Stranding of a satellite-tagged southern right whale off southwest Australia

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ABSTRACT

A southern right whale (*Eubalaena australis*) was found dead, stranded on a remote rock platform at Torndirrup, Western Australia, on 20 September 2022. Subsequent inspection of the animal showed it had been satellite tagged 11 days prior as part of an investigation into southern right whale movements within inshore breeding grounds and to offshore feeding grounds. This tagged whale was tracked east and then offshore in a southeasterly direction for nine days post tagging, before the track suddenly turned north and ended up at the stranding site. Gross necropsy evaluation was constrained by difficult access, but a rapid inspection of the carcass and collection of tissue samples *in situ* was conducted on 23 September 2022. The whale had large open wounds on both the back left peduncle region and head region. There was no external or subcutaneous inflammation around the tag site on the front right dorsal side. Findings were inconclusive and mortality could not be attributed to any single event. Possible causes or contributing factors to mortality include an adverse response to the tagging, vessel strike and killer whale predation.

INTRODUCTION

Recovering populations of baleen whales remain threatened by fishing gear entanglement and vessel strikes (Clapham *et al*., 1999; Thomas *et al*., 2016). Pollution, disease, habitat degradation and the impact of ocean acidification and climate change are also of increasing concern (Thomas *et al*., 2016). Right whale (*Eubalaena* spp.) health and population trends are shaped by a combination of lethal and sublethal anthropogenic impacts and environmental factors (Leaper *et al*., 2006; Seyboth *et al*., 2016; Corkeron *et al*., 2018; Harcourt *et al*., 2019; Agrelo *et al*., 2021; Reed *et al*., 2022, 2024). Identifying which factors assist the recovery of healthy populations may help the management of more vulnerable and/or declining populations (Harcourt *et al*., 2019)

Identification of foraging grounds is key to understanding how environmental variability influences population viability in right whales (Mate *et al*., 2011; Seyboth *et al*., 2016; Carman *et al*., 2019; Derville *et al*., 2022). Stable isotope analysis and satellite telemetry data are two of the most robust methods for understanding migratory baleen whales' connections between foraging grounds and winter breeding areas, including right whales (e.g., Zerbini *et al*., 2015, 2018; Mackay *et al*., 2020; Derville *et al*., 2022).

Satellite tagging baleen whales usually involves one of three types of tags:

- Type A tags use retention barbs anchored into the blubber beneath the external epidermis, with the electronics outside the whale body.
- Type B tags are bolted to the dorsal surface (usually the dorsal fin). These tags are therefore restricted to animals that have a dorsal ridge or fin and can be captured. As a result, they are rarely used for large baleen whales.

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- Type C tags are consolidated tags, with the electronics contained in a cylinder implanted into the blubber or anchored at or below the muscle/blubber interface using remote deployment systems (Andrews *et al*., 2019). Ideally, only the antennae should protrude at the time of attachment to ensure long-term retention.

In Australia, nine southern right whales were tagged in 2014 (Fowlers Bay, South Australia) and a single right whale was tagged in 2010 (Pirates Bay, Tasmania) with Wildlife Computers (Redmond, Washington, USA) Type C tags that were either articulated at the anchor/transmitter interface (2010) or strengthened with a stainless-steel collar to reinforce the anchor/transmitter interface (Mackay *et al*., 2020; Charlton *et al*., 2023). Since this time, the Type C satellite tag design manufactured by Wildlife Computers has evolved to create a more robust, fully integrated tag (i.e., there is no interface between the electronics package and the anchoring system), resulting in improved tag performance and safety for individual whales (Zerbini *et al*., 2017). These fully integrated Type C tags have been used on large baleen whale species since 2017 (Bamford *et al*., 2022; Bedriñana-Romano *et al*., 2022), including southern right whales off Argentina, South Georgia, New Zealand and South Africa (Vermeulen *et al*., 2023; Zerbini *et al*., 2023). On southern right whales, the average deployment duration of integrated Type C tags can be protracted. For example, in two recent studies, for tags 75% or more implanted, Study 1, mean deployment = 6.3 months, range = 11–234 days, n = 28 southern right whales (Zerbini *et al*., 2023); Study 2, mean = 8.4 months, range = 165–369 days, n = 4 southern right whales (Vermeulen *et al*., 2024). These longer tag-deployment durations are important for understanding the large-scale migratory movements of whales to undefined foraging grounds. Nevertheless, information about the effects of tagging on individuals is critical to understand why some tags do fail in the short term and to minimise adverse impacts on individuals.

Here we report on the stranding of a dead southern right whale on the Western Australian (WA) coast in September 2022. This whale was tagged in the weeks prior to stranding, allowing for a record of its movements to be captured and analysed. The stranded whale was subject to a limited examination and pathological investigation due to its location on an inaccessible beach during a period of stormy weather. Findings were inconclusive and mortality could not be attributed to any single event. Possible causes of mortality include an adverse response to the tagging, vessel strike and killer whale (*Orcinus orca*) predation.

METHODS & MATERIALS

Satellite tagging

As part of a multi-year study of inshore movements and offshore foraging ground locations, we biopsied and satellite-tagged southern right whales in Flinders Bay, Augusta, WA (34°18’38”S, 115°15’11”E – see Fig. 1) in September 2022. Here we focus on a female with calf tagged on 9 September 2022. A transdermal Wildlife Computer SPOT-372 satellite tag that provides Argos location data and includes a temperature and light sensor was deployed. Tag dimensions were 293 × 24 mm in length and diameter respectively, and 390 g in weight. Assuming the weight of an adult lactating southern right whale is around 40 tonnes (Christiansen *et al*., 2019), the tag corresponds to less than 0.001% of the whale’s body weight. The tag was deployed with an Air Rocket Transmitter System (ARTS), a modified pneumatic line-thrower (Heide-Jørgensen *et al*., 2001; Gales *et al*., 2009), by a highly skilled and experienced researcher (N. Gales) at 14 bar of pressure and 4 m distance. Deployment followed advice from previous studies of right whales (Zerbini *et al*., 2015) and best-practice guidelines (Andrews *et al*., 2019).

The tag was fully embedded. The individual’s behavioural response was mild (response category 2; Carroll *et al*., in review). The individual was resighted 27 hours later (13:39 AWST, 10 September 2022), travelling eastwards slowly inshore while her calf was breaching. The tag position was rephotographed (Fig. 2).

