Quantifying fishing activity targeting subsea pipelines by commercial trap fishers

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Abstract

Over 1,400 km of oil and gas pipeline infrastructure exists within the boundaries of the Pilbara Trap Managed Fishery (PTMF) operating on the North West Shelf of Australia. Some of this infrastructure has reached the end of its operational life and requires decommissioning. Location and speed data collected from 2008-2018 using vessel monitoring systems (VMS) onboard all trap fishing vessels (n = 3) operating in the PTMF were used to understand how fishing activity near pipelines has changed through time, and to identify the best predictive variables to explain hours spent fishing km^{-2} week^{-1}. The proportion of fishing activity within 200 m of a pipeline increased over the survey decade and averaged 4.2% across all years. Hours spent fishing km^{-2} within 200 m of any pipeline was found to be 8.0 hours km^{-2}, ~11.4 times more than that recorded in the rest of the entire PTMF (0.7 hours km^{-2}), and ~4.6 times more than the western portion of the PTMP (1.7 hours km^{-2}) where all pipeline infrastructure exists. Fishing activity within 1 km of pipelines increased after their installation, and hence time since installation was the best predictor of fishing. This study demonstrates that trap fishers in the PTMF allocate a small proportion of their time targeting pipeline infrastructure, with the area close to a pipeline experiencing a

greater magnitude of fishing than that elsewhere in the PTMF. As such, the results of this study provide decision makers with an understanding of the intrinsic value of this infrastructure to trap fishers.

Keywords

Decommissioning, North West Shelf, trap fisheries, VMS, management

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Introduction

The North West Shelf (NWS) in Australia has undergone an anthropogenic transformation involving the installation of thousands of kilometres of oil and gas (O&G) pipelines since gas reserves were discovered in the 1970's, as well as the installation of numerous platforms, floating structures, and seafloor facilities. Many of these pipelines have a small diameter, 12 in (305 mm) or less, and transport gas tens of kilometres, while others are up to 42 in (1066 mm) in diameter, connecting offshore fields to onshore processing facilities hundreds of kilometres away. Despite the prevalence of cyclones in the region, much of this pipeline infrastructure lies exposed on the seafloor, providing the opportunity for marine organisms to grow on it and mobile organisms to interact with it (McLean et al. 2017; Bond et al. 2018a). Similarly, commercial fishers can find the exposed pipelines using echo sounders, or locate many of them on marine charts. Much of the older infrastructure has reached, or will soon reach, the end of its commercial life, when production fields are no longer economically viable, and companies decide to abandon the field and decommission the infrastructure (Chandler et al. 2017), at which point understanding the value of offshore structures to fish and fisheries becomes highly relevant.

The United Nation Convention on the Law of the Sea (UNCLOS) holds relevance for offshore infrastructure in Australian waters, and although it does not specifically mention 'decommissioning', it refers to 'abandoned' platforms which shall be removed, taking into account 'generally accepted international standards' (Hamzah 2003; Chandler et al. 2017). The International Maritime Organisation requires an additional case-by-case evaluation of any structure proposed to remain on the seafloor (IMO 1989). The criteria used in this evaluation are far-reaching, but reference to 'new use or other reasonable justification' could encompass utilising these structures as artificial reefs, an approach adopted in the United States of America in its 'rigs-to-reefs' policy (Bureau of Safety and Environmental Enforcement 2013). Current Australian legislation requires complete removal (Commonwealth of Australia 2019) of pipelines unless a titleholder can demonstrate an alternative outcome that reduces the environmental impacts and risks to acceptable levels that are as low as reasonably practicable (ALARP; DIIS, 2018). This process needs to consider all financial, social, and environmental impacts, both positive and negative. There are, however, numerous gaps in our knowledge and understanding of the commercial fisheries that operate around O&G infrastructure, or if the distribution of fishing activity is influenced by the presence of this infrastructure.

The Department of Primary Industries and Regional Development (Government of Western Australia, DPIRD) manages the sustainability of the fisheries resources on the NWS. The state-managed commercial Pilbara

Demersal Scalefish Fisheries (PDSF) comprise the Pilbara Fish Trawl (Interim) Managed Fishery (PFTIMP), the Pilbara Trap Managed Fishery (PTMF), and the Pilbara Line Fishery, and are managed using a combination of control measures including, among others, annual effort allocations (time), gear limits, and spatial boundaries (Newman et al. 2018, 2019). The majority of O&G infrastructure is located in the western portion of the PDSF which primarily includes the area fished by the PTMF (Figure 1). The PTMF is a multi-species scalefish (teleost) fishery with management boundaries introduced in 1992, restricting operations to depths of approximately 30-200 m (see trap construction in Newman et al. 2011). In 2017, the PTMF yielded a total annual catch of 573 t, targeting highly valued species primarily belonging to Lutjanidae, Lethrinidae, and Epinephelidae (Newman et al. 2019). Three vessels operated in this trap fishery in 2017, yielding catches of scalefish with an estimated value in the range of $1-5 million (AUD) (Newman et al. 2019). Commercial fishing compliance within the spatial boundaries of the fishery, and the annual effort allocations, are monitored and enforced using a satellite-based vessel monitoring system (VMS). These compulsory, automatic location communicators are installed on all vessels operating in the fishery, and transmit their geographical position at intervals of minutes to hours, depending on location.

VMS data are used worldwide to understand the spatial and temporal extent of fishing activity. Since the initial publication of Rijnsdorp et al. (1998) using automated position records, the utility of VMS data to understand the distribution of fishing amongst natural habitats has become common, with results often linked with catch logbooks to calculate catch per unit effort (CPUE) for given spatial areas. Much of this work focuses on trawl vessels (see Lee et al., 2010), with few studies investigating fisheries that use traps (Mullowney and Dawe 2009; Charles et al. 2014; Feist et al. 2021), particularly those that target scalefish. Utilising VMS data from fisheries that use traps and other static gear presents challenges because realised effort depends on gear soak time rather than just the area of operation (Lee et al. 2010). Regardless of fishing method, the most common approach to define vessel activity uses vessel speed (Fock 2008; Gerritsen and Lordan 2011; Campbell et al. 2014; Enever et al. 2017). Some studies have included directionality when speed was not available, which resulted in a very small improvement for mobile fishing methods (Mills et al. 2007). Recently, machine learning techniques (Marzuki et al. 2018; Sunarmo et al. 2021), and convolutional neural networks (Kim and Lee 2020) have become an increasingly popular approach used to decipher VMS data, however they require pings at short, regular intervals for the best results. Rouse et al. (2018b) were the first to quantify fishing activity around artificial structures, namely pipelines in the North Sea. Further, Rouse et al. (2018b) calculated fishing effort (in hours) within 200 m of pipelines was 2.52% of the total effort, compared to 1.33% in an equivalent area 1 km away, which implied a modest aggregation of fishing around pipelines.

The objective of this study is to quantify the proportion of fishing activity associated with pipelines distributed on the NWS of north-western Australia. Furthermore, this study sought to understand how the distribution of fishing activity changes with pipeline depth, as well as how fishing activity changed over time after the installation of a pipeline. Results from this study will inform decommissioning and management decisions regarding pipelines that are at or near end-of-life utility, and provide fisheries managers with an improved understanding of trap fishing activity relative to pipelines within the PTMF.

