was not significant, so was dropped. This indicated there was little auto-correlation between the number of surface events in successive periods and that mean values did not have to be adjusted for this effect. Bias-corrected, back-transformed means estimated from the residual maximium likelihood (REML) analysis are presented in Figure 4.14.

Table 4.3 Residual Maximum Likelihood (REML) analysis of surface events per period

(Wald test for fixed effects)

Fixed term	Wald statistic	d.f.	Wald/d.f.	Chi-sq prob
Capture method	40.46	1	40.46	<0.001
Period (i.e., time since release)	143.11	10	14.31	<0.001
Capture method x period interaction	17.62	10	1.76	0.062

Figure 4.14 Bias-corrected back-calculated mean surface events per hour for trawl-caught and rodeo-caught sea turtles post-release monitored using TDRs.



Dive intervals – in minutes

TDRs provided the most continuous coverage of changes in dive duration (= dive interval). Dive intervals generally increased with time since release for both trawl-caught and rodeo-caught sea turtles. All sea turtles displayed a diving pattern that included 'regular long dive intervals' at some point during the period they were monitored.

The continuous dive profiles recorded by the TDRs gave the approximate timing when the trawl-caught and rodeo-caught sea turtles changed their diving patterns from 'erratic short dive intervals' to 'regular long dive intervals'. The trawl-caught sea turtles settled into a pattern of 'regular long dive intervals' at 17 hours post-release for T5 (Figure 4.9), with a dive interval of 30 minutes and at about 50 hours post-release for T6 (Figure 4.10), with dive intervals of about 46 minutes. Rodeo-caught sea turtles settled into a pattern of 'regular long dive intervals' more quickly after release than the trawl-caught sea turtles, with R1 and R2 settling into a regular dive pattern within six hours of release

(Figure 4.11 and 4.12). R1 and R2 displayed the longest dive intervals (Table 4.4), with a maximum-recorded dive interval of 222 minutes (i.e., 3 hours, 42 minutes). This was considerably longer than any dive interval reported for free-diving *C. caretta*. This was unlikely to be an artefact of the telemetry equipment, because during this phase, the dive profile of R1 strongly suggests that this sea turtle was resting in water depths of 20 to 24 m and the surface events were clearly discernible within the TDR recording intervals of 70 seconds (Figure 4.11).

The partial dive profiles for trawl-caught sea turtles T1, T2, T3 and T4 were more difficult to interpret due to the incomplete data. However, all displayed a period of 'regular long dive interval' diving patterns during the time they were monitored i.e., ~37 to 42 and ~58 to ~63 hours post release for T1 (Figure 4.5), ~51 to 55 hours post-release for T2 (Figure 4.6), ~33 to ~36 hours post release for T3 (Figure 4.7), and ~6 to ~9 and ~39 to ~40 hours post-release for T4 (Figure 4.8).

Table 4.4 Dive intervals of trawl-caught and rodeo-caught sea turtles

Time since release (hours)	**Mean dive interval (± s.e.) in minutes**							
	Trawl-caught sea turtles						Rodeo-caught sea turtles	
	Ultrasonic, 1 second interval				TDR, 35 second interval		TDR, 70 second interval	
	T1	T2	T3	T4	T5	T6	R1	R2
	C. caretta	*C. caretta*	*C. caretta*	*C. mydas*	*C. caretta*	*L. olivacea*	*C. caretta*	*C. caretta*
0 to 6	-	6.4 ± 1.18	-	2.7 ± 2.42	7.5 ± 1.23	7.0 ± 0.93	20.0 ± 4.72	12.3 ± 2.40
6 to 12	-	6.4 ± 1.68	17.5 ± 5.96	7.0 ± 0.80	13.5 ± 1.78	10.6 ± 2.05	108.1 ± 12.42	46.2 ± 10.78
12 to 18	-	-	35.5 ± 5.66	13.9 ± 1.08	11.6 ± 1.99	14.1 ± 2.21	103.8 ± 16.26	70.0 ± 15.91
18 to 24	-	-	-	-	20.4 ± 3.58	13.4 ± 1.45	158.1 ± 7.01	79.9 ± 8.11
24 to 30	-	-	-	-	23.2 ± 4.70	18.9 ± 2.76	170.3 ± 0.00	91.3 ± 6.79
30 to 36	-	-	10.3 ± 2.42	2.4 ± 0.81	28.6 ± 3.78	25.7 ± 3.02	161.6 ± 1.24	87.5 ± 2.89
36 to 42	41.7 ± 5.08	-	-	3.6 ± 0.31	31.4 ± 4.71	16.0 ± 1.34	178.5 ± 9.90	91.0 ± 2.71
42 to 48	-	-	-	-	33.0 ± 3.57	29.0± 2.63	178.5 ± 1.65	74.4 ± 20.01
48 to 54	-	19.7 ± 3.04	-	-	30.6 ± 4.00	35.7 ± 3.67	196.0 ± 0.00	111.6 ± 13.52
54 to 60	-	-	-	-	-	57.1 ± 5.61	198.9 ± 2.06	119.0 ± 2.40
60 to 66	54.7 ± 3.67	-	-	-	-	46.0 ± 7.59	186.6	97.7 ± 7.84