Tag sterilisation/disinfecting process

The tag was made from surgical-quality stainless steel. The Tristel Trio wipes system was used to provide a high-level of disinfection, following previous studies (Goetz *et al*., 2018). This system includes wipes that are

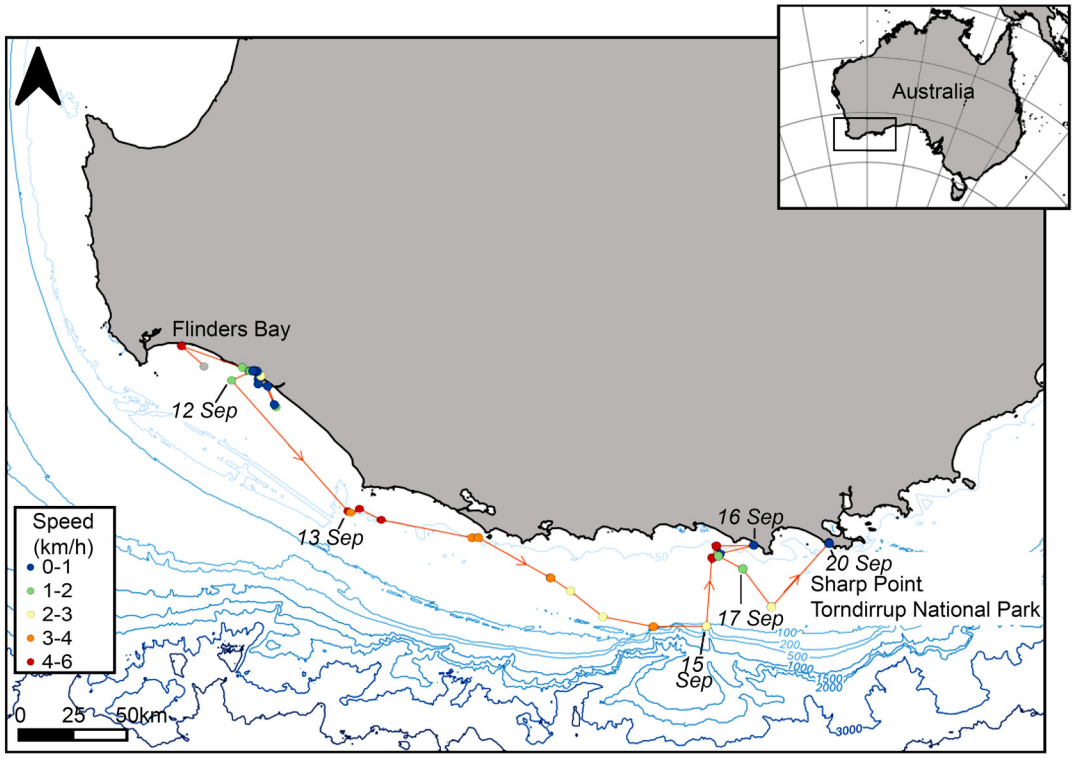

Figure 1. Study location showing ARGOS satellite tag locations, corrected with a correlated random walk model, of the stranded southern right whale off southwest Australia, from tagging (Flinders Bay: –34° 21' S, 115°15'E) to stranding (Torndirrup: 35° 07'S, 117°52'E). Locations (n) are colour coded to reflect the speed of travel (kmh^{-1}) from point n–1 to n. Therefore, the first location does not have a travel speed associated with it (grey).

impregnated with Tristel Base Solution (citric acid). The Tristel Activator Foam is a dilute solution of sodium chlorite. It is a three-step wipe system. When applying the Activator Foam onto the Wipe and scrunching together, chlorine dioxide is generated. The tags were then stored in plastic zip lock bags also disinfected with Tristel wipes prior to deployment. The Tristel system has been used before in baleen whale tagging projects as it effectively kills bacteria, fungi and mycobacteria (e.g., Tzanidakis *et al*., 2012; Goetz *et al*., 2018). Based on this previous research, the Tristel system was used because a suitably cool (< 30°C) ethylene oxide gas sterilisation chamber, as recommended by Andrews *et al.* (2019), was not available (and is phased out in many countries e.g., New Zealand).

Stranding event

On the afternoon of 20 September 2022, a 'very large whale' was seen stranded by a member of the public in the rocky bay to the east of Sharp Point, Torndirrup National Park, near Albany, WA, and reported to the Department of Biodiversity, Conservation and Attractions (DBCA), Albany Office. The tagging research team was informed of the dead whale by the Large Whale Disentanglement Team in Albany on the night of 20 September. The report was coincident with location data from one of the eight southern right whales tagged in the study, a whale tagged 11 days earlier (Sprogis *et al*., 2023). Visual confirmation was made by the research team at 06:00 (AWST) on 21 September. The rugged terrain combined with strong winds and large seas meant that photographs were taken with a DSLR camera from a cliff top ~1 km from the stranded whale. At this distance, it could not be discerned if the individual was an adult or calf. The animal was rolling in the large surf. We had been receiving locations from one animal in this vicinity over the previous 24 hours, with the last transmission received from that tag on 20 September, approximately midnight local time (Fig. 1). Here we describe data collection and analysis of satellite telemetry data used to reconstruct the travel path of the whale prior to the stranding as shown in Figure 1. We use these data to infer a probable series of events, while recognising the uncertainty of these data and conclusions.