Methods

Data sources

A spatial dataset of pipeline infrastructure, titled *WAPPIPE*, was obtained from the Department of Mines, Industry Regulation and Safety (2019), Western Australia, and identifies all major pipeline structures in the state. Data were provided as a shapefile with polygon features which were converted to lines located within the centre of each polygon feature. On request, the spatial boundaries of the Pilbara Trap Managed Fishery were provided by DPIRD in the form of a shapefile.

VMS data were provided by DPIRD for all vessels (n = 3) operating within the PTMF at any time from 1 January 2008 to 31 December 2018. Although VMS transponders have been installed on vessels in the PTMF since 2000, data transmitted after 2008 were more frequent. A single VMS record, hereafter referred to as a 'ping', is transmitted via satellite to an online server and includes time, speed, and vessel location. The time interval between pings can vary from 15 minutes to several hours, and VMS pings are more frequent when vessels are closer to the management boundaries of the PTMF. Vessel speed is calculated using the time and distance between the 'current' and 'previous' ping, hence it is not instantaneous.

VMS data analyses

All data validation and review was completed in R using tidyverse (Wickham 2016) and lubridate (Wickham and Grolemund 2011) packages. The packages sp (Pebesma and Bivand 2005), rgdal (Keitt et al. 2009), raster (Hijmans 2016), and geosphere (Hijmans 2017) were used for formatting spatial data for analyses.

VMS pings were sorted chronologically by boat and the elapsed time between each ping was calculated. A 'duration' value (D_p) was calculated for each ping; this value being the average time between the ping and its immediately prior and successive pings.

$$D_p = \frac{(T_p - T_{p-1}) + (T_{p+1} - T_p)}{2},$$

where D = duration (minutes), T = date and time, and p = any given ping. If (T_{p+1} - T_p) > 12 hours, T_{p+1} was removed from the equation to preclude assigning a disproportionate amount of time that would have followed a period of missing data. Typically, such instances occurred when a vessel exited the fishery and returned to port. Once duration was calculated, all pings outside the PTMF were removed and data were cleaned of erroneous pings (< 0.1%), including those without speed data, or where speeds greater than 20 knots were recorded (see Watson and Haynie, 2016), and others with no date or time. Occasionally, vessel position was erroneously distant from its nearest neighbour, resulting in illogical locations and these positions were subsequently removed from the dataset (1.98%).

The modal distribution of vessel speeds were used to determine if boats were either at anchor or drifting, fishing, or steaming (see Lee et al. 2010). Four modes were identified which included: 0-0.2 knots, defined as 'on anchor/drifting'; 0.2-5.0 knots, defined as 'fishing'; and two 'steaming' categories, with modes at approximately 8 knots and 11 knots. As such, fishing activity was presumed to occur when a vessel exhibited speeds of 0.2 to 5.0 knots. There are little empirical data available on fishing with static gear (here, fish traps) to help identify speeds during fishing, but this range of speeds is comparable with that determined by Lee et al. (2010) in the context of European fisheries that use pots, traps, uncovered pound nets, and fyke nets. Finally, we calculated the distance from each fishing ping to the closest pipeline.

The total number of fishing hours km^{-2} was calculated within three distances from a pipeline (200 m, 500 m, and 1,000 m) and compared with values across the entire PTMF, and an area less than 40 km from the nearest pipeline (defined as the western portion of the PTMF). Thirteen pipelines were installed in the period from 2008-2018. The installation date for each pipeline was defined as the date when the laying of the pipeline was completed, in the absence of more specific data. Hours fished km^{-2} was calculated as the duration of each ping divided by the area within 200 m, 500 m, and 1,000 m of any pipeline present at the time of that ping and summed per calendar year. Supplementary Table 1 summarises the length of pipeline and surface area at the end of each calendar year.

Analyses of fishing before and after pipeline installation

To investigate changes in targeted fishing before and after (BA) the installation of a pipeline, four pipelines were chosen for more detailed investigation (Table 1; Figure 1). Pings within 1 km (hereafter referred to as the '1 km BA zone'), and occurring after the installation date of the nearest pipeline, were identified as 'after' pings. Pings within the 1 km BA zone, and occurring before the nearest pipeline was installed, are identified as 'before' pings. Visitation to the 1 km BA zone was calculated as a proportion of days spent fishing before and after pipeline installation.

A smaller zone within 250 m of a pipeline (hereafter referred to as the '250 m BA zone') was also defined, and pings within this zone were used to investigate how the fine scale attributes of a pipeline may influence fishing activity. The 250 m BA zone of each pipeline was split into 5 km long sections along the length of the pipeline, and the average depth of each section was calculated using General Bathymetric Chart of the Oceans (GEBCO) bathymetry data. Total hours fished was summed per 5 km section for each week of available data before and after installation.

The influence of each pipeline, its depth, and the number of weeks since installation, on the hours spent fishing km^{-2} week^{-1} was investigated using generalised additive models (GAMs). All possible combinations of predictor variables were considered, with the maximum number of predictor variables set to three (Fisher et al. 2018). Pipeline sections were considered sample units and hours spent fishing km^{-2} week^{-1} the response variable. *Depth* and *Week* were continuous predictors and *Pipeline* was a fixed factor. Each 5 km section was given a unique identification code (*Section ID*) which was included as a null term with random effect. Interrogation of raw data revealed differences in the distribution of fishing activity between vessels, but to maintain anonymity and confidentiality it was only used as a null term with random effect. Models were fitted with a log-link function and Tweedie error distribution (Tweedie 1984), which has an advantage over delta-type two-step models by handling zero data in a unified way. Model selection was based on Akaike Information Criterion (AIC) and AIC weights (wAIC). The best model was selected as that model that was within two AIC units of the top model and revealed the least number of predictors, or was the most parsimonious. See Fisher et al. (2018) for more information on this approach and model selection.

Results

Fishing in the PTMF

A total of 110,250 VMS pings were extracted from all fishing vessels (n = 3) operating within the PTMF over the eleven years from 2008-2018, of which 64,572 (60.0%) were deemed as 'fishing' (Figure 2) and 2,570 (2.3%) were discarded as erroneous. A total of 809 fishing trips were defined, and the average trip length was 5.1 days

(± 0.07). Fishing occurred year-round and 32.9% of fishing activity occurred in water depths of 30-60 m, 46.2% in 60-90 m, and 21.9 % in > 90 m (Supplementary Figure 1). Although fishing was recorded at all times of the day, 85.6% occurred between 0400 and 1900 hours (Figure 3). Total hours spent fishing varied among years, with a conspicuous reduction in hours and days spent fishing in 2014 that coincided with a change in the ownership of fishing licenses. Otherwise, the hours spent fishing were relatively consistent among years, ranging from 5,368-6,703 hours. A similar trend was exhibited for the total number of days at sea, ranging from 271-324 $year^{-1}$ (excluding 2014), with the highest number of days recorded in 2009, 2010, and 2015 (i.e. > 320 days $year^{-1}$; Figure 5).

A total of 1,449 km of pipeline were located within the PTMF as of 31 December 2018. The sum of hours spent fishing from all vessels across all years decreased with increasing distance from any pipeline, and peaked within 500 m of any pipeline, most notably within 200-250 m of any pipeline (Figure 4). The proportion of area located within 200 m, 500 m, and 1,000 m of all pipelines represents 0.58%, 2.14%, and 2.76% of the entire PTMF respectively and 1.4%, 3.46%, and 6.75% of the western PTMF respectively (Supplementary Table 1). Hours and days spent fishing within 200 m of a pipeline peaked in 2016 at 435 hours and 87 days (Figure 5). The highest proportion of fishing activity near any pipeline also occurred in 2016 (7.7% of hours spent fishing within 200 m, 11.1 % within 500 m, and 14.8 % within 1 km; Table 2), however 2011 had the highest concentration of fishing km^{-2} $year^{-1}$ (1.0 hours km^{-2} $year^{-1}$ within 200 m of any pipeline; Table 3). Over the eleven year period a total of 4.8% of hours spent fishing occurred within 200 m of a pipeline (Table 2), which equates to 7.8 hours km^{-2}, 11.4 times more than for the entire PTMF, and 4.6 times more than for the western PTMF (Table 3).