Percent-time-submerged

Time submerged was defined as when the sea turtle was not within 1.25 m of the surface. In general, sea turtles displayed the lowest percent-time-submerged during the first six hours after release. Thereafter, the number of surface events per hour decreased and dive intervals increased, resulting in the percent-time-submerged increasing to between 97% and 99% (Table 4.5).

Table 4.5 Percent-time-submerged of trawl-caught and rodeo-caught sea turtles

Time since release (hours)	**Percent-time-submerged[A]**							
	Trawl-caught sea turtles						Rodeo-caught sea turtles	
	Ultrasonic, 1 second interval				TDR, 35 second interval		TDR, 70 second interval	
	T1 *C. caretta*	T2 *C. caretta*	T3 *C. caretta*	T4 *C. mydas*	T5 *C. caretta*	T6 *L. olivacea*	R1 *C. caretta*	R2 *C. caretta*
0 to 6	-	96.0	-	80.2	91.1	90.1	84.1	90.3
6 to 12	-	95.5	97.3	92.1	95.8	92.4	97.1	96.8
12 to 18	-	-	98.7	97.4	94.2	91.6	97.1	98.1
18 to 24	-	-	-	-	95.3	90.3	98.7	98.7
24 to 30	-	-	-	-	97.2	92.9	98.7	96.7
30 to 36	-	-	96.4	74.3	97.4	94.8	98.4	97.7
36 to 42	97.3	-	-	85.8	97.4	87.5	98.1	97.7
42 to 48	-	-	-	-	97.1	93.9	98.4	98.4
48 to 54	-	97.3	-	-	97.3	96.4	98.1	98.4
54 to 60	-	-	-	-	-	97.7	98.1	97.1
60 to 66	97.3	-	-	-	-	97.1	99.0	98.1

[A] Percent-time-submerged was defined as the proportion of time a sea turtle was not within 1.25 m of the surface.

Diurnal activity patterns

Trawl-caught sea turtles did not display the diurnal diving activity patterns reported in the literature within the period they were monitored (i.e., 66 hours post-release). Rodeo-caught sea turtles R1 and R2 appeared to move into shallow water (i.e., one to three metres deep) most likely to be associated with the intertidal banks on which they were originally caught at 111 and 85 hours post-release respectively (Figure 4.11 and 4.12). From this time onwards, the rodeo-caught sea turtles displayed much shorter dive intervals and diurnal differences in their dive profiles that were consistent with that reported in the literature as ‘normal’ patterns of diving activity for sea turtles (Dodd 1988, van Dam and Diez 1997).

4.5 DISCUSSION

4.5.1 Evidence of delayed post-trawl mortality

Delayed post-release mortality of trawl-caught sea turtles does occur (Limpus and Reimer 1994), but its frequency and contributing factors are difficult to define and quantify. In the current study, there was no evidence of delayed post-release mortality of trawl-caught sea turtles, although the sample size was small and the duration of monitoring was at most 66 hours after release.

Implications of observed condition upon capture for mortality rates

No dead or comatose sea turtles were observed during the trawl capture of seven sea turtles, despite tows of 90 and 120 minutes duration. The probability of observing a dead or comatose sea turtle varied depending on the mortality rate assumed to apply to sea turtle by-catch. Observed mortality rates for the Moreton Bay sector of the Queensland East Coast Trawl Fishery were low (see Chapter 3, section 3.4.5) compared with estimated mortality rates for prawn (=shrimp) trawl fisheries in the southeastern USA (Henwood and Stuntz 1987; this thesis Chapter 3, section 3.4.5). This was likely to be a consequence of the large difference in mean tow durations between the fisheries i.e., 76 minutes in Moreton Bay compared to 186 minutes in the USA (see Chapter 3, section 3.4.7). If the relationship between tow duration and sea turtle mortality derived by Henwood and Stuntz (1987) was applicable to the sea turtles caught during the current research, then there would have been a ~59% chance of observing a dead individual amongst the sample of trawl-caught sea turtles (Table 4.6).