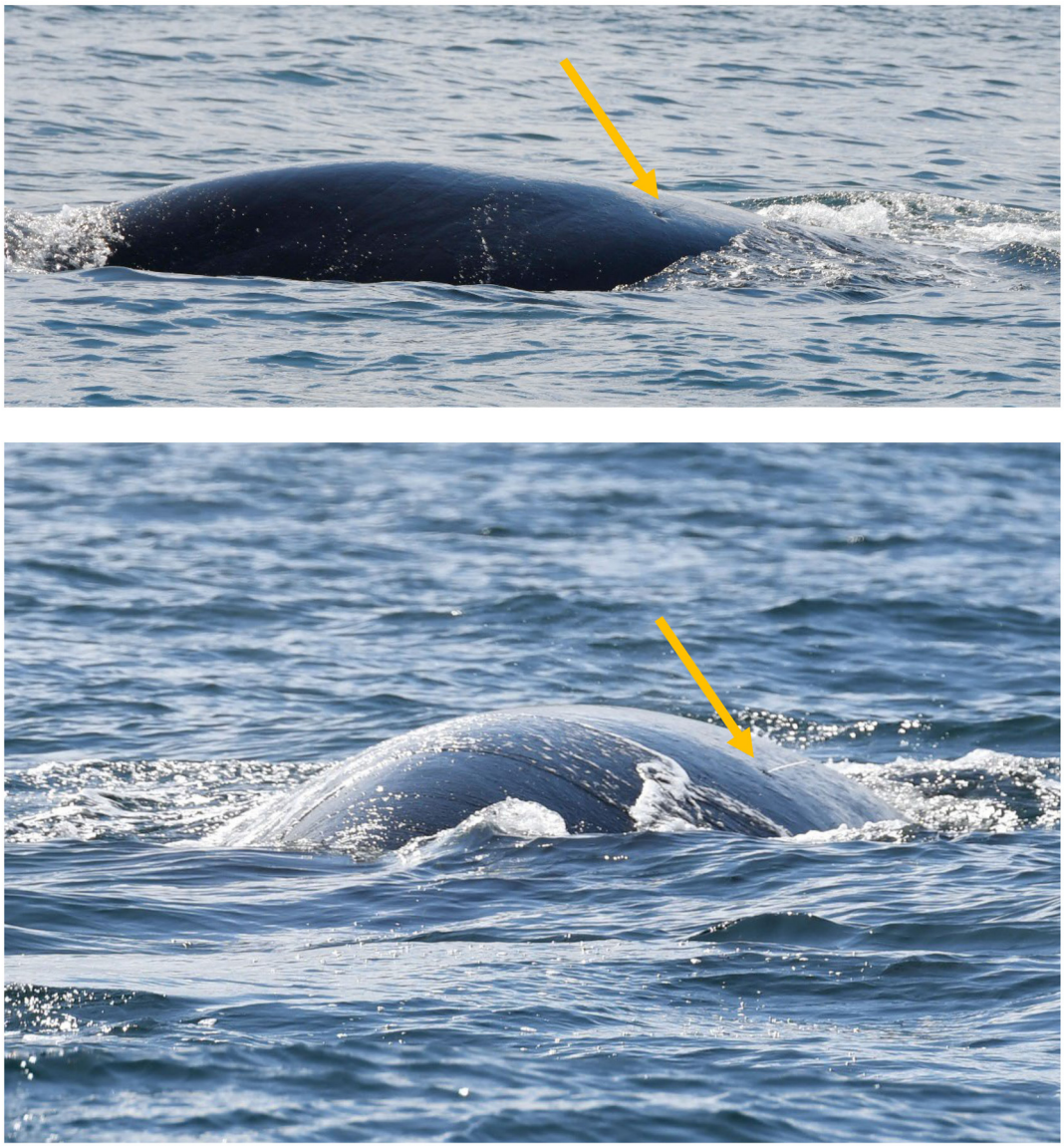

Figure 2. Top: position of tag immediately after deployment (9 September 2022). Bottom: 27 hours later (10 September 2022) with the whale swimming away from the vessel. The tag is fully implanted, with its position indicated by the arrows.

Visual inspection and data collection from stranded whale

Due to inclement weather and difficult access, a drone with an altimeter (DJI Phantom 4 Advanced) was initially flown over the carcass on 22 September 2022 (Fig. 3). Photogrammetry from the drone footage estimated that the individual was 14.1–14.2 m – an adult southern right whale (Christiansen *et al*., 2018) (Fig. 3). These measurements were calibrated by measuring known-sized objects. Given this size (average size for a mature female), the proximity of the last tracking locations and cessation of transmissions, our supposition was that the stranded whale was likely to be the tagged individual.

On 23 September 2022, a helicopter took a research team to the stranding site, where the carcass was examined *in situ* on 23 September by veterinary pathologists: S. Besier & D. Forshaw (Department of Primary Industries and Regional Development (DPIRD) WA), along with T. Button (Department of Biodiversity, Conservation and Attractions, WA) and K. Sprogis (Macquarie University and University of Western Australia). The necropsy examination was time limited, with examination limited to the tag site and a wound on the dorsum, with only external examination for the remaining body regions (e.g., the head). The tag was located in the carcass and removed from the blubber. Samples of blubber and fluid (see below) were taken from the tag location, along with photographs and measurements.

Figure 3. High-resolution drone still showing the whale carcass on the beach and injuries to carcass at the time of filming (22 September 2022). Image shows the whale dorsal side up. Arrow points to tag location. There were multiple white whale bones from other dead whales (species unknown) in the vicinity, some of which can be seen in this figure (bottom right).

Expert consultation

International experts on mortality, vessel strikes and pathology were consulted. A conference call was held with the authors and Expert Panel on 10 November 2022. The Panel included Dr. Frances Gulland, from the IWC's Expert Advisory Panel on Strandings, and Dr. Marcela Urhart and Dr. Alex Zerbini, both experts in right whale ship strikes and satellite tracking. In addition, a leading whale necropsy expert, Dr. Alex Costidis, commented on the observed pathology. Dr. Simon Childerhouse acted as rapporteur. The views reported here remain those of the authors, not the Expert Panel Members.

Satellite sensor, track and ship movement analysis

To account for the spatial error associated with Argos locations, we fitted a correlated random walk model using the *fit_ssm* function from the R package *aniMotum* (Jonsen *et al*., 2023) and new location estimates at each of the original observed Argos location times. Travel speed was calculated using the distance (*distanceTrack* function from the *argosfilter* package; Freitas *et al*., 2008) and the time difference (*difftime* function in base R) between two consecutive locations. The tag also transmitted the temperature measured by a sensor located near the comms port, close to the top of each tag. When the tag is deployed and still fully implanted, the temperature sensor sits in the blubber and therefore may provide insight into the individual's body temperature. However, the timestamp associated with temperature data is 'date received,' and temperature values do not always have an associated Argos location. We investigated the change in tag-derived temperatures by date.

Vessel tracking data were downloaded from the Australian Marine Safety Authority (AMSA) Craft Tracking System (CTS). CTS collects vessel traffic data from a variety of sources, including terrestrial and satellite shipborne Automatic Identification System (AIS) data sources. We extracted vessel traffic data for the months from May to November 2022. The dataset covers the extent of Australia's Search and Rescue Region. The individual's track was interpolated to match the hourly time stamp of the AIS data using the *align_move* function (package: *moveVis* (version: 0.10.5; Schwalb-Willmann *et al*., 2020)) and the distance between the whale and vessel locations calculated using the *pointDistance* function (package: *raster* (Hijmans R, 2023)) in R. Vessel density (km traversed by vessels in each grid cell) was calculated using the *spatstat.geom* (version: 3.2–9; Baddeley *et al*., 2015), *traipse* (Sumner, 2022), *terra* (Hijmans, 2022) and *trip* (version 1.8.5; Sumner *et al*., 2009) packages in R. A 0.5° × 0.5° raster grid was created using the *rast* function (package: *terra*; Hijmans, 2022) and vessel distance travelled was calculated using the *track_distance* function (package: *traipse*; Sumner, 2022). The vessel tracks were

Figure 4. Large, open wound on the dorsal to beginning of the peduncle region.

then converted into a *trip* object for easy conversion to a *spatstat line segment pattern* to convert to an image for mapping.