Fishing activity before and after pipeline installation

Average hours spent fishing per week within the 1 km BA zone was variable among pipelines (Figure 6). Pluto and Wheatstone had the highest average hours spent fishing $week^{-1}$ before installation of the pipeline, followed by Jansz (Figure 6), whereas GWF-1 had the lowest average number of hours spent fishing $week^{-1}$ prior to installation (Table 1). After installation, the average hours spent fishing $week^{-1}$ increased most notably at Wheatstone, but also increased at Pluto and GWF-1. The distribution of fishing activity within the 1 km BA zone of Jansz moved closer to the pipeline (< 350 m; Figure 6) after installation. The frequency distribution of hours spent fishing in the vicinity of the Wheatstone and Pluto pipelines increased notably within 150 m and decreased with increasing distance from the pipeline (Figure 6). Plots of the smoothed conditional means of hours spent fishing $week^{-1}$ using GAMS show an increase in fishing within the vicinity of all four pipelines over time (Figure 7). Hours spent fishing $week^{-1}$ at Pluto begins to decrease after approximately 240 weeks, and reduces at Wheatstone after approximately 90 weeks. Jansz and GWF-1 have been installed for the same length of time (6-7 years), and hours spent fishing within 1 km of either pipeline continues to increase with time (Figure 7).

The proportion of days any fishing vessel fished within the 1 km BA zone (visitation) was higher before the installation of Jansz, Pluto, and Wheatstone, but not GWF-1 (Table 4). Despite this, average hours spent fishing day^{-1} increased at all pipelines (Table 4). The average hours spent fishing day^{-1} increased by ~2.4 times at GWF-1, and visitation increased by 0.68%. Most notably, average hours spent fishing day^{-1} at Wheatstone increased by ~2.3 times, despite visitation decreasing by 2.5%.

The best model to predict the hours spent fishing km^{-2} week^{-1} for all fishers within 250 m of the four pipelines included one predictor; *Week* (Table 5; note R^2 values were low due to the high number of zero samples or weeks that had no fishing). Predicted hours spent fishing km^{-2} week^{-1} decreased before installation, then increased after installation to a level higher than the pre-install period (Figure 8).

Discussion

Trap fishers in the PTMF allocate a small proportion (4.8%) of their total hours fishing to targeting pipelines, but considering the small footprint of the pipelines, the concentration of fishing near a pipeline (within 200 m) is ~11.4 times greater km^{-2} than the rest of the PTMF. However, noting that the eastern part of the PTMF is more remote due to the distances required to travel from the main access ports (primarily Point Samson (near Karratha) and secondarily Exmouth), it is more applicable to compare targeting with the western portion of the PTMF where all pipeline infrastructure exists, which is ~4.6 times greater km^{-2}. This proportion is almost twice the amount of time trawl fishers allocate to fishing along pipelines in the North Sea (2.5%; Rouse et al. 2018b), which is likely due to two reasons: static *vs* active fishing methods, and the attributes of the pipeline structures themselves. Trawl fishers operating around O&G pipelines in the North Sea risk snagging their gear which can result in financial loss, vessel abandonment, and even injury/fatality (Rouse et al. 2018a). In comparison, trap fishers in the PTMF use smaller static gear which reduces their risk of snagging. Also, given traps are a static gear, they can be retrieved from a range of direction angles facilitated by the capacity to release lines and manoeuvre vessels to different retrieval points, not possible with snagged trawl vessels. Moreover, the financial consequence of losing one snagged trap is much less than losing an entire trawl net. Of particular concern to trawl fishers in the North Sea are free spanning pipelines, which can snag trawl doors and clump weights (de Groot 1982; Rouse et al. 2018a). Concrete mattresses are used extensively throughout the UK to mitigate against free spanning pipelines (Oil & Gas UK 2013). Draped over pipelines, they provide protection and stability, rectify free spans, and reduce the risk of trawlers becoming snagged. Although, concrete mattresses may reduce the risk of trawlers becoming snagged on free spanning pipelines, their application may reduce the artificial reef effect of a pipeline. For example, on the NWS, sections of free spanning pipeline have a higher abundance of commercial fish compared to pipelines that are partially buried (McLean et al. 2017; Bond et al. 2018a), and it may be these sections of pipeline that trap fishers in the PTMF are targeting.

Investigating changes to fishing activity after pipelines are installed provided an insight into fisher behaviour, and how they value pipelines as a suitable and sometimes preferred fishing ground. Prior to installation, fishers visited the 1 km BA zone more often than after installation, but the total hours spent fishing increased after installation (Table 3). These results suggest fishers have amassed some fishing activity, specifically targeting the pipeline, and not returning to fish there as often as they would have fished before the pipeline was installed. It may also suggest they fish longer on a pipeline because the economic value of the localised catches is maintained for longer periods. This behaviour reflects a form of self-governance and rotational spatial management, a practise formalised in fisheries that target single, less mobile species such as scallops (Hart 2002), abalone (Sluczanowski 1984), or sea cucumbers (Lowden 2005; Hart et al. 2019). Self-governed fisheries are those where participants are responsible for important aspects of management decision-making (FAO 2008). Although the PTMF is not formally self-governed, licence holders generally optimise the economic viability of their catch, by withholding their return to a pipeline until they perceive the fish numbers have been replenished. Self-managing a fishery in such a way could be effective as a consequence of the low number of commercial vessels and the extensive area of the PTMF (86,009 km^2). The chance that two fishers target the same section of pipeline in the same week, month or quarter year, is low. We suggest future research could investigate the visitation intervals of fishers to sections of pipeline and how this influences catch composition and catch rates.

The concentration of fishing within 200 m of the pipelines (after installation), suggests pipelines are a favourable fishing area compared to adjacent habitats. These results might reflect artificial reef effects of enhanced productivity or fish aggregation (Claisse et al. 2014; Smith et al. 2016). Bond et al. (2018b) showed that the value of fish was ~8.6 times higher on the Echo Yodel pipeline - located within the PTMF in 135 m water depth - compared to the adjacent seafloor. Similarly, Bond et al. (2018b) found the value of fish to be ~2-3 times higher on the Griffin pipeline, which is also located within the PTMF. Differences in the catch value on and off-pipeline reported by Bond et al. (2018b, 2018c) were attributed to the higher abundance of valuable species, including *Pristipomoides multidens*, *Epinephelus multinotatus*, *Lutjanus sebae*, *L. malabaricus*, and *L. russellii*. Two of these species, *L. sebae* and *E. multinotatus*, were in the top three species landed by commercial fisheries in the Pilbara in 2017 (Newman et al. 2019). These commercially valuable species are commonly associated with complex epibenthic invertebrate assemblages (Sainsbury et al. 1997; Newman 2002; Newman and Dunk 2003; Speare and Stowar 2007; Fitzpatrick et al. 2012; McLean et al. 2017), and are known to persist on pipelines in the PTMF (McLean et al. 2017; Bond et al. 2018a). Interrogation of VMS data show fishers target pipelines like Griffin and Echo Yodel most likely because they provide structurally complex habitat favourable for commercially valuable species. Unfortunately, both these pipelines were installed prior to 2008, therefore it is not known if they were installed in an already favourable fishing habitat.