Table 4.6 Probability of encountering a dead trawl-caught sea turtle based on a range of mortality scenarios

Number of trawl-caught sea turtles sampled	Mortality rate scenario				
	0.6%	3.7%	1.1%	5.8%	11.9%
	Observed direct Robins 1995	Observed Potential Chapter 3	Expected direct 90 min tows Chapter 3	Expected potential 90 min tows Chapter 3	Expected direct 90 min tows Henwood & Stuntz 1987
5	0.030	0.172	0.054	0.258	0.469
6	0.035	0.202	0.064	0.301	0.532
7	**0.041**	**0.232**	**0.075**	**0.342**	**0.588**
10	0.058	0.314	0.105	0.450	0.718
50	0.260	0.848	0.425	0.950	0.998
100	0.452	0.977	0.669	0.997	1.000
500	0.951	1.000	0.996	1.000	1.000
1000	0.998	1.000	1.000	1.000	1.000

Probability is derived from P(mortality) = 1-(non-mortality rate)^n (Zar 1996); The number of trawl-caught sea turtles observed in the current study was seven.

The lack of observed dead sea turtles suggests that mortality rates of trawl-caught sea turtles in Moreton Bay were unlikely to be as high as that suggested by the tow duration versus mortality relationship reported by Henwood and Stuntz (1987). Therefore, application of the USA mortality rates with tow duration (as per Chapter 3, sections 3.5.8 and 3.5.3) may overestimate the annual kill of sea turtles, particularly in the Moreton Bay, which accounts for >50% of sea turtle by-catch in the Queensland East Coast Trawl Fishery. With hindsight, confirmation of sea turtle by-catch mortality rates in the Moreton Bay sector of the Queensland East Coast Trawl Fishery warranted an observer program to validate the mortality rates. This would have required the observation of between 100 and 500 sea turtle captures, which would have been about equal to between 300 and 1,500 days of fishing, assuming one sea turtle caught per three days of fished. This was beyond the resources of my research.

4.5.2 Interpretation of post-release behaviour

The dive profiles of trawl-caught and rodeo-caught sea turtles were interpreted to examine the question of altered behaviour as a response to trawl capture that might lead to increased risk of boat strike, shark attack or recapture in a trawl net. TDR dive profiles of trawl-caught sea turtles were different to those of rodeo-caught sea turtles. I speculated that the responses of sea turtles in the current study could be classified into two phases prior to ‘normal’ activity patterns being displayed. This speculative interpretation of the dive profiles is discussed below.

Phase one – high number of surface events per hour = hyperventilation

Trawl-caught and rodeo-caught sea turtles displayed similar behaviour when first released, remaining near the surface with frequent surfacing events. This behaviour was initially associated with the sea turtle swimming away from the point of release, as reported by Yano and Tanaka (1991), but continued for several hours post-release. The observed behaviour was consistent with hyperventilation (i.e., increased breathing frequency), which is reported for sea turtles forcibly submerged in a trawl net for eight minutes (Stabenau *et al*. 1991). Sea turtles near the surface are unlikely to be recaptured in another trawl net (Caillouet *et al*. 1996) because trawl nets fish on the sea floor and as the net is hauled in, the mouth (=opening) of the trawl closes. Therefore, diving behaviour associated with hyperventilation may have reduced the possibility of trawl recapture and subsequent mortality in areas where fishing effort was intensive. In the current study, trawl-caught sea turtle T5 was not recaptured in a trawl net within six hours of its release, despite 14 trawlers intensively working within the area in which T5 remained.

However, post-release diving behaviour typical of hyperventilation supports speculation that trawl-caught sea turtles might be more susceptible to shark attack or boat strike. The later of these was an increasing source of mortality of sea turtles in Moreton Bay

(Limpus and Reimer 1994; Haines and Limpus 2000). However, it is difficult to interpret whether stranded sea turtle carcasses that are the victims of boat strike were undertaking normal diving activities or were recovering from trawl-capture (Haines and Limpus 2000). Secondary mortality of trawl-caught sea turtles may have been a significant problem in areas where there was intensive trawling and heavy traffic of speed-boats. These areas tend to be shallow estuaries or embayments adjacent to large coastal cities where recreational boating is a frequent activity. Areas with these features on the Queensland east coast include Moreton Bay, which is adjacent to city of Brisbane, Burnett Heads, which is adjacent to the town of Bundaberg and Cleveland Bay, which is adjacent to the town of Townsville (see Figure 1.1). Limpus and Reimer (1994) identified boat strike as a contributing factor in the decline of *C. caretta*. If boat strikes were a consequence of altered sea turtle behaviour post-release from a trawl-capture, then boat strike mortality should decline with the use of TEDs in the Queensland East Coast Trawl Fishery. However, boat strike mortality is thought to be in the tens of individuals for any particular Queensland embayment (e.g., Moreton Bay, and Cleveland Bay, Limpus and Reimer 1994) and changes in boat strike mortality rate may be beyond the limits of detection given the relatively small number of individuals involved.