RESULTS

Pathology

The tag site was evident on the right dorsolateral aspect of the caudal abdomen, cranial to the peduncle area, with 30–35 mm of the antennae protruding from the dermis. The epidermis had been shed at this site. A primary goal of the limited necropsy examination was to establish if an abnormal inflammatory response to the tag was

Figure 5. The lower mandible with the skull and rostrum missing/damaged and tongue missing.

present, and if this may have contributed to mortality. Red-brown liquid was exuding from the tag site. An incision along the tag entry tract located the tag at the deep aspect of the blubber, just in contact with the vertebral musculature and lying diagonally to the entry tract, with the tag head pointing caudally (Fig. 6). The tag was embedded with a cavity formed by macerated, red-brown tissue, approximately 30 cm long and 15 cm deep. The macerated tissue in the cavity and intact muscle around the tag site were sampled for testing. Upon removal of the tag, soft, shredded red-brown tissue was entangled around its barbs. The entry tract did not display significant areas of discolouration or textural change. Further sites along the tag tract were not sampled for tissue but photographs were taken. The tract of the tag through the dermis and blubber appeared normal without obvious inflammation. The deep aspect of the site contained a large focus of macerated red-brown tissue which likely contributed to the exudate noted at the superficial aspect of the tag tract.

A large, open wound, approximately 2 m long by 1.5 m wide, ran longitudinally over the dorsum to the peduncle area (Fig. 4). The lesion had sharply defined edges with no reddening or thickening of the wound margins (where accessible for examination). Large amounts of degenerated, shredded blubber and fascia spilled from the site. Inflammatory or necrotic exudate was not present. The wound did not penetrate the coelom or expose the vertebrae.

The oral cavity appeared abnormal. The mandibles were flared laterally, with collapse of the maxilla/rostrum into the oral cavity, potential apparent loss of the tongue and an absence of baleen (Fig. 5).

Histological examination of this tissue did not reveal inflammation or any reparative attempts. This was an unexpected finding as a reasonably florid tissue reaction to a recently implanted tag would be expected (Moore *et al*., 2013). Interpretation of the site was complicated by several factors, including advanced autolysis and likely seawater (osmotic) damage to the tissues. While both autolysis and osmotic damage are likely to have obscured the tissue, it is likely that some evidence of inflammation, haemorrhage or fibrosis (scarring) would have been visible histologically. The pathologists suspect post-mortem movement of the carcass had driven the tag deeper and at a caudal angle from the original implantation site and contributed to the maceration of tissue (i.e., as the body rolled on the rocky reef platform in heavy surf).

Figure 6. The tag entry tract, with the antennae visible. The entry tract did not display significant areas of discolouration or textural change. The tag tract through the dermis and blubber appeared normal without obvious inflammation.

This implies that the original implantation site was more superficial within the blubber layer. As the tract was incised towards the tag, no gross evidence of abscessation was observed. However, as the tract was not sampled along its entire depth, no histological evidence is available to confirm or refute the presence of inflammation along the tract. As an extensive examination could not be performed at the time, examination of tissues that may provide more insight into local or systemic inflammation (e.g., regional lymph nodes, etc.) were not performed. A bacterial culture of the tag site and dorsal wound was undertaken. No significant organisms were isolated.

The full pathology report is appended as Supplementary Material 1.

Expert consultation

Based on the presented findings, several potential causes of the dorsal wound were considered by the Expert Panel, including collision with a sharp object prior to death (boat prow, propellor, floating object), post-mortem damage and decomposition artefact. The exceedingly sharp edges of the incision and the lack of evidence of inflammation in the histological results suggest this could have been a post-mortem event. However, as in the case of the tag site, extensive autolysis and osmotic damage may have obscured inflammatory changes that would signal an ante-mortem lesion. Post-mortem damage from being washed onto rocks was considered likely.

During discussion with the Expert Panel, Dr. Marcy Uhart showed the panel an image of a decomposing whale off Argentina that had split along the dorsum. This is a very unusual pattern of post-mortem change but indicates that decomposition artefact cannot be excluded as a potential cause of the dorsal wound.

Whale behaviour and satellite tag data

Argos generated satellite tag locations indicated that the whale moved slowly eastwards along the southern coast, from Flinders Bay towards Torndirrup, in the days prior to stranding (daily average # locations = 3.75, range = 0–7) (Fig. 1). Immediately following tagging, the whale tracked very slowly (1–2 kmh^{-1}) along the coast until 13 September, and then departed the coast at ~115.49° longitude, moving at an increased speed (3–6 kmh^{-1}) southeast towards the edge of the continental shelf, with what appeared to be a fairly directed path of travel and regular transmissions (Fig. 1). On 15 September, the track changed, and the satellite-derived locations indicated that the whale moved northwards back towards the coast, with a gap in transmissions. No location data were received on 18 or 19 September (see Supplementary Material 2 – red lines are ship tracks). It seems possible that this was a period of time when the whale was floating on its back (after death) and so the saltwater switch prevented transmissions. The last satellite-derived locations were at or near Torndirrup beach on 20 September – the date the carcass was reported.

From 9–16 September, the tag-derived temperature data slowly rose to the low 30s°C, followed by a four-day gap in received data which started on the 16/17 September. Temperature readings started again on 20