The Griffin and Echo Yodel pipelines are both 12-nch diameter flowlines, 3-4 times smaller in diameter than the Wheatstone, Pluto, and Jansz trunklines investigated in this study. Although *Pipeline* (representing pipeline diameter and other unique attributes) was not included in the best model selections, it may influence fishing activity. Rouse et al. (2018b) reported the highest intensity of fishing activity in their study occurred around larger trunklines, similar to Wheatstone and Pluto. Should a similar relationship exist in the PTMF, the catch values reported by Bond et al. (2018b, 2018c) for smaller pipelines may not be indicative of all pipelines on the NWS. It is difficult to elucidate if the catch on 12-inch diameter pipelines will be more because they are targeted less often, or less because the artificial reef effects are influenced by the size of a structure (Bohnsack et al. 1994; Baine 2001).

Predicted hours spent fishing km^{-2} $week^{-1}$ from the GAM analysis decreased immediately prior to the date of installation (week = 0). This response is likely due to the enforced implementation of an exclusion zone for non-contracted vessels while the pipeline is being laid. Pluto and Wheatstone are both over 180 km in length and took over a year to install, therefore we must treat the exact 'installation date' with caution. Considering a higher rate of fishing was recorded around all pipelines, it is likely that a greater disparity exits before and after installation than is reported herein. This might explain an increase in average hours spent fishing per week before the week of installation (week = 0). When the final sections of Pluto and Wheatstone were being laid, the start of both pipelines had already been installed for many months, during which time fish would potentially aggregate and fishers were free to target them. Flexibility in the installation date can be accounted for in the model, however the exact date that each kilometre of pipeline was installed is unknown. Furthermore, calculating hours spent fishing from speed data could be an underestimation if vessels travel quickly between setting and hauling traps that are spaced far apart, or alternatively, it could be an overestimation if vessels travel below 5 knots without traps in the water. The accuracy of our data on fishing activity could be improved if trap fishers provided corresponding logbook records. Our methods also assume a binary form of effort, i.e. fishing or not-fishing. Estimates of fishing effort could be improved if information on the number of traps used was known.

Fishing activity within 250 m of a pipeline increased after installation, and for the five years post installation. The continued increase in fishing activity years after installation may reflect a fisher's response to a more favourable fishing area as the pipeline matures. McLean et al. (2017) described the evolution of marine growth on two pipelines located on the NWS over a seven-year period, recording an increase in the percent cover of structurally complex invertebrate organisms. This coincided with an increase in the abundance of some commercially targeted and valuable fish species, including *L. malabaricus* and *Glaucosoma buergeri*. Models of fish-habitat relationships at the Echo Yodel pipeline show similar trends; increased percent cover of sclerobionts coincided with an increase in the abundance of commercial species (*E. areolatus* and *L. malabaricus*).

The decrease in hours spent fishing km^{-2} $week^{-1}$ at the tail of the GAM has increased error, a result of a lack of data points and the extremes of the model. Despite increased error, this may reflect a true relationship that fishers have with mature pipelines. Traditional concepts suggest pipelines go through processes of scour, sagging, and backfilling and eventually self-bury at free-spans or for the entire pipeline (Sumer and Fredsøe 2002). Should this happen on the NWS, pipeline spans may reduce in length and height, and the cover of structurally complex marine growth may decrease, consequently impacting the abundance and species diversity of fish (McLean et al. 2017; Bond et al. 2018a). However, Leckie et al. (2015) described the mature state of a pipeline on the NWS as 'self-lowering' with a pseudo-static profile regularly alternating between buried and spanning. Uncertainty still exists around the long-term self-burial of pipelines. If an end-point is partial or full self-burial, any positive affect pipelines have on the PTMF currently, will likely be reduced in the future. Further work should disentangle interactions with pipeline maturity, self-burial, and the cover of sclerobiotic invertebrates and associated fish abundance, and species diversity. Comparing catch data on- and off-pipelines will add to our current knowledge of fish interacting with pipelines and how this compares to favourable fishing areas off-pipeline. The aggregation effect of structures is well-known, and a reason why fishers target pipelines, however, it is still unclear if pipelines attract a distinct assemblage of fish compared to surrounding areas without infrastructure. Furthermore, we know little of the true productive value of pipelines to commercial fisheries.

Implications for the decommissioning of pipelines

To determine the best decommissioning strategy for each pipeline, operators will compare all options, including decommissioning *in-situ*, and provide the results of a comparative assessment to the regulator who makes the final decision (Department of Industry, Innovation and Science 2018). Until now, operators and decisions makers have had limited resources to understand fishing activities that occur near their infrastructure. This study provides the most detailed description of commercial trap fishing around O&G pipelines on the NWS, and contributes valuable information for comparative assessments. It is clear that fishers in the PTMF target pipelines, and they fish them more often as the pipeline ages. Our understanding of how fishing activity has changed through time for pipelines > 10 years old (including those soon to be decommissioned) is limited, but as information on the extent of their burial becomes available, more informed estimates of fishing activity can be developed. Furthermore, although pipeline age was the best predictor for average hours spent fishing km^{-2} $week^{-1}$ (indicated by the variable *Week*), our results suggest each pipeline is unique, is impacted by varying amounts of fishing activity, and has seen variable differences in fishing intensity pre- and post-installation. This is likely a reflection of a complex mosaic of factors including, but not limited to, the location, direction, and depth in which the pipeline is situated. As a result, decision makers should continue to consider each pipeline on a case-by-case basis, and consult DPIRD and commercial fishers to understand the fishing activity relevant to the specific pipeline in question. Such case-by-case considerations are fully aligned with the legislative framework for decommissioning decision making. Nevertheless, the results of this study provide decision makers with an understanding of the unique and intrinsic value of pipeline infrastructure to trap fishers, and the likely value of these structures to fishers more generally.

Considering the higher concentration of fishing activity within 200 m of a pipeline and changes in trap fishing activity before and after installation, it is difficult to predict what would happen if a pipeline were to be removed on decommissioning. Will fishers revert to historical non-decommissioned pipeline fishing areas? Will they re-allocate their time to another pipeline? Our results show an aggregation of fishing activity to a pipeline post installation, most likely because the fish are attracted there. Should a pipeline such as Wheatstone be removed, we might assume that fish would return to the surrounding area, but how will fishers respond? Developing models of fisher behaviour could be used to predict the distribution of fishing activity under different decommissioning scenarios. Such models would benefit from fine-scale catch data. For example, fishers may target a pipeline to catch a particular species that are otherwise difficult to catch in some areas or are in low abundance in areas away from pipelines. Consequently, if this pipeline is removed, fishers may be more likely to re-allocate their time to another pipeline rather than natural habitat.

Here, we quantify an increase in fishing activity near pipelines after they are installed and demonstrate increased fishing activity as the pipelines ages. This response is likely due to the aggregation effect – perceived or real – that artificial structures can generate. However, before we understand the true value of pipelines to fisheries like the PTMF, we must understand how the initial aggregation of fish translates into the production of new fish biomass, and how much of that new biomass is available for harvest and is subsequently caught. For a fishery to genuinely benefit with both an increase in catch and an increase in standing stock, any concentration of fishing activity to a pipeline must not result in more fish biomass being extracted than is produced. Coupling data from this study and catch data at a fine spatial scale will play an important role in attempting to assess fishing mortality on- and off-infrastructure, which can be used to calculate production rates. This information is critical for decision-makers in order to determine the best practical decommissioning approach.

