Integrating systematic and citizen science surveys for monitoring and management of near-threatened Indo-Pacific bottlenose dolphins in the Swan Canning Riverpark, Western Australia

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Executive Summary

Despite recognition of the need for ongoing dolphin conservation, decision makers are often faced with limited knowledge to inform management. This is primarily due to little or no resources being available to conduct scientific surveys and the high cost of surveying relatively large areas with sufficient resolution to detect biological trends. Government departments charged with management often also have the responsibility of educating the public about relevant regulations and enforcing them. Increasingly, citizen science programs are being implemented as a cost-effective solution for collecting research data to inform management and simultaneously educate the public. Advantages of citizen science is its ability, in many instances, to cover a larger geographic area many times greater than scientific surveys can due to its relative cost-effectiveness and potential to use an *army* of observers to conduct surveys. Disadvantages are biases introduced by opportunistic reporting and error born from variability in knowledge and experience of observers. Advantages of scientific surveys are tighter control over the experimental design, greater accuracy due to highly experienced and trained observers, and increased complexity of data collected. Scientific experimental designs such as systematic surveys that reduce survey bias, however, are often limited in the number and spatial extent of surveys due to their higher associated costs.

The aim of this study was to undertake a comparative analysis of spatial and temporal patterns of Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) sighted in the Swan Canning Riverpark (Western Australia) collected from two survey modes (citizen science and scientific surveys); and thereby inform management directly and plan for ongoing future monitoring. Indo-Pacific bottlenose dolphins are listed as near threatened by the International Union for Conservation of Nature (IUCN). Around ~20 dolphins make up the community of year-round residents of the Swan Canning Riverpark. Located within Western Australia's capital city of Perth, the Riverpark is a highly urbanised environment with ongoing and changing pressures that place the dolphin community at high vulnerability to human impacts. The citizen science program called *Dolphin Watch* was established in 2009, shortly after the sudden death of six of the resident dolphins in the Swan Canning Riverpark, as a partnership between the Western Australian Department of Biodiversity, Conservation and Attractions (DBCA) and Edith Cowan and Murdoch universities. *Dolphin Watch* is an integral part of the provision of education and awareness of estuary health and threats to dolphin conservation.

This study used a dataset generated over 10 years by *Dolphin Watch*. With this decadal milestone reached, a substantial, long-term dataset has become available from which to evaluate sighting patterns for a long-lived species. The specific objectives of this study were to: 1) evaluate the spatial and temporal extent and resolution of data collected during citizen science and scientific vessel surveys, and 2) compare spatial and temporal patterns in dolphin groups sighted resulting from statistical models using data collected by each of the two survey platforms and their data combined. For analyses that included *Dolphin Watch* data, we also compared the reliability of models using opportunistic observations (where a survey was reported only when dolphins were observed; called presence-only data) and more formal surveys, where reported, when dolphins were present as well as when they were absent (called presence-absence data). Based on our findings, we provide a range of recommendations for the next decade of the *Dolphin Watch* program and suggest a framework for their joint integration into research and conservation management programs.

The results of this study demonstrated that the combination of citizen science and scientific vessel-based surveys provided a more complete and robust representation of dolphin ecology in the Swan Canning Riverpark than a single survey platform did. Dolphin Watch surveys defined the full minimum extent of dolphin's ranging, from the Inner Harbour up to the upper reaches of the Swan and Canning

Rivers. Combined *Dolphin Watch* and Scientific vessel surveys identified shifts in spatial patterns in expected probability of sighting dolphin groups in the lower-mid reaches of the estuary, in the Swan River, and in the Canning River; with higher probability of sightings expected in downstream areas of these locations in the autumn and winter months and higher probability expected in upstream areas in the spring and summer months. While this study identifies seasonal and spatial predictors of expected probabilities in sighting dolphin groups, these represent a component of a range of possible drivers that influence locations of dolphin occupancy in different seasons. It is known that there are links between dolphin occupancy and abiotic (e.g., water quality) and biotic (e.g., fish, crustaceans) conditions in the Riverpark, although the exact nature of these is not yet clear. Identifying effects such as abundance and distribution of dolphins' prey as a driver for where dolphins spend time is a relatively intuitive exercise, while identifying direct effects of abiotic conditions may not be so clear. Despite this, a recent study documented dolphin mortality events due to 'freshwater skin disease' at a time of a marked drop in salinity due to rainfall in the estuary. It is not clear, however, whether there may be a direct link in dolphin habitat occupancy and freshwater input into the system. Scientific vessel surveys identified specific locations where there were relatively high numbers of group sightings. These locations included areas around the Fremantle bridges, the Narrows Bridge and the entrance of the Canning River, and locations along the river that likely have structure in which prey may occur in greater densities (yacht clubs). Notably, at least one of these locations, the Narrows Bridge, is a popular fishing spot. High dolphin occupancy where there is significant discarded fishing line entanglement risk places these locations as high priority for targeted beach clean-ups and promoting responsible fishing practices (particularly with the ongoing history of fishing line entanglement-related dolphin mortalities in the Riverpark). We recommend that as part of ensuring the viability of the Swan Canning Riverpark dolphin community into the future, locations of seasonal dolphin 'hotspots' identified in this study be overlayed with mapped threats and pressures and their risks within the Riverpark. By evaluating their overlap, the nature of threats and pressures at high-risk locations can be identified, and management and conservation actions (e.g., adjustments to human usage such as speed limits; compliance efforts; and initiatives such as additional *Reel it in* fishing line bins, beach clean-ups, and education campaigns) that will reduce the risk of dolphins to mortality and improve the dolphin community's viability can be identified.

Recommendations for ongoing future *Dolphin Watch* monitoring in the Swan Canning Riverpark, based on findings from this study, include the following:

- **Continue to monitor broad ranging patterns of dolphins** as an integral part of ongoing long-term dolphin management in the Swan Canning Riverpark environment.
- **Make presence-absence surveying a standard** for trained *Dolphin Watch* citizen scientists. We suggest that with the use of a smartphone App, it will be possible to make conducting these more formal surveys easier and more accessible to *Dolphin Watch* citizen scientists.
- **Obtain high resolution *Dolphin Watch* spatial data.** With a smartphone App that allows tracking, high resolution spatial information will be possible.
- **Incentivise increased spatial coverage of *Dolphin Watch* effort**.
- **Continue Scientific vessel surveys** to gain insight into additional attributes within the dolphin community, and to provide complementary knowledge and a validation tool for the citizen science program.

More generally, we recommend that a framework for integrating citizen science and traditional scientific surveys include:

- The implementation of both survey modes at the beginning of a program for validation of citizen science surveys and identification of limitations and complementarity, and
- Where a citizen science program cannot provide a full representation of the attributes of a system being studied, but improves on what is achievable otherwise, that the two survey modes be undertaken in tandem to address management needs.