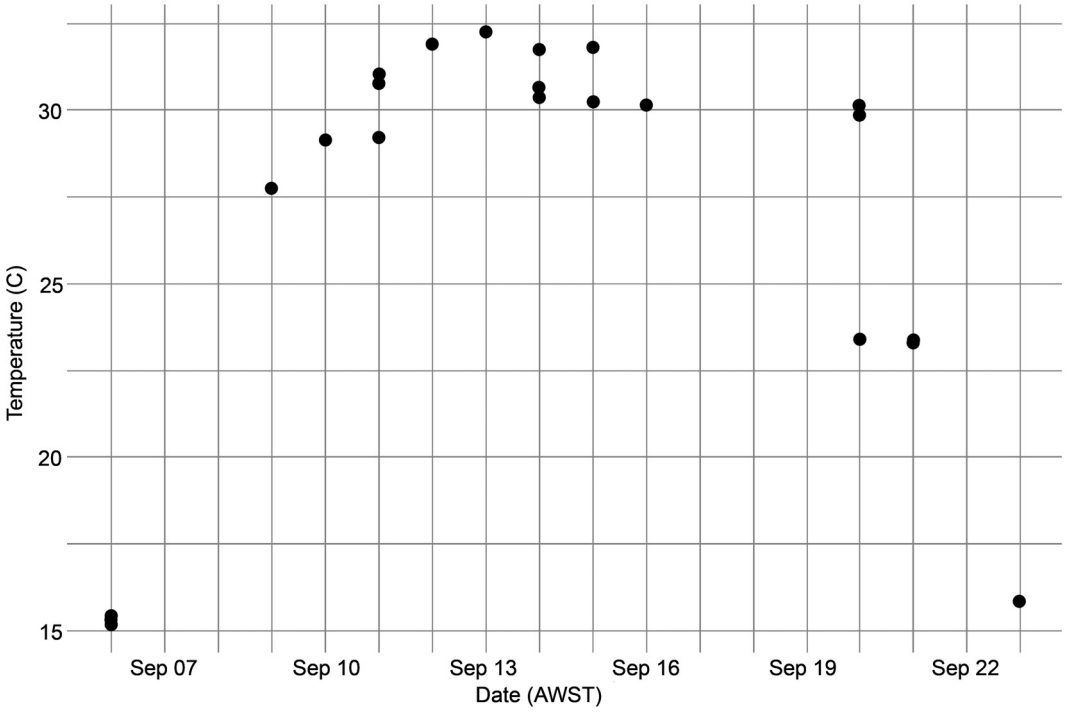

Figure 7. Temperature (°C) received from the Wildlife Computer SPOT-372 satellite tag retrieved from the stranded whale. Tag temperature data should reflect the internal temperature of the whale's blubber when the sensor is still fully embedded in the whale.

September at about 30°C but then dropped rapidly to ~23°C (Fig. 7). Dr. Alex Zerbini confirmed that the temperature data ranges were within the same range (25–35°C) that they receive from free swimming southern right whales tagged in Argentina.

Whale and shipping movement

The location at which the tagged whale changed direction away from the continental slope, back towards the coast around 15 September coincides with the shipping lane. Several different types of vessels, including large cargo, tankers, fishing vessels and cruise ships, transit east and west along the shipping lane (Fig. 8). Analysis of Automatic Information System (AIS) data shows a number of vessels passing east-west through this area around the same time (Figs. 8 and 9; Table 1). However, no vessel strikes were entered in the Australian Government's Vessel Strike Database for this region during these dates.[6] Although the satellite tag transmissions ceased on 17 September and resumed on 20 September 2022, the interpolated whale track indicates that the whale may have come within 5 km of vessel traffic on 17 September (cargo vessel, length: 157 m, draught: 10.5 m) and within 2 km of vessel traffic on 18 September (cargo vessel, length: 177 m, draught: 10.5 m).

Table 1

Number of vessels and their estimated minimum distance to the interpolated track of the tagged whale. Estimates were made based on tag-derived whale location data and vessel data from the Australian Marine Safety Authority (AMSA) Craft Tracking System.

Date (AWST)	Number of vessels in the region	Estimated minimum vessel distance to the SRW (km)
10.9.22	29	12
11.9.22	30	37
12.9.22	33	30
13.9.22	32	20
14.9.22	29	31
15.9.22	36	18
16.9.22	42	15
17.9.22	40	5
18.9.22	34	2
19.9.22	25	12
20.9.22	25	8

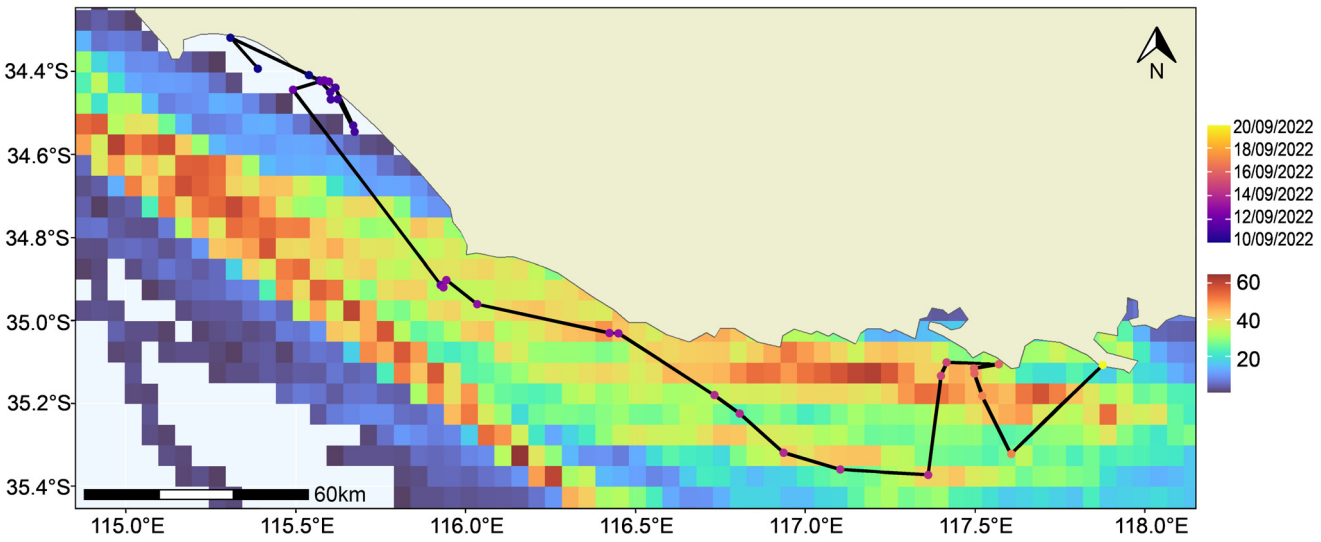

Figure 8. Movement of the whale offshore off southwest Australia (black track line with points coloured by date), and the shipping density (km traversed per 0.05° × 0.05° grid cell, blue to red colour scale) derived from AMSA's Craft Tracking System across the tag deployment period using all vessel types and sizes.