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Tables

Table 1: Specifications of pipelines installed during the VMS time series selected to investigate before and after installation impacts on fishing activity. *Jansz production pipeline is 30 in for the first ~20 km when it enters the fishery, before changing to 34 in. Date installed is the oldest date known when the entire pipeline was installed, representing a conservative approach.

Pipeline	Install date used	Length (km)	Depth range	Diameter (in)
Great Western Flank – 1 (GWF-1)	30/04/2014	15.6	110-125	12
Jansz	31/10/2013	72.3	23-263	30-34*
Pluto	31/12/2009	186.4	27-241	36
Wheatstone	1/12/2015	197.3	59-127	44

Table 2: Proportion of fishing hours located within 200 m, 500 m, and 1 km from a pipeline from 2008 - 2018.

Year	% hours spent fishing within		
	200 m from pipeline	500 m from pipeline	1 km from pipeline
2008	2.5	3.2	4.3
2009	1.9	2.6	3.5
2010	3.9	5.4	7.1
2011	5.7	7.5	10.7
2012	5.4	7.1	10.3
2013	4.7	6.7	9.5
2014	4.4	6.9	9.5
2015	3.9	5.9	8.1
2016	7.7	11.1	14.8
2017	5.0	6.9	9.6
2018	5.6	8.1	11.0
All years	**4.8**	**6.9**	**9.7**

Table 3: Number of hours spent fishing km^{-2} located within and beyond 200 m, 500 m, and 1 km from a pipeline from 2008 - 2018 and summed across all years. Values beyond the pipeline are calculated across the entire PTMF and an area within 40 km of the nearest pipeline representing the western portion of the PTMP.

Year	**Within 200 m of a pipeline**	**Beyond 200 m of a pipeline**		**Within 500 m of a pipeline**	**Beyond 500 m of a pipeline**		**Within 1000 m of a pipeline**	**Beyond 1000 m of a pipeline**	
		Entire PTMF	Within 40 km of nearest pipeline		Entire PTMF	Within 40 km of nearest pipeline		Entire PTMF	Within 40 km of nearest pipeline
2008	0.66	0.06	0.15	0.35	0.06	0.16	0.23	0.06	0.16
2009	0.52	0.07	0.18	0.29	0.07	0.18	0.20	0.07	0.18
2010	0.81	0.07	0.17	0.45	0.07	0.17	0.31	0.07	0.17
2011	1.03	0.06	0.15	0.55	0.06	0.15	0.40	0.06	0.15
2012	0.97	0.06	0.16	0.54	0.06	0.16	0.38	0.06	0.16
2013	0.76	0.06	0.15	0.44	0.06	0.15	0.32	0.06	0.14
2014	0.40	0.04	0.10	0.25	0.04	0.10	0.18	0.04	0.10
2015	0.62	0.07	0.18	0.38	0.07	0.18	0.27	0.07	0.18
2016	0.89	0.06	0.15	0.52	0.06	0.15	0.36	0.06	0.15
2017	0.57	0.06	0.15	0.33	0.06	0.15	0.23	0.06	0.15
2018	0.76	0.07	0.18	0.46	0.07	0.18	0.32	0.07	0.18
Sum of all years	**7.98**	**0.70**	**1.73**	**4.56**	**0.69**	**1.72**	**3.18**	**0.68**	**1.72**

Table 4: Number of unique days spent fishing (all vessels) and average time spent fishing per day within 1 km of four pipelines, before and after their installation. All values are calculated for the entire length of each pipeline.

Pipeline	**Visitation %**		**Δ visitation %**	**Average time spent fishing (hrs)**		**Δ average daily effort**
	Before	**After**		**Before**	**After**	
GWF-1	0.62	1.30	0.68	2.01	4.84	↑ x 2.41
Jansz	3.43	1.41	-2.02	2.95	4.83	↑ x 1.64
Pluto	9.51	8.05	-1.46	3.38	5.01	↑ x 1.48
Wheatstone	8.53	6.03	-2.50	2.67	6.05	↑ x 2.27

Table 5: Best generalised additive models (GAMs) for predicting hours spent fishing km^{-2} week^{-1} for all vessels within 250 m of a pipeline. eDF, estimated degrees of freedom; AIC, Akaike Information Criterion; wAIC, Akaike Information Criterion weights; R^2, Coefficient of Determination. Model selection was based on the most parsimonious model – i.e. having the lowest AIC value.

Best Model	eDF	AIC	wAIC	R^2
Week	75.89	92260.9	0.836	0.0048
Depth	68.75	92264.43	0.143	0.00344
Pipeline	72.00	92269.54	0.011	0.00437
null	72.01	92269.66	0.011	0.00439

Figures

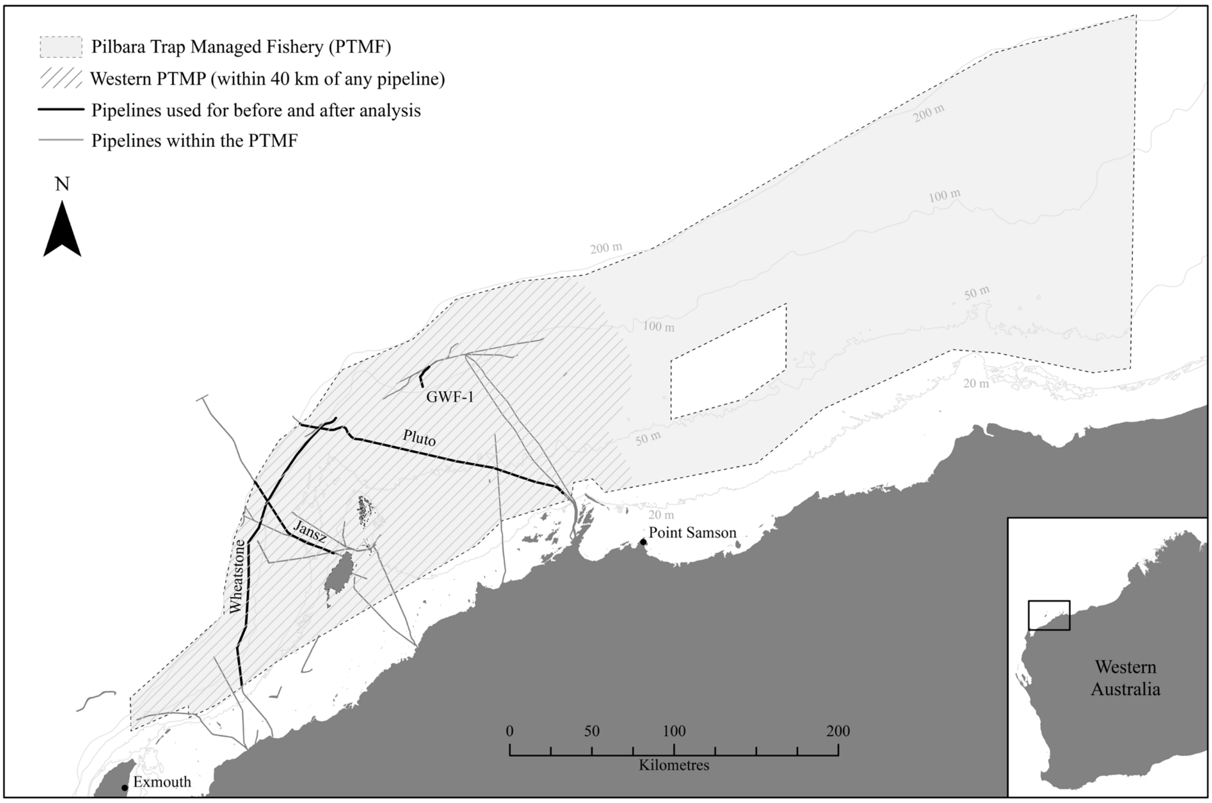

Figure 1: Location of pipelines within the Pilbara Trap Managed Fishery. Pipelines shown as black lines were installed at varying times throughout the study period and used to investigate changes in targeted fishing before and after the installation of a pipeline. Other pipelines in the PTMF are shown as dark grey lines. The Western PTMP is the area within 40 km of any pipeline and displayed as diagonal grey hatching. Main access ports shown as a black dot and include primarily Point Samson and secondarily Exmouth.