Only through such an approach can meaningful monitoring be sustained over many decades that would otherwise be too expensive to undertake. As a result, detection of serious changes in the environment and prediction of future scenarios, such as those anticipated with a changing climate, can allow effective action to be taken.

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1 Introduction

Decision makers are often faced with limited knowledge to inform management actions and regulation, despite the need for ongoing conservation. For many species such as dolphins, this is primarily due to little or no funding being available to conduct Scientific vessel surveys and the high cost of surveying relatively large areas with sufficient temporal resolution to track biological trends. To compound the problem of making management decisions with limited or outdated information, government departments charged with management often also have the responsibility of educating the public about relevant regulations and enforcing them. Increasingly, citizen science programs are being implemented as a cost-effective solution for collecting research data to inform management that simultaneously educates the public.

Citizen science combines community and science efforts in undertaking research to address real-world problems. Advantages of citizen science are its potential to complement standard scientific research programmes by covering a larger geographic spatial and temporal extent and greater sample sizes than vessel surveys, in addition to their lower relative cost. Disadvantages of citizen science research include heavier biases than traditional scientific research, as observations are often collected opportunistically with a wider margin for error due to variability in training and knowledge, across citizen scientists. Advantages of traditional scientific vessel-based surveys are tighter control over the experimental design, including systematic sampling, and biases being controlled or accounted for and a tendency toward greater accuracy due to highly trained observers, and an increased complexity of data collected. Systematic vessel surveys, for instance can reduce bias by designs that increase equal probability of spatial coverage across the study area. Systematic surveys, however, are often limited by the number that can be undertaken due to the relatively high associated cost. Conducting citizen science and traditional science vessel-based surveys are, of course, not mutually exclusive, and simultaneously conducting them may improve the utility and interpretation of citizen science data and depth of knowledge of the environment. Through their integration, it may be possible to evaluate bias introduced by Citizen Science surveys and increasing the limited sample size of systematic vessel surveys at a relatively low cost.

Limited research has been conducted on the complementarity of citizen science and vessel surveys and how they might be integrated jointly to informing management (Harvey et al., 2018). This study aims to help fill this knowledge gap, using a dataset generated from a decade of Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) sightings collected through the citizen science program '*Dolphin Watch*' and Scientific vessel dolphin surveys conducted in the Swan Canning Riverpark, Western Australia.

Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) are a distinct species from the more ubiquitous species called the common bottlenose dolphin (Rice, 1998). Indo-Pacific bottlenose dolphins are discontinuously distributed in warm-temperate and tropical waters within the Indo-Pacific region, from Australia to southeast Asia and around the northern Indian Ocean rim down to western South Africa. Indo-Pacific bottlenose dolphins occur mainly in shallow coastal and estuarine waters (Jefferson et al. 2015). As a result of the nature of their distribution and threats, in 2019 the species was listed as near threatened by the International Union for Conservation of Nature (IUCN) (Braulik et al., 2019).

In Australia, Indo-Pacific bottlenose dolphins occupy a diversity of habitats, including coastal waters, bays, and riverine and semi-enclosed estuaries, and many are found in small communities with limited genetic or outside social networks exchanges (Chabanne et al., 2021; Manlik et al., 2019; Wiszniewski et al., 2010). This is the case for the ~20 dolphins that are year-round residents of the Swan Canning

Riverpark in southwest Western Australia. The Swan Canning Riverpark is located at the heart of Western Australia's capital city of Perth with a population of 1.4 million people. The Riverpark, thus, is a highly urbanised environment with ongoing recreational use and regular development and transport activities along the riverbanks and in the estuary waters. The strong site fidelity of the dolphins to the Riverpark and relatively small home range make them vulnerable to anthropogenic pressures and environmental change (Wilson et al. 1999; Ross 2006; Chabanne et al. 2012, (Chabanne et al., 2017)).

The citizen science program '*Dolphin Watch*' was established shortly after the sudden death of six of the resident Indo-Pacific dolphins in the Swan Canning Riverpark's in 2009. While *Dolphin Watch* was already in its early stages of development at the time of the mortalities, community concerns and a government enquiry over the deaths spurred its formation. *Dolphin Watch* is a collaborative citizen science research and education project delivered in a partnership between the Western Australian Department of Biodiversity, Conservation and Attractions (DBCA) and Murdoch and Edith Cowan universities. *Dolphin Watch* is an integral part of the provision of education and awareness of estuary health and monitoring dolphins. To date, over 1000 volunteer citizen scientists located in Perth have been trained, with around 30 of them consistently active. *Dolphin Watch* monitoring data consist of opportunistic land (e.g., from the banks of the Riverpark) or vessel-based (e.g., kayak or boat) dolphin sightings recorded by trained volunteers who choose the time, duration, and location in the Riverpark where they undertake their monitoring. In addition to reporting sightings, *Dolphin Watch*ers also report dolphin entanglements, injuries, and mortalities. Through this activity, tracking of an entangled dolphin's location and condition improves the chances for managers (i.e., DBCA) to release it successfully. Monitoring data are regularly analysed to track gross changes in injury and mortality rates, and the number of dolphins in the community and their distribution in the Riverpark. Since 2011, the *Dolphin Watch* program has been complemented by traditional science vessel-based surveys in the Swan Canning Riverpark. These involve conducting repeated single-day vessel surveys that cover a large extent of the Riverpark with observers recording dolphin encounter information.

To maximise the outcome and utility of the citizen science and scientific survey data, we: 1) evaluated the spatial and temporal extent and resolution of data collected during citizen science and scientific vessel surveys, and 2) compared spatial and temporal patterns in dolphin group sightings resulting from statistical models using each of the two survey modes and with their combined data. Based on our findings we make recommendations for a framework that combines and integrates both methods in future abundance and distribution modelling for determining important areas used by dolphins in the community for key life processes to inform conservation management. In addition, we make recommendations for the direction of the next decade of *Dolphin Watch* monitoring. Not only does this study inform the future direction of *Dolphin Watch* in the Perth region this research provides a case study for assessing the performance and complementarity of these approaches in cetacean research elsewhere. Consequently, this study has broad application for improving management and conservation efforts, especially in information-poor regions of the world.

2 Methods

2.1 Study area and period

The Swan Canning Riverpark is located within the Swan Canning estuary system in southwestern Australia (31.96 S, 115.84 E; Figure 1). The estuary experiences hot summers and cool winters, consistent with a Mediterranean climate, and has two tributaries, the Swan and Canning Rivers. The lower-reaches of the estuary opens to Cockburn Sound (in the Indian Ocean) through Western Australia's (WA) largest general cargo port in the Fremantle Inner Harbour.