[6] *https://data.marinemammals.gov.au/shipstrike*

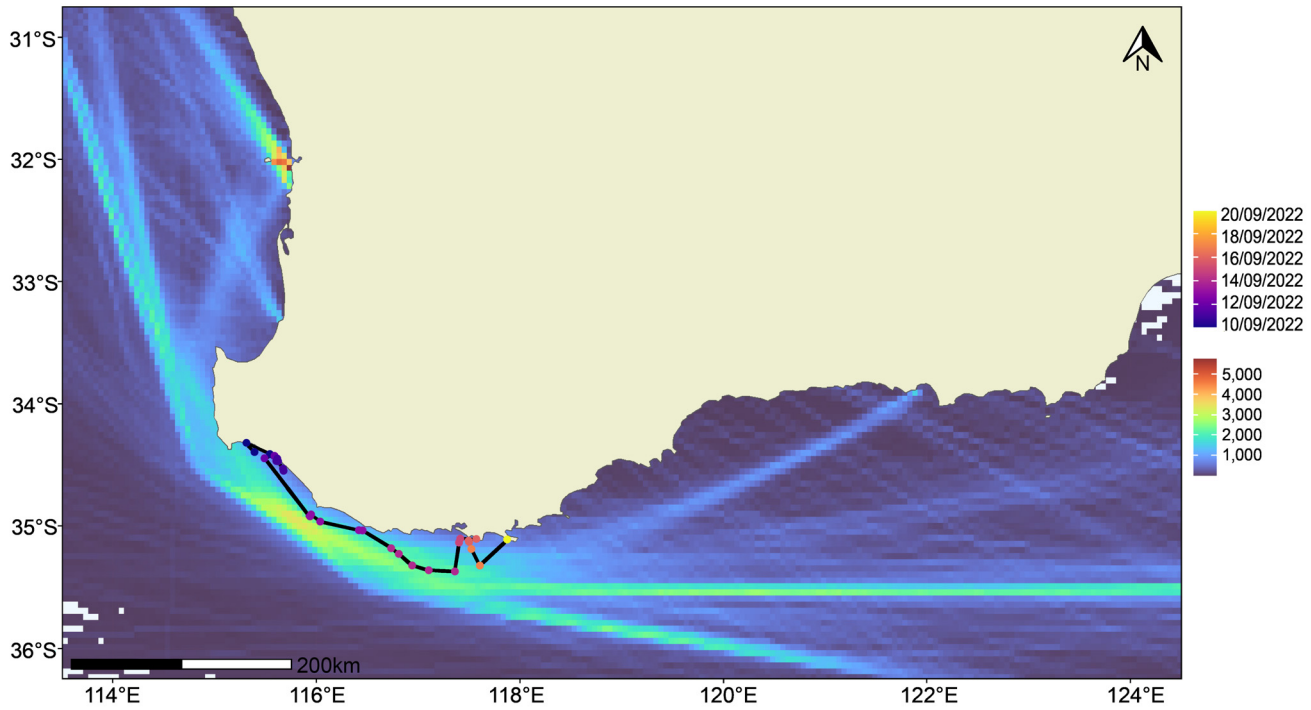

Figure 9. Movement of the whale offshore off southwest Australia (black track line with points coloured by date), and the shipping density (km traversed per 0.05° × 0.05° grid cell, blue to red colour scale) derived from AMSA's Craft Tracking System for May through to November 2022 for vessels > 24 m.

DISCUSSION

Overall, the findings were inconclusive, and mortality could not be definitively attributed to any single cause. Given the limited data, we synthesise the available evidence and input provided by the Expert Panel to better evaluate several possible causes of mortality. We acknowledge that there may be more than one contributing factor to the death of this whale.

Adverse response to tagging

The Expert Panel provided information from the mortality of a killer whale tagged in 2016 (LIMPET Tag, Type A; Andrews *et al*., 2019). This killer whale was necropsied more than a week after its death, but despite this delay, tag loss, tag petal retention with biofilm formation or direct pathogen implantation, and the development of a fungal infection at the tag site were all agreed to have contributed to the individual's illness, stranding and death.[7] While our knowledge of the effects on tagging of small cetaceans has improved (Heide-Jorgensen *et al*., 2017; Burek-Huntington *et al*., 2022; Deegan *et al*., 2023), our understanding of the short and long-term effects of deep penetrating tags on large whales is still nascent. For southern right whales, earlier tag designs were not associated with an increase in mortality or decrease in reproductive output in reproductive females (Best *et al*., 2015). As we are not able to exclude the possibility that the tag itself contributed to the stranding of this individual, we believe it is important to communicate what we know and review any relevant issues around tag design, handling and application.

The pathology reported from the tag site did not suggest a major, localised or regional infection (i.e., no abscess or inflammation), but the data obtained were not adequate to rule out an acute infection and potential septicaemia. Pathologic findings indicated that the whale likely died several days prior to stranding, as per breakdown of the carcass. Histopathology analysis indicated that there was no evidence of inflammatory cells around the tag location (inferring there was no prior inflammation). Pathology findings suggested that the depth

[7] Necropsy report: *https://media.fisheries.noaa.gov/2021-11/l95necropsy.pdf*; Expert Panel report: *https://media.fisheries.noaa.gov/2021-11/l95-expert-panel.pdf*

and angle of the tag at the time of death and maceration of the flesh internally may have been due to the whale stranding upside down and being rolled around in the waves, with the pressure contributing to the tag position and maceration of muscle. Expert opinion, based on photographs, suggested that the tag insertion area looked like a typical tag insertion without complications: the skin surface was normal with no obvious swelling, normal colour and texture of the blubber and tight adherence of the tag shaft (F. Gulland, pers. comm.).