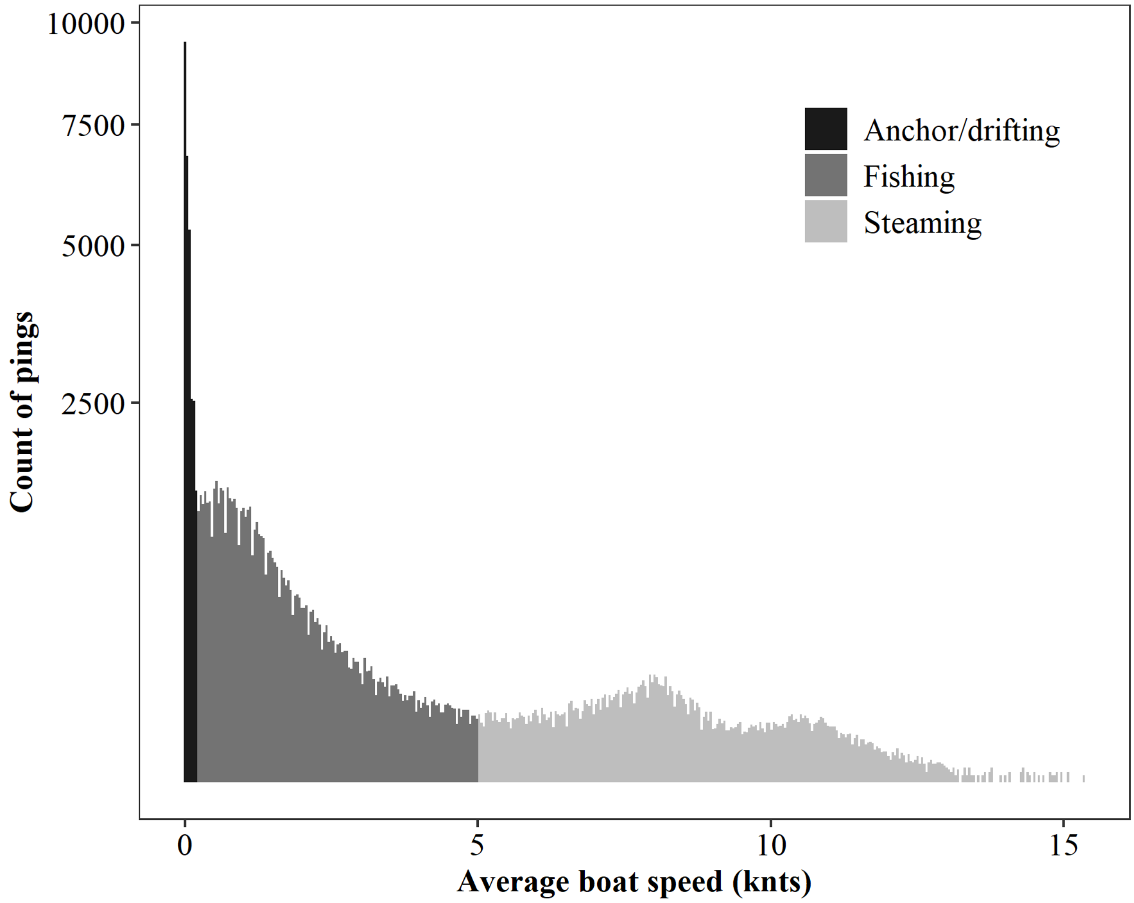

Figure 2: Frequency distribution of the average speed (knots) of all vessels in the Pilbara Trap Managed Fishery from 2008-2018, assumed to be at anchor/drifting (black bars), fishing (dark grey bars) or steaming (light grey bars). Note the y-axis is presented on a square root scale.

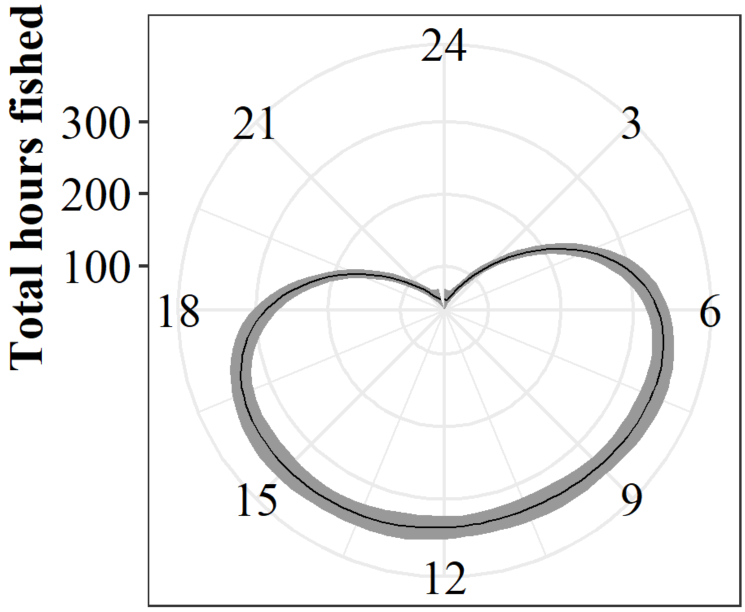

Figure 3: General additive model (solid line) ±95% confidence limits (grey shade) fitted to the relationship between the total hours spent fishing and the time of day for all vessels in the Pilbara Trap Managed Fishery from 2008 - 2018.