Phase two - regular long dive intervals = recovery phase

The regular long dive intervals displayed by most sea turtles in the current study is typical of resting or stationary behaviour (Brill *et al.* 1995; Minamikawa *et al*. 1997; Hays *et al.* 2000). During this phase, trawl-caught and rodeo-caught sea turtles undertook few surface events per hour, and the sea turtle often remained at or near the surface for several minutes before diving to the depth from which it came. Lutcavage and Lutz (1991) reported that the number of breaths during a surface event increased with dive interval (r^2=0.64) and that as many as 10 breaths were recorded following a dive interval of greater than 30 minutes. Regular long dive intervals were observed in the current study (Figure 4.4) and were interpreted as a recovery phase, during which resting behaviour was interspersed with surface intervals. Lactic acid produced as a result of anaerobic metabolism, such as might occur during a forced submergence, is cleared very slowly and requires a long surface time to be assimilated (Schreer and Kovacs 1997). The recovery phase displayed during the current study may have assisted the trawl-caught sea turtles to exchange carbon dioxide and assimilate lactic acid that was accumulated during the forced submergence. An unexpected result was the display of a recovery phase by the rodeo-caught sea turtles, which had not been subject to a forced submergence. However, rodeo-caught sea turtles were confined out-of-water onboard a large research vessel for about six hours. In hindsight, this is likely to have been a 'stressful' event from which the rode-caught sea turtles required a period of recovery.

Determining the duration of the recovery phase for T1, T2, T3 and T4 was difficult due to the incomplete nature of their dive profiles as recorded by real-time ultrasonic equipment. The continuous dive profiles of trawl-caught sea turtles T5 and T6 suggested that recovery diving behaviour began at 18 and 48 hours post-release and continued at least until 66 hours post-release, when data-logging stopped. Rodeo-caught sea turtles R1 and R2 displayed recovery diving behaviour at about six hours post-release, and displayed 'normal' diving profiles by 85 and 111 hours post-release. Assuming that trawl-caught sea turtles remain in a recovery phase for at least the same amount of time as the rodeo-caught sea turtles (i.e., ~90 hours), then it may have taken in the order of 108 hours to 148 hours before the trawl-caught sea turtles displayed 'normal' diving patterns. The impact of a trawl capture and the consequential recovery period will vary depending upon the circumstance of each sea turtle caught i.e., when it entered the net, how long it was forcibly submerged and therefore the degree of recovery required. However, the recovery periods observed for rodeo- and trawl-caught sea turtles were considerably longer than previously reported i.e., 24 hours (Lutz and Dunbar-Cooper 1981). The disturbance of 'normal' diving patterns associated with feeding and resting activities has possible implications on the feeding rates of sea turtles subject to ongoing but non-fatal trawl captures e.g., once per week or fortnight. This may also impact on activities dependent on nutritional intake, such as breeding periodicity. Prior to the regulation of TEDs, some sea turtles may have experienced repeated non-fatal trawl captures in area of high intensity trawling effort. Individuals that were repeatedly caught in non-fatal trawl-captures may have had their normal feeding activities regularly disrupted. It is questionable whether sea turtles could become accustomed to such captures particularly if the recovery period is associated with physiological recovery rather than behavioural recovery. However, the use of

TEDs in trawl fisheries should eliminate prolonged forced submergence and ameliorate the stress associated with incidental capture in a trawl net to a large degree.

4.5.3 Implications for sea turtle research

As discussed in the previous section, the duration of the recovery phase displayed by rodeo-caught sea turtles was an unexpected result, because these individuals had not suffered a forced submergence similar to that of a trawl-capture. Confinement or handling of sea turtles can elicit maximal tachycardia (Lutz and Dunbar-Cooper 1991) and the effect of being rodeo-caught and confined in air on a large vessel for about six hours was sufficient for a recovery period of about 90 hours. Therefore, research studies that monitor sea turtle behaviour or diving activity after capture and handling by humans require careful consideration of possible recovery phase impacts.

4.6 CONCLUSIONS

Trawl captures appear to be a stressful event for sea turtles. There is some evidence that even non-fatal captures markedly affect the behaviour of sea turtles and could increase the risk of secondary mortality, such as boat strike. Trawl-caught sea turtles required extended periods of time to recover from the capture event, during which it was likely that normal feeding and resting activities were not undertaken. This has potential impacts on the nutrition and growth (and possible breeding periodicity) of sea turtles in heavily trawled areas. The potential presence of non-lethal impacts associated with trawl capture support the use of TEDs to minimise sea turtle by-catch and mortality as well as the stress associated with non-fatal trawl captures. Evidence of altered dive patterns from the current study also suggests that sea turtles are stressed by other interactions with humans, such a rodeo-capture and handling and require a much longer recovery period than previously thought.