Vessel strike

The high level of traumatic injury reported on the carcass, along with the limited pathology results, could be explained by a vessel strike, the high-energy stranding on a rocky substrate, or a combination of the two. Vessel strikes on North Atlantic right whales (*Eubalaena glacialis*) are a major cause of mortality of this species in the North Atlantic (Corkeron *et al*., 2018). Vessel strikes can either be from the hull and/or the propeller of ships (i.e., sharp or blunt force trauma), with many large ships not knowing or at least not reporting that they have hit a whale (Moore *et al*., 2004). A satellite-tagged dead sei whale (*Balaenoptera borealis*) was found stranded off Chile, with the cause of death attributed to a large impact in the thoraco-abdominal area (possibly from a vessel), causing fractured ribs and a diaphragmatic hernia with fatal consequences (Zegers *et al*., 2020). In the Southern Hemisphere, vessel strikes on southern right whales are frequent and scattered across their distribution range (Schoeman *et al*., 2020). In South Africa, Best *et al.* (2015) reported on one stranded southern right whale carcass that showed some similarities with the whale here. For that whale, images and observations indicated that the individual had been hit by a vessel before stranding, with one flipper partially severed, the rostrum broken and baleen missing. In Australian waters, reported ship strikes have been relatively unusual, providing only ~15% of the reported worldwide vessel strike records involving large whales (Peel *et al*., 2018). This figure probably reflects the lower shipping rates in Australian waters than elsewhere (Pirotta *et al*., 2021). However, confirmation of a vessel strike fatality is only possible when the collision is observed, or the whale is accessible (does not sink) with traumatic injuries evident or identified via necropsy. As such, and even with dedicated survey effort, it is likely that a proportion of southern right whale fatalities are unobserved and unrecorded along the coastline (cryptic mortality – Pace *et al*., 2021), especially in uninhabited regions. For example, Carroll *et al.* (2022) reported evidence of vessel strikes on southern right whales wintering in the remote and uninhabited New Zealand subantarctic Auckland Islands. In modern times (1997–2015), there have been nine reported fatal vessel strikes on southern right whale in Australian waters, with 10 confirmed mortalities. The 2014 Moreton Bay (Queensland) fatality involved a strike on both the mother and calf (Carroll *et al*., 2015; Lanyon & Janetzki, 2016; Peel *et al*., 2018). In southwest Australia, one vessel strike injury was reported for a lactating female sighted in Flinders Bay in 2008 and a propeller strike on an adult off Bunbury in 2023. The southern Western Australian coastline has been identified as a location of highest relative risk for southern right whale fatality from large vessels (> 80 m in length; Peel *et al*., 2018).

Killer whale predation

Killer whale predation of great whales, including right whales, has long been recorded (Shaler, 1873) and can fundamentally alter the behaviour of their prey (Sironi *et al*., 2008). Killer whale predation is often detected only by inference. In this region, killer whales prey on blue whales (Totterdell *et al*., 2022) and beaked whale species (Wellard *et al*., 2016). Elsewhere, killer whales are known to attack adult southern right whales, e.g., off Crozet Islands (Vermeulen *et al*., 2024) and Argentina (Sironi *et al*., 2008). The tongue and lips of baleen whales are a common food preference for killer whales, and the tongue of the stranded whale was missing (later reported to have washed ashore). The top jawbone was missing/broken, but there were no obvious rake marks that might point to killer whale predation. Excluding killer whale predation is difficult, but sightings of killer whales in the area, attacks on southern right whales, and rake marks on both live whales and carcasses that are not too decomposed, may help identify attacks and therefore should be recorded.

Conclusions

There are many important insights into the relationship between megafauna and their marine habitats that can only effectively be derived from satellite tagging. Not only can it help identify major movement corridors,

breeding and foraging areas, but it can also help to identify anthropogenic pressures on cetacean populations (McKenna *et al*., 2015; Aschettino *et al*., 2020; Blondin *et al*., 2020). Satellite tagging has even revealed hitherto unknown and unreported global hotspots of ship strike mortality for whale sharks (Womersley *et al*., 2022). The conservation value of this approach is well established, and satellite tagging will continue to provide benefits for the foreseeable future, including potentially identifying vessel strikes hitherto unknown and unrecorded.

Our finding of a recently deceased southern right whale shortly after implantation of a satellite tag, even if unrelated to the mortality, reinforces the importance of carefully considering the conservation value and potential outcomes of tagging against ethical and welfare considerations (McMahon *et al*., 2012). Given the potential consequences if things do go wrong, invasive tagging should not be considered without considering the worst-case scenario (mortality) and ensuring all steps are taken to prevent an adverse outcome.

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Supplementary Material 1

Department of Primary Industries and Regional Development
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DDLS - Animal Pathology Report

3 Baron-Hay Court South Perth, WA 6151 . Tel: +61 (0)8 9368 3351 . Fax: +61 (0)8 9474 1881

Case Number: AS-22-2888-F-V1 **Final Report** **1/4**

Date: 29-Nov-2022 Your Ref:

Enquiries: Dr Shane Besier (Veterinary Pathologist)

To: Hon. Prof. Robert Harcourt
Macquarie Park-School of Natural Science
Balaclava Road
Macquarie Park
NSW 2019

CC:

Owner: Not Available PIC: Not Available

Project: Diagnostic Wildlife submission

Species: Cetacea

Samples Received: 2 Fresh 2 Swabs 3 Fixed

Date Collected: 23-Sep-2022 Date Received: 28-Sep-2022 Submission:

Testing performed on a charge exempt basis

Laboratory testing in this case was valued at $2066.93.

History summary

Examination of a dead adult female southern right whale was undertaken, with a focus on a recent satellite tag site. The whale was tagged twelve days previously to being found dead onshore. Limited examination was undertaken to assess the healing state of the tag site and a dorsal wound.

Necropsy Findings

One dead southern right whale examined at Sharp Point Beach (SBesier, D.Forshaw [DPIRD], K.Sprogis, T.Button [DBCA], 23/09/22). The necropsy examination was strictly time limited with examination limited to the tag site and a wound on the dorsum with external examination only of rest of the whale.

The tag site as evident on the right dorsolateral aspect of the caudal abdomen, cranial to the peduncle area,with 30-35mm of the antennae protruding from the dermis; the epidermis had been shed at this site. Red-brown liquid was exuding from the tag site. Incision along the tag entry tract located the tag at the deep aspect of the blubber, just in contact with the vertebral musculature and lying diagonally to the entry tract, with the tag head pointing caudally. The tag was embedded with a cavity formed by macerated, red-brown tissue, approximately 30cm long and 15cm deep. On removal of the tag, soft, shredded red-brown tissue was entangled around the barbs of the tag. The macerated tissue in the cavity, from around the tag and intact muscle deep to this site were sampled for testing. The entry tract along which the antennae lay did not display significant areas of discolouration or textural change; further sites along the tag tract were not sampled.

A large wound approximating 2m long by 1.5m wide ran longitudinally over the dorsum of the peduncle area. The lesion had sharply defined edges with no reddening or thickening of the wound margins (where accessible for examination). Large amounts of degenerate, shredded blubber and fascia spilled from the site. Inflammatory or necrotic exudate was not a feature. The wound did not penetrate the coelom or expose the vertebrae.

The oral cavity appeared grossly abnormal. The mandibles were flared laterally with collapse of the maxilla/rostrum into the oral cavity, apparent loss of the tongue and sloughing of baleen.

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Case Number: AS-22-2888-F-V1 **Final Report** **2/4**

Fresh and fixed samples of the tag site, dorsal wound and fixed eye were obtained for further testing. Photographs of the examination were obtained by DBCA staff.