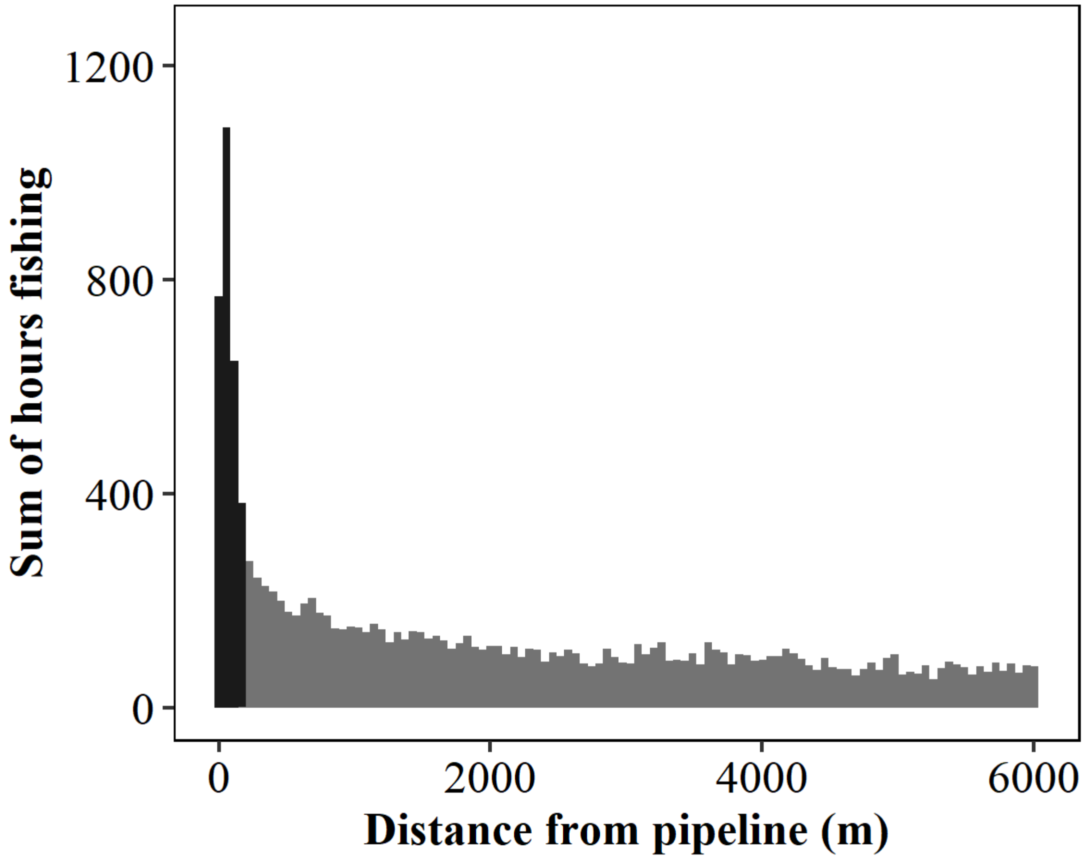

Figure 4: Sum of hours spent fishing in close proximity to (black bars, < 200 m) or with increasing distance from any pipeline (grey bars, > 200 m) for all vessels in the Pilbara Trap Managed Fishery pooled from 2008 - 2018.

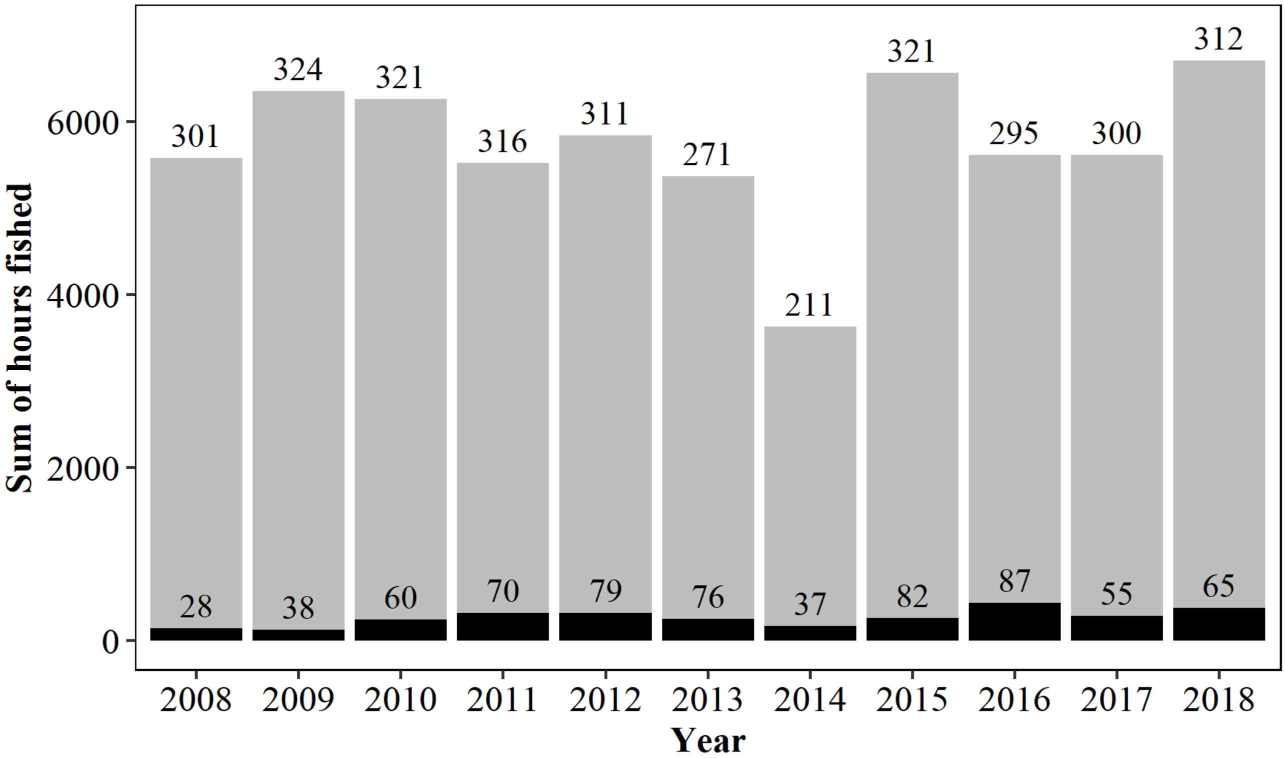

Figure 5: Total hours spent fishing per year by the Pilbara Trap Managed Fishery that were within (black bars) or greater than (grey bars) 200 m from any pipeline. Numbers indicate the total days fished per year overall (above grey bars) and those within 200 m of a pipeline (above black bars).

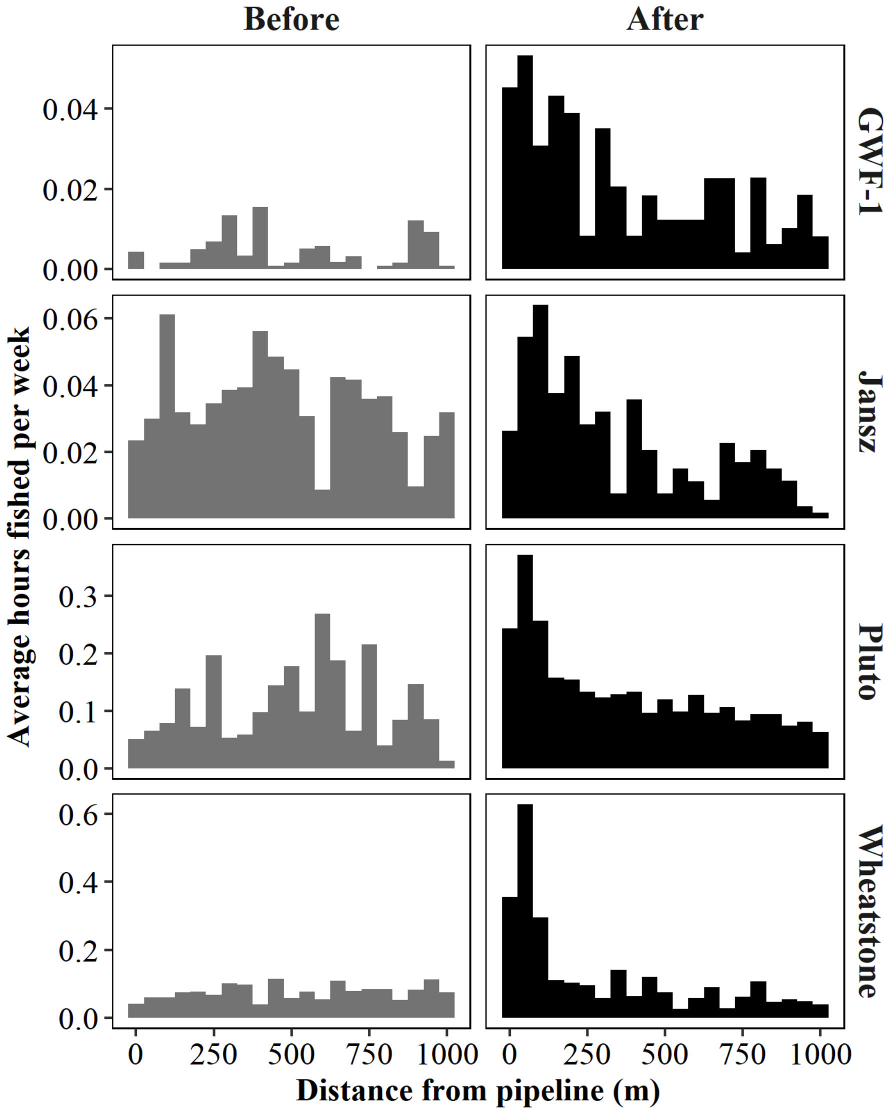

Figure 6: Average hours spent fishing per week for all vessels from the Pilbara Trap Managed Fishery within zero to one kilometre from four different pipelines (i.e. GWF-1, Jansz, Pluto, and Wheatstone) before (grey bars) and after (black bars) they were installed.

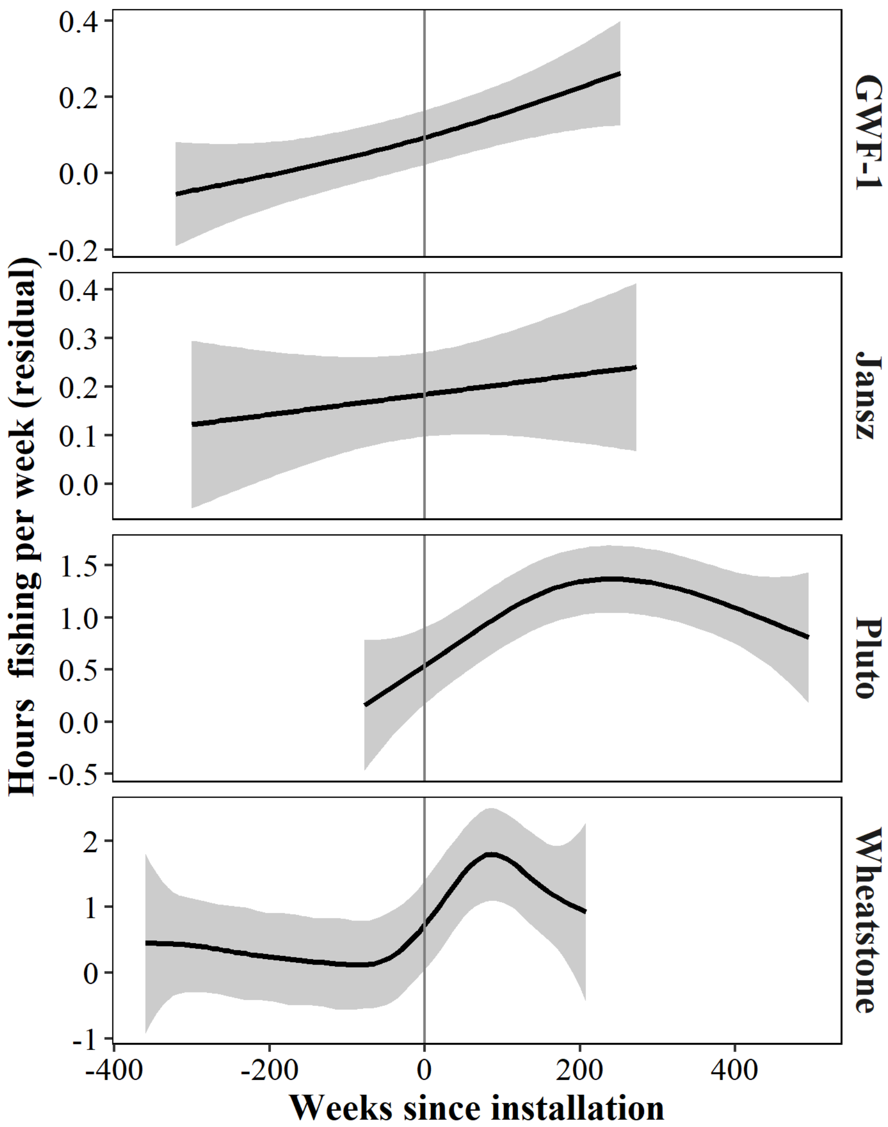

Figure 7: Hours spent fishing per week (residuals) within 1 km of GWF-1, Jansz, Pluto and Wheatstone pipelines pre and post-installation. Black lines represent smoothed conditional means using GAM and the shaded area is ±2 × SE of the estimate. Plot position is dependent on the date each pipeline was installed and grey vertical line represents the date when the laying was complete (Week = 0).

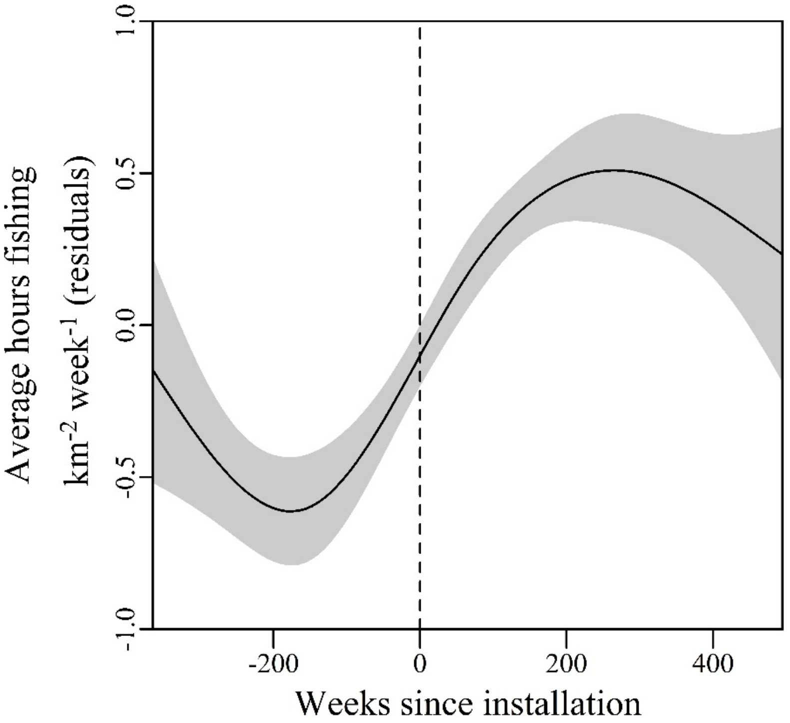

Figure 8: Average hours spent fishing km^{-2} week^{-1} (residuals) for all vessels within 250 m of all four pipelines combined (i.e. GWF-1, Jansz, Pluto, and Wheatstone pipelines), predicted using week since installation, the single predictor in the top model. The model is fitted using GAM. The solid line represents the predicted smoothing curve and the shaded area is ±2 × SE of the estimate. Dashed vertical line represents the time of installation of all pipelines.