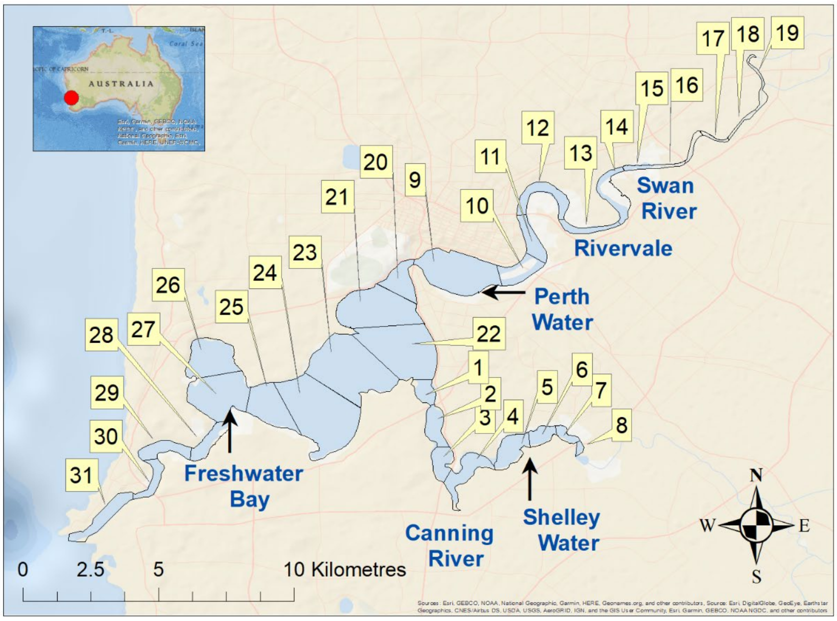


Figure 1. Swan Canning Riverpark, Western Australia, and *Dolphin Watch* monitoring zones.

2.2 Survey methodology and data

While dolphin sightings have been recorded since 2009 by *Dolphin Watch*, data included in this report were those from June 2011 to January 2020 to match the temporal extent of the Scientific vessel surveys.

2.2.1 Dolphin Watch

Dolphin Watch (DW) data were available from two distinct datasets generated from volunteer sightings. This was a result of the evolution of the data management system and resulting transition from one management environment to another. Between 2009 and 2016 data reports were input by webform, and Quality Checked (QC) by a DW volunteer (J. Hunt) in Microsoft Excel (using a macro developed by DW volunteer R. Broadway). From 2016 onward, a second management system that accepted data from the webform and a purpose-built mobile phone (smartphone) App was implemented (developed by GAIA Resources). As a consequence of the transition, the output formats varied and there were some inconsistencies introduced in some observational fields. Therefore, the data first needed to be integrated, comparable fields extracted, reformatted, and QC checked.

Observations recorded by DW volunteers included: observer name; survey start and end time and date; dolphin group sighting start and end time and date; the number of total dolphins in the group sighted; the number of calves in the group; direction the dolphin group was travelling (upriver, downriver, or staying in the area); their general behaviour (milling and diving, travelling, resting, etc.);

whether the tide was incoming, outgoing or slack; whether the observers consistently submitted reports when dolphins were not observed as well as when they were observed (called presence-absence data), or they were mostly consistent in reporting presence-absence surveys (but sometimes didn't submit reports when no dolphins were seen), or they were sometimes reported on surveys in which dolphins were absent, or never reported survey when dolphins were absent (referred as opportunistic presence-only data); and the location of the surveys. Opportunistic presence-only data are biased towards locations and times dolphins are present, and do not capture those in which dolphins are not present.

The spatial location of surveys was recorded as one of 31 pre-defined monitoring zones (Figure 1) based on easily recognizable local landmarks. This allowed volunteers to participate, regardless of whether they had access to GPS recording technologies (e.g., GPS, mobile phones, etc.), and reduced error in recording the monitoring zones by defining zones via prominent and easily recognisable land and river features.

2.2.2 Scientific vessel surveys

Scientific vessel-based data have been collected from a 5.4 or 4.8m powerboat since 2011. Survey data until August 2019 were included in this report. The vessel followed a pe-determined transect route designed to maximise coverage of the areas covered with the Swan Canning Riverpark. The vessel was driven at a constant speed (8 knots, unless restricted to 5knots) and conducted in good weather conditions only (Beaufort Sea state ≤ 3) and with two to five trained observers (median = 3) onboard.

For each group of dolphins encountered during the transect, researchers used photo-identification (Würsig and Jefferson 1990) to identify each individual dolphin present in the group and recorded the group size (i.e., individuals who were estimated to be within 10 m of any other individuals, Smolker et al. 1992), age-sex composition, and location (northing/easting using a hand-held GPS). Behavioural methods followed the sampling protocol and ethogram used by researchers involved in the long-term dolphin study site in Shark Bay, Western Australia (Smolker et al. 1992; Mann 1999; Mann et al. 2000) and in previous studies in the Perth area (Donaldson et al. 2012; Salgado Kent et al. 2018a).

Start time and the duration of each survey within each zone were extrapolated from the distance navigating in a zone and converted based on 7.5 knots vessel speed. If the zone was traversed twice during one day, the duration of effort per zone per day was summed over the two times traversed. Time spent with a group of dolphins was described as 'off effort' and therefore not included in total duration of effort.

2.3 Comparison of survey effort between survey platforms

The spatial and temporal extent and resolution of the data are reported for each of the survey platforms (citizen science and scientific surveys). Spatial extent is reported in terms of the location and area covered, and the temporal extent as the first to the last survey date included in the study. The spatial and temporal resolution are reported as the number of surveys and hours of survey effort over days, months, and years and over the spatial extent of the Riverpark. Effort maps were produced at the spatial resolution of the survey platform, which included monitoring zones for DW data and a 250m buffer on either side of the vessel for Scientific vessel surveys (resulting in a 500m-by-500m gridded area). For calculation of vessel survey effort, the buffer of 250m was added to both sides of each survey track to include the estimated range of detection, assuming a uniform detection function.

Effort was then calculated at the resolution of the vessel survey by laying a grid with cell sizes of 500m by 500m over the entire survey area and summing the total area over all surveys within each grid cell. Following this, the time taken to survey the summed area over all years was calculated assuming an average vessel speed of 7.5 knots. Boundary effects of the riverbank were not accounted for in the analyses presented here, nor were decreasing detection with increasing range from the track line or variation in vessel speed. Integration of these where relevant is left for future work.

To compare spatial and temporal patterns in survey effort for the two survey platforms, statistical models were fitted for each of the two platforms (DW surveys and Scientific vessel surveys). This approach was taken (two separate models fitted for each platform, rather than a single model with survey platform as a factor) to reduce the number of interactions that would need to be included in models to capture all combinations of variables of interest. Comparisons between models for the two survey platforms were, thus, described (and were not of a statistical nature). To allow for more direct comparison between survey platforms, Scientific vessel surveys effort was calculated and analysed on the same spatial resolution as the DW data (i.e., DW monitoring zone).

2.4 Comparison of dolphin group sightings between survey platforms

For visual interpretation of patterns in observed dolphin group sightings and their distribution, the number of groups sighted were adjusted for survey effort using hours of survey effort (as indicated above, for Scientific vessel surveys this was estimated based on an average vessel speed of 7.5 knots per hour). Survey-based maps were produced at the spatial scale resolution of the survey platform.

As for survey effort, to compare spatial and temporal patterns in dolphin groups sighted from the two survey platforms, models were fitted using data for each of the two platforms (DW surveys using all data generated and Scientific vessel surveys). A set of four statistical models were fitted for comparative purposes (Table 1). The first included all DW data (opportunistic presence-only and presence-absence data). Because of biases inherent in DW surveys with all data generated (including opportunistic presence-only and presence-absence data), a model of DW surveys that only included presence-absence data (i.e., data absent of biases caused by opportunistically only reporting surveys when dolphins are seen, and not when they are not seen) was also included. The third model included Scientific vessel Surveys (which inherently is presence-absence type data). The fourth model combined all available presence-absence data from DW and Scientific vessel survey data.

Table 1. Dolphin group sighting models fitted using *Dolphin Watch* (DW) and Scientific vessel Surveys.

Model Num.	Model	*Data Used*
1	DW – all data	DW opportunistic (presence-only) and presence-absence survey data
2	DW – presence-absence	DW presence-absence survey data
3	Scientific vessel Surveys	Scientific vessel Survey data
4	Combined DW & Scientific vessel Surveys	Combined DW presence and absence data & Scientific vessel Surveys data

2.5 Statistical modelling approach

Generalized Additive Models (GAMs) are powerful for modelling nonlinear functional relationships between explanatory and outcome variables (Wood, 2017). GAMs are extensions of generalised linear model (GLM) which allow for non-normally distributed response data to be modelled using a range of link functions that may approximate their distribution. Effort data (recorded in hours of effort), being all positive continuous values, were non-normally distributed, and approximated a gamma distribution. Consequently, a gamma GAM with a log-link function was used for survey effort models. In contrast, dolphin groups sighted were recorded as presence or absence (a binary response), and approximated a binomial distribution. A binomial GAM with a cloglog link function was used.

In contrast to GLMs, GAMs response variables depend linearly on unknown smooth functions of predictor variables, thus there is greater flexibility in non-parametric fits due to relaxed assumptions regarding the relationship between response and predictor variables. To model spatial and temporal patterns in survey effort and dolphin groups sighted, monitoring Zone, Month, and Year were included in models as explanatory variables. As effort and groups sighted were not anticipated to be linear functions of these spatial and temporal explanatory variables, the non-parametric smoothing spline fits of GAMs were deemed appropriate. Because the Swan Canning Riverpark is not comprised of a single river system (i.e., just the Swan River that flows out through the Inner Harbour to Cockburn Sound), but instead of the Swan and Canning Rivers, not all monitoring zones could be allocated unique sequential numbers to represent downstream to upstream locations. Consequently, two Sectors were defined, and Zone re-numbered into sequential values of equal interval between 1 and 30 from Upstream to Downstream; first for the Swan River to the estuary entrance, and then for the Canning River so that they represented two 'Sectors' (referred to as the 'Swan' and 'Canning' Riverpark 'Sectors' in GAMs models). These values were not designed to represent relative distance from the upstream monitoring zone. Rather, they represented the relative sequence of monitoring zones from the most upstream to the most downstream zone in each Sector (future analyses might consider distance). Thus, the relationship between the response variables (i.e., survey effort and dolphin groups sighted) and explanatory variables (Zone, Month, and Year) and were modelled for each of the two sectors of the Riverpark, by including Sector as a factor in the models. For models that included dolphin groups sighted as the response variables, because effort varied in its duration among surveys, the logarithm of survey effort (in hours) was included as an offset.

Before fitting models, data were explored using histograms and scatter plots to identify outliers that would overly influence results. For example, *Dolphin Watch* surveys that had a duration over 15 hours were removed as likely user error (e.g., not logging the end of a survey in the smartphone App until after the observer had returned home). Survey durations < 15 hours were included, as some users log while on a day out on a vessel, which could have such a duration. While allowing for this margin of survey duration may still have resulted in a few erroneous surveys, surveys with such long durations were very few. In addition, collinearity among explanatory variables was explored using variance inflation factors (VIFs were less than 3; Zuur et al., 2009), however no variables were collinear (thus none required removal).

Models were fitted by constraining the basis functions, K, to 15. Isotropic smooths based on thin plate regression splines with penalties given as 1 (e.g., the order of the derivatives; Wood 2003) were used for fitting smooth functions. Maximum Likelihood Estimation (RMLE) was used for fitting models. Goodness-of-fit of each model was evaluated by confirming that no clear relations between the residuals and fitted values were visible in a scatterplot. In addition, residuals were assessed using QQ plots of the relationship between the deviance residuals (Wood 2017) and their theoretical expectation for the chosen family. Overall fit was also evaluated using a plot of response versus fitted values.

Model goodness of fit was quantified using QQ-Plots, histograms, plots of residuals versus fitted values and fitted values versus observed values, and the percentage of deviance explained (Zuur & Ieno, 2016). Temporal autocorrelation in residuals of fitted GAMs was evaluated, and as it was not a notable feature an autocorrelation structure was not included in models.

Relationships between response and explanatory variables were evaluated based on model outputs, including the effective degrees of freedom (EDF), model statistics, p-values, and plots for visualising the relationships. EDFs provides information about the how “wiggly” the explanatory terms are in their relationship with the response variable. The model statistic and p-value provide information about how important effects are and whether they are significant. Deviance explained is the percent of the total deviance explained by the explanatory variables in the model. The remainder remains unexplained (i.e., a high percentage is suggestive of a strong association between response and explanatory variables).

Visualisations in the form of partial plots provided information on the nature of the relationship between the response variable and an explanatory variables after eliminating the effect of the other explanatory variables. Partial response functions were plotted in three dimensions using contour plots with Zone on the vertical axis, Month on the horizontal axis, and the predicted value of the response variable as a heatmap with values indicated on the contours within the plots. A set of nine plots were produced for each year included in the analyses. Heat map values varied among plots (to allow for variation within years to be identified, regardless of whether the extent of variation differed from other years). The lowest predicted values were illustrated with red, mid-range values with yellow, and highest values with white.

2.6 Software

All analyses were performed using R v4.0.0 (R Core Team 2018) in RStudio Version 1.1.419 - © 2009-2018 RStudio, Inc.. R Packages used included dplyr, gtools, gridExtra, ggmap, and rgdal, car (Fox & Weisberg, 2011); lattice (Sarkar, 2008); MASS (Venables & Ripley, 2002); mgcv (Wood, 2006); MuMIn (Barton, 2016); and stats (R Core Team 2018). LOESS (Locally Estimated Scatterplot Smoothing) curves with 95% CIs were plotted using *ggplot* (Wickham, 2016) in R. ArcMap v 10.7 (ESRI, 2019) was used for all mapping.

3 Results

3.1 Spatial and temporal extent and resolution in survey effort

The spatial extent of the two survey platforms differed, with *Dolphin Watch* surveys having a greater spatial extent than Scientific vessel surveys. *Dolphin Watch* surveys were completed in all 31 predefined monitoring zones in the Swan Canning Riverpark, which extended from the opening of the Swan River at the Fremantle Inner Harbour, upriver through the Canning River up to Kent Street Weir and up the Swan River as far as Guilford (Figure 2). The straight-line distance from monitoring zone centroid to centroid through all monitoring zones was 44.08 km. Through the Swan River the straight-line distance between centroids was 34.69 km and through the Canning River 9.39 km. Scientific vessel surveys crossed 12 of the lower and mid-reaches of the estuary *Dolphin Watch* zones, with occasional or partial surveys conducted in an additional four zones that extended to the lower reaches of the Swan and Canning rivers (Figure 2).

The spatial resolution of surveys varied, with Scientific vessel surveys having a higher resolution than *Dolphin Watch* surveys. The monitoring zones ranged in sizes between 0.09 and 4.76 km^2 (mean = 1.24, SD = 1.28), with the spatial resolution defined by the monitoring zone size (Figure 2). In contrast, the resolution of Scientific vessel survey data was $0.06 m^2$ (250 by 250 grid defined by the range at which detection is assumed to be uniform) (Figure 2).

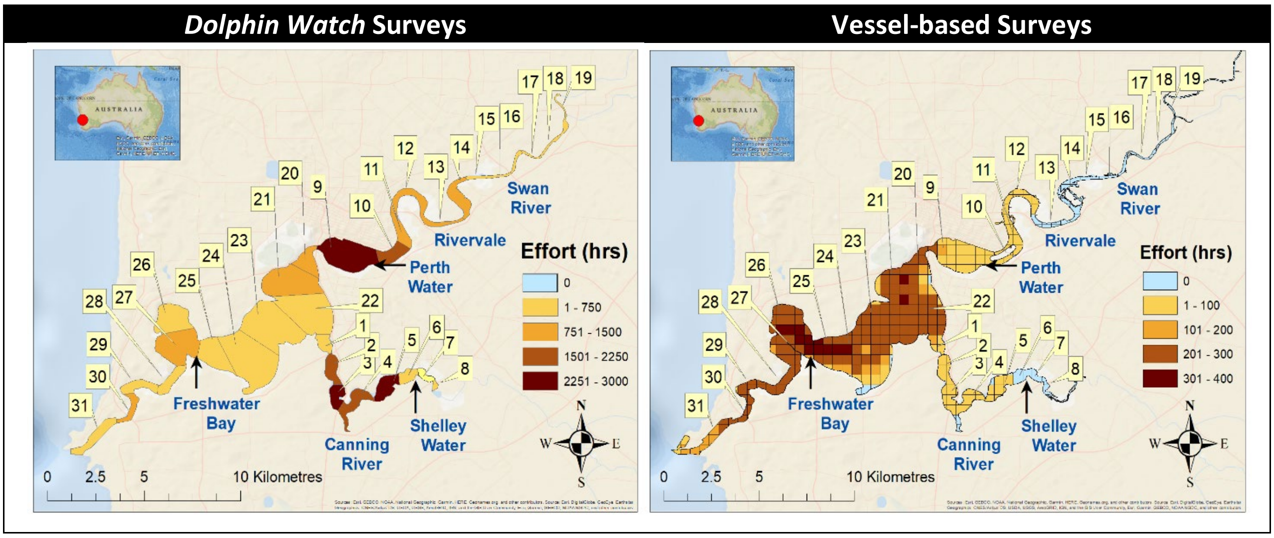


Figure 2. Spatial extent and resolution of *Dolphin Watch* and Scientific vessel survey total effort over period between 2011 and 2020 in the Swan Canning Riverpark, Western Australia.

The temporal extent of the surveys was comparable as the *Dolphin Watch* data were subsetted to only include those over the decadal period for which data are being compared between platforms, despite the *Dolphin Watch* program commencing in 2009. The temporal resolution of data collected differed, with *Dolphin Watch* data having greater resolution than Scientific vessel surveys data. *Dolphin Watch* surveys were conducted during a total of 3,130 days between 2 June 2011 and 23 Jan 2020, comprising 99% of days available between these dates (Table 2). A total of 19,730 hours of effort was conducted during a total of 28,528 surveys. Survey duration ranged between a second and 14.4 hours (mean = 59.4 min, SD=6.0 min). On average 9.1 surveys with a total duration of 6.3 hours were conducted on days surveyed, with an average of 54.0 hours of surveying a week completed.

Scientific vessel surveys, however, were conducted during a total of 178 days between 22 June 2011 and 12 Aug 2019, comprising 6% of days available between these dates (Table 2). A total of 470 hours of effort was conducted during a total of 175 surveys. Vessel survey duration ranged between 1.3 hours and 5.7 hours (mean = 2.7 hours, SD=3.6 min).

Table 2. Temporal extent and resolution of *Dolphin Watch* and Scientific vessel surveys over the decadal (2011-2020) dataset in the Swan Canning Riverpark, Western Australia.

Effort	*Dolphin Watch*	Scientific Surveys
Total Days Surveyed	3,130	178
Percent of Days Surveyed	99%	6%
Total Number of Surveys	28,528	175
Total Hours	19,730.2	469.2
Mean Survey Duration (min-max)	59.4 min (1 sec-14.4 hrs)	2.7 hrs (1.3 hrs – 5.7 hrs)
Mean Survey Hours per Week	54.0 min	N/A

3.1.1 Patterns in spatial and temporal survey effort

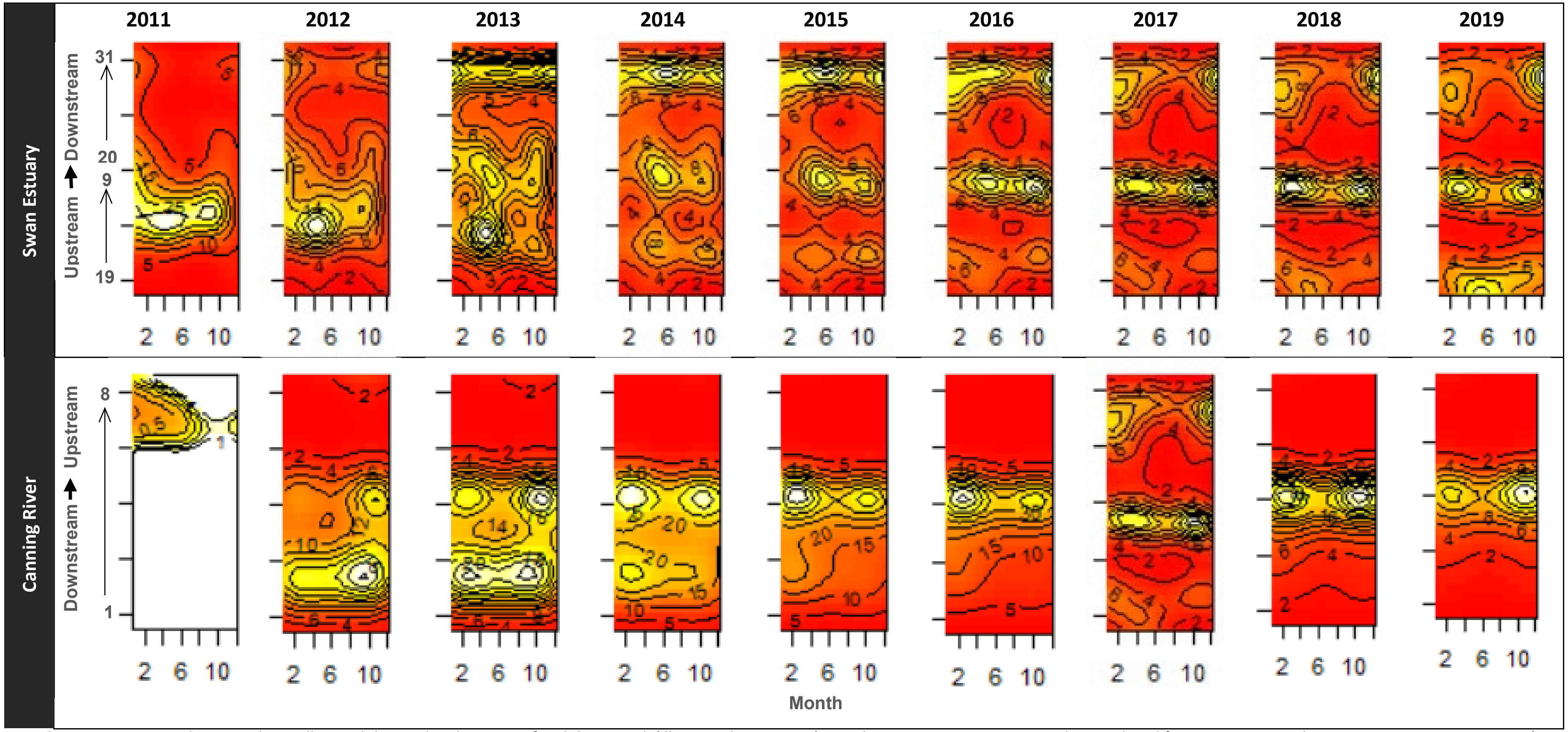
Effort varied greatly among survey platforms. Overall spatial and temporal survey effort was more uniform for Scientific vessel surveys than *Dolphin Watch* surveys (Table 2, Figure 3, Figure 4). *Dolphin Watch* survey effort was greatest around Perth Water, the lower to mid-Canning River, and between Freshwater Bay to the opening of the estuary to the Cockburn Sound (Figure 2, Figure 3, Figure 10, Table 2). In contrast, greatest Scientific vessel survey effort was between the estuary entrance to Matilda Bay, with relatively little effort in Perth Water and the Canning River (Figure 2, Figure 3, Figure 10, Table 2), those being opportunistic surveys done aside the systematic surveys repeated since 2011. While spatial effort of *Dolphin Watch* surveys was mostly maintained in the middle Canning and Perth Waters areas over the years, effort in other regions of the Swan Canning Riverpark varied (Figure 2). *Dolphin Watch* survey effort tended to be greatest in summer months, regardless of the year (Figure 2). In contrast, Scientific vessel survey effort was increasingly limited to the main area of the estuary over the years (up to the entrance of the Canning River and the entrance to Perth Water. Surveys that were conducted further up the Canning River were undertaken in the early years of the decadal dataset, opportunistically and during the summer months (Figure 3).

Table 3. Generalized Additive Models (with a Gamma log link function) predicting effort as a function of estuary sector (Swan = Upper reaches of Swan River to mouth of the Riverpark estuary, Canning = Canning River), Month, Year and Zone sequence (from upper reaches to lower reaches) for *Dolphin Watch* and Scientific vessel surveys (DW = *Dolphin Watch*, RV = Research Vessel). Results include parametric coefficient estimates, standard error, t-value, and p-value and approximate significance of smooth terms including effective degrees of freedom estimated (edf), reference degrees of freedom (Ref. df), F-value, and p-value.

Parametric terms	Estimate		Std. Error		t-value		p-value	
	DW	RV	DW	RV	DW	RV	DW	RV
(Intercept)	1.57	-7.34	0.04	3.18	37.25	-2.31	<0.001***	0.021*
Estuary Sector (Estimate = Swan)	-0.02	6.29	0.05	3.18	-0.44	1.98	0.661	0.048*
Smooth terms	**edf**		**Ref. df**		**F-value**		**p-value**	
	DW	RV	DW	RV	DW	RV	DW	RV
s(ZoneSeq,Month,Year):Canning	48.29	13.58	63.68	15.62	15.75	3.56	<0.001***	<0.001***
s(ZoneSeq,Month,Year):Swan	99.02	83.68	107.31	95.59	8.69	15.69	<0.001***	<0.001***

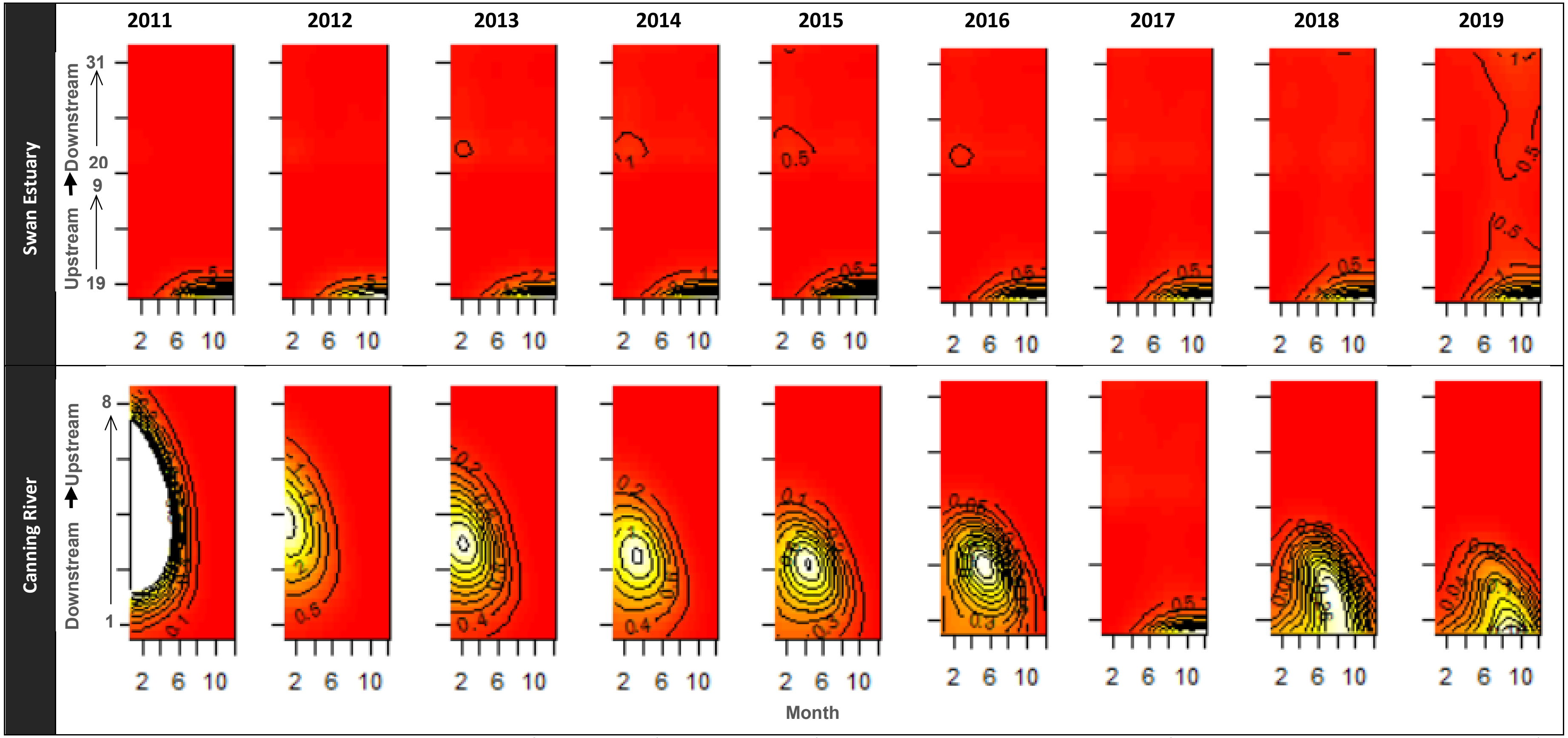
Signif. codes: <0.001 = '***', 0.01='**', 0.05='*', 0.1 = '•'

Model: Hours ~ River + s(ZoneSeq, Month, Year, by = River)
DW: R-sq.(adj) = 0.306, Deviance explained = 41.3%, GVC = 1.157, Scale est. = 0.972, n = 2,635
RV: R-sq.(adj) = 0.306, Deviance explained = 61.1%, GVC = 0.309, Scale est. = 0.0.28, n = 1,094



Note: the y-axis zone numbers are those allocated during development of *Dolphin Watch* (illustrated in Figure 1). For the Swan Estuary, zone numbers ordered from upstream to downstream are: Zones 19 to 9 (i.e., counting backwards from 19, 18, 17...) corresponding to the upper-most zone in the Swan River to Perth Waters, and Zones 20 to 31 (i.e., 20, 21, ...) corresponding to Matilda Bay to Fremantle Inner Harbour. Consequently, at Narrows Bridge there is a jump from Zone 9 (Matilda Bay) to Zone 20 (Perth Water). The y-axis scale places Swan Estuary zones in order from Upstream to Downstream, regardless of the zone numbers, thus the y-axis label has both zone numbers and direction relative to upstream/downstream.

Figure 3. Generalized Additive Model (binomial) partial response plots for *Dolphin Watch* survey effort over the study period (2011-2020) in the Swan Canning Riverpark, Western Australia. Contour plots are on the scale of the response variable (total hours of effort in that zone and month). Note that colour scales differ among the Canning River and Swan Estuary sectors and the values in the contour plots should be referred to for values corresponding to the colour scales.



Note: the y-axis zone numbers are those allocated during development of Dolphin Watch (illustrated in Figure 1). For the Swan Estuary, zone numbers ordered from upstream to downstream are: Zones 19 to 9 (i.e., counting backwards from 19, 18, 17...) corresponding to the upper-most zone in the Swan River to Perth Waters, and Zones 20 to 31 (i.e., 20, 21, …) corresponding to Matilda Bay to Fremantle Inner Harbour. Consequently, at Narrows Bridge there is a jump from Zone 9 (Matilda Bay) to Zone 20 (Perth Water). The y-axis scale places Swan Estuary zones in order from Upstream to Downstream, regardless of the zone numbers, thus the y-axis label has both zone numbers and direction relative to upstream/downstream.

Figure 4. Generalized Additive Model (binomial) partial response plots for Scientific vessel survey effort over the study period (2011-2020) in the Swan Canning Riverpark, Western Australia. Contour plots are on the scale of the response variable (total hours of effort in that zone and month). Note that colour scales differ among the Canning River and Swan Estuary sectors and the values in the contour plots should be referred to for values corresponding to the colour scales.

3.2 Spatial and temporal relative abundance of dolphin groups

A total number of 12,479 (10,969 during *Dolphin Watch* surveys and 1,510 during Scientific vessel surveys) dolphins in 4,115 groups were recorded over the decadal period, with 91% (3,726) and 9% (389) of groups observed by *Dolphin Watch*ers and during Scientific vessel surveys, respectively. On average, encounter rates were greater during Scientific vessel surveys than *Dolphin Watch* surveys, with 0.87 and 0.19 groups sighted per hour during Scientific vessel and *Dolphin Watch* surveys, respectively.

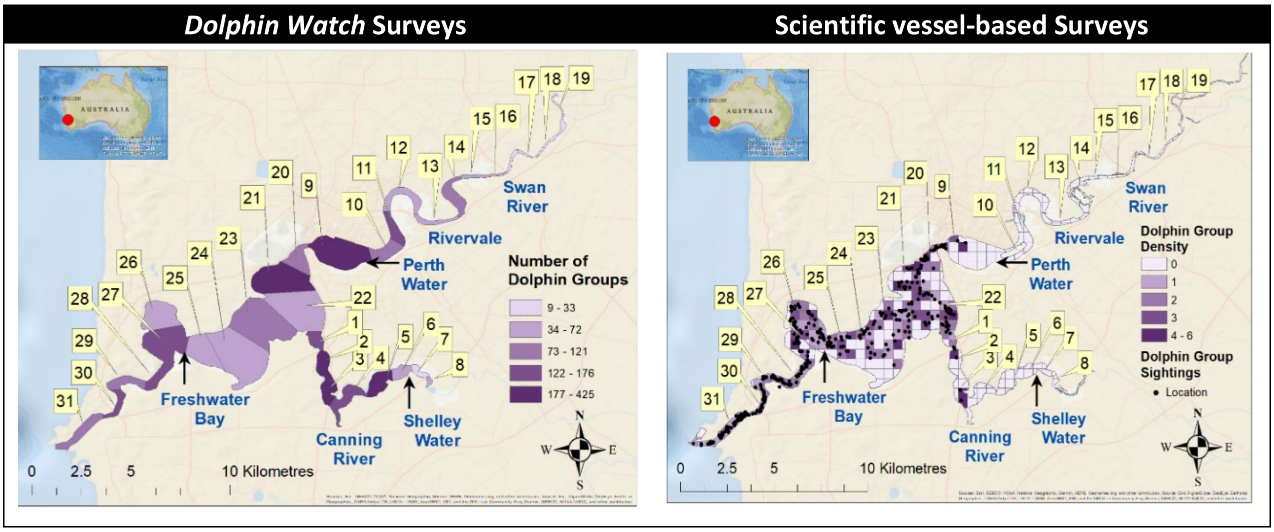


Figure 5. Total dolphin group sightings for *Dolphin Watch* and density for Scientific vessel surveys over the period between 2011 and 2020 in the Swan Canning Riverpark, Western Australia. Points in the Scientific vessel survey map represent the location where dolphin groups were sighted.

Of the three models that were fitted to explore spatial and temporal patterns in number of group sightings in the Swan Canning Riverpark, all identified the entrance to the estuary from Cockburn Sound, the area around the Narrows Bridge and Perth Water, and areas with the Canning River as having relatively greater numbers (adjusted for effort) (Table 6 and Figure 12 to Figure 15). All models identified the months between approximately February and June as having greater dolphin group sightings in the estuary entrance than at other times of the year. Winter months had greater group sightings in the Narrows Bridge to Perth Water area across all models, however, Scientific vessel surveys also identified this area as having greater sightings in summer months relative to other months as did some years in the model that included all *Dolphin Watch* data (including presence data and presence-absence data). Both *Dolphin Watch* survey models, including all data (presence data and presence-absence data) and presence-absence only data, suggested that the entrance of the Canning River had greater number of sightings in the winter months, while greater numbers of sightings occurred further up the Canning River in the summer months.

From the higher resolution map of dolphin groups sightings adjusted for effort, the highest number per unit effort were located near the Fremantle train and traffic bridges, on the west and east sides of the Narrows Bridge, near the Royal Freshwater Bay Yacht Club and various locations in Freshwater Bay, and at various locations within the Canning River (Figure 6).

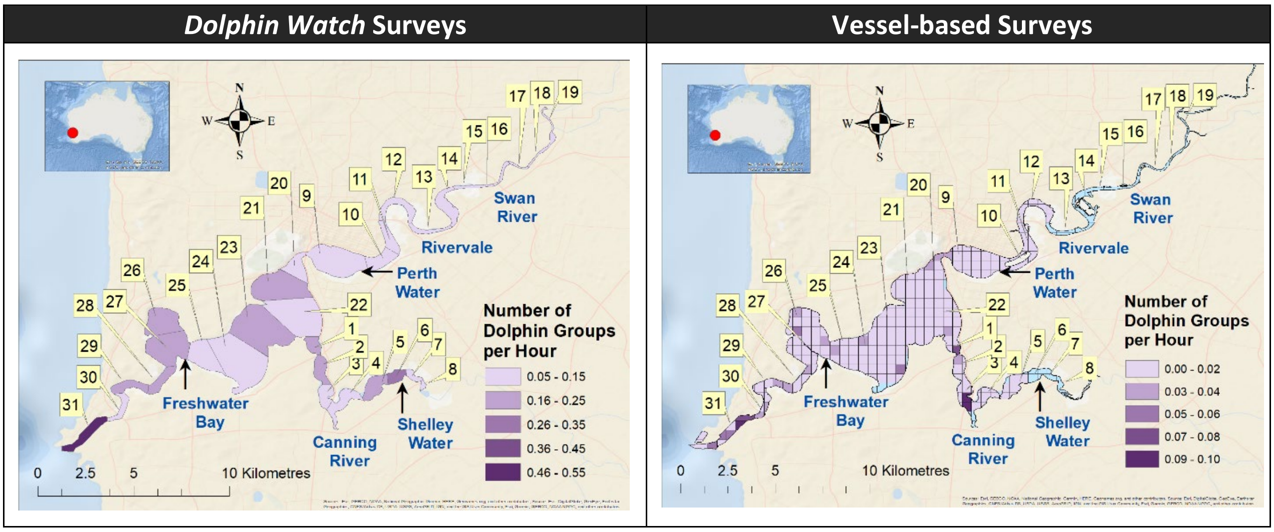


Figure 6. *Dolphin Watch* dolphin group and Scientific vessel survey sightings adjusted for effort over the period between 2011 and 2020 in the Swan Canning Riverpark, Western Australia.

There were limitations in all models. The *Dolphin Watch* model that included all data (presence data and presence-absence data) is likely biased towards locations where and when observers that only report sightings when dolphins are sighted tend to survey. The *Dolphin Watch* model including only presence-absence data and the Scientific vessel model are less prone to such biases, however, the sample sizes were only a small fraction of all *Dolphin Watch* data. As a result, a model that includes Zone, Year and Month may be overfitting over a small number of observations (Table 2).

Table 4. Binomial (cloglog link) Generalized Additive Model predicting dolphin group sightings for combined Scientific vessel and *Dolphin Watch* surveys that always recorded presence and absence with Month, Year and Along-river Zone Location by Region as explanatory variables. Results include parametric coefficient estimates, standard error, t-value, and p-value and approximate significance of smooth terms including effective degrees of freedom estimated (edf), reference degrees of freedom (Ref. df), F-value, and p-value.

Model Num.	Model		Model	R-sq (adj)	Deviance Explained	n	Limitations
1	*Dolphin Watch* Survey	All data (opportunistic presence-only and presence-absence)	Groups ~ River + s(ZoneSeq, Year, Month, by = River, k = 15) + offset(log(Effort.hrs))	017	9.97%	27,272	Biased by presence-only surveys.
2		Presence-absence data only		0.31	32.6%	5,291	Certain combinations of Year, Month, and Zone not surveyed. Potential overfitting occurring when including all variables.
3	Scientific vessel Survey			-0.08	5.21%	3,001	Upper reaches of rivers not surveyed, and limited sample size.
4	Combined surveys (Scientific vessel Surveys + *Dolphin Watch* Survey– Presence-absence data only)		Groups ~ River + s(ZoneSeq, Month, by = River, k = 15) + offset(log(Effort.hrs))	0.103	20.7%	8,292	Certain combinations of Year, Month, and Zone not surveyed, although sample size is greater. Overfitting likely reduced.

3.3 Combining *Dolphin Watch* and Scientific vessel Surveys data

By combining *Dolphin Watch* and Scientific vessel survey data, the extent and resolution of information can be improved (see Figure 7). While a model exploring patterns in dolphin groups in the Swan Canning Riverpark increased the spatial extent of which robust predictions could be made, the models were still likely overfitting over a relatively small number of observations in certain periods and regions of the study area due to the variability in spatial and