Histopathology

Slide/s	Tissue/s	Slide/s	Tissue/s
1-10	Tag site	18-20	Eye
11-17	Dorsal wound site	21-22	Optic nerve

Tag site: muscle sections from around and deep to the location of the tag displays increased endomysial space, filled by amorphous, moderately eosinophilic material (proteinaceous fluid). Within this interstitial material are large numbers of elongate bacteria, sometimes forming chains. The myofibres are diffusely fragmented and usually lack visible nuclei, but each segment retains elongate, cylindrical morphology and cross-striations (degeneration likely to reflect autolysis rather than myonecrosis). Section #2 displays distinct areas of muscle change as above with a sharply demarcated focus of dense fibrous tissue and compact skeletal muscle; while this still displays a similar bacterial population, fragmentation of the myofibres is not present (possible deep margin of wound with 'normal' muscle). #3 contains a small focus of perimysial fluid accumulation with eosinophilic pigment (presumed haemoglobin/lysed erythrocytes and or fragmented collagenous tissue). Rare, rounded to elongate non-staining foci that slightly compress or displace adjacent tissue are present, suggesting possible gas production (likely post-mortem; very minor change). Remaining samples from this site display similar changes.

Dorsal wound site: multiple sections of the skin margin, blubber and deep fascia examined. No inflammatory reaction is evident, with only mild separation of adipose and fibrous tissue within the blubber layer. Heavy multifocal bacterial growth is present in each section.

Eye: within the lumen of the ocular chambers there is heavy, mixed bacterial overgrowth without host inflammatory reaction (presumed post-mortem proliferation). The cellular detail of the eye is diffusely lost with sloughing of the visual layers.

Remaining tissues do not contain significant findings.

Morphological diagnoses
None made; see comments

Aetiological diagnoses
See comments

Comments
On gross examination, the tag aerial was found protruding from the right dorsolateral aspect of the abdominal area, associated with a thin, red-brown liquid exudate. A primary goal of the limited necropsy examination was to establish if an abnormal inflammatory response to the tag was present, and if this may have contributed to mortality. The tract of the tag through the dermis and blubber appeared bland without grossly obvious inflammation. The deep aspect of the site contained a large focus of macerated red-brown tissue which likely contributed to the exudate noted at the superficial aspect of the tag tract.

Histological examination of this site did not reveal inflammatory or tissue reparative attempts. This was an unexpected finding as a reasonably florid tissue reaction would be expected to a recently implanted tag. Interpretation of the site is complicated by several factors, including advanced autolysis and likely seawater (osmotic) damage to the tissues. It is also possible that post-mortem impact of the carcass on the coast may have moved the tag from the implantation site and contributed to maceration of the site. While both autolysis and osmotic damage are likely to have obscured the tissue, it is likely some evidence of inflammation, haemorrhage or fibrosis (scarring) would have been visible histologically. I suspect post-mortem movement of

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the carcass has driven the tag deeper and at a caudal angle from the original implantation site, and contributed to maceration of tissue.

This implies the original implantation site was more superficial within the blubber layer. As the tract was incised towards the tag, no gross evidence of abscessation was observed. However, as the tract was not sampled along its entire depth (spot samples only), no histological evidence is available to confirm or refute the presence of inflammation along the tract. As extensive examination could not be performed, examination of tissues that may provide more insight to local or systemic inflammation (such as regional lymph nodes etc) was also not performed.

Several potential causes of the dorsal wound were considered collision of a live whale with a sharp object (boat prow, propellor, hull, floating object), post-mortem damage and decomposition artefact. The exceeding sharp edges of the incision and lack of inflammation histologically strongly suggest this is a post-mortem event but, as for the tag site, extensive autolysis and osmotic damage may be obscuring inflammatory changes that would signal an ante-mortem lesion. Post-mortem damage from being washed onto rocks is considered likely. During a video conference expert group discussion (10/11/22), Dr Marcy Uhart provided an image of a decomposing whale that had split along the dorsum. This is a very unusual pattern of post-mortem change but indicates that decomposition artefact cannot be excluded as a cause of the dorsal wound.

Bacterial culture of the tag site and dorsal wound was undertaken without significant organisms isolated. Mixed bacterial growth from both sites suggest environmental contamination. Note only the heaviest growths are reported below; this is not representative of the wide range of organisms isolated.

The oral cavity anomaly appeared, on gross examination, to be a combination of loss or sloughing of the tongue and baleen with collapse of a deformed rostrum into the oral cavity. Deformation of the rostrum may be post-mortem damage to the carcass but ante-mortem injury cannot be excluded. Necropsy examination of the maxilla/rostrum was not conducted.

The eye was examined histopathologically but the extent of autolysis precluded any useful interpretation.

Bacteriology Results

Test Type: Culture for Anaerobic bacteria

Date Tested: 10/10/2022

Spec No	Spec ID	Spec Description	Anaerobic culture	Hathewaya limosa
0001		Wound Tissue	heavy growth	heavy growth
0002		Wound Tissue	heavy growth	heavy growth
0003		Wound/ Tag Swab in Amies	moderate growth	moderate growth
0004		Wound/ Tag Swab in Amies	moderate growth	moderate growth

Test Type: Culture for routine fish bacteria

Date Tested: 10/10/2022

Spec No	Spec ID	Spec Description	Routine fish bacterial culture	Photobacterium damselae subsp.damselae

Department of Primary Industries and Regional Development
GOVERNMENT OF WESTERN AUSTRALIA

DDLS - Animal Pathology Report

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Case Number: AS-22-2888-F-V1 **Final Report** **4/4**

Spec No	Spec ID	Spec Description	Routine fish bacterial culture	Photobacterium damselae subsp.damselae
0001		Wound Tissue	growth of Photobacterium damselae subsp damselae	scanty growth
0002		Wound Tissue	no significant isolates	-
0003		Wound/ Tag Swab in Amies	no significant isolates	-
0004		Wound/ Tag Swab in Amies	no significant isolates	-

Test Type: Culture for routine bacteria

Date Tested: 10/10/2022

Spec No	Spec ID	Spec Description	Routine culture
0001		Wound Tissue	growth
0002		Wound Tissue	no significant isolates
0003		Wound/ Tag Swab in Amies	no significant isolates
0004		Wound/ Tag Swab in Amies	no significant isolates

Yours faithfully

Dr Shane Besier
Veterinary Pathologist

Supplementary Material 2

Follow *this link* to view an animation of the movements of the tagged southern right whale in relation to AIS-tracked shipping in the region for the duration of this study from the Australian Antarctic Data Centre. This animation is available under a *Creative Commons Attribution 4.0 International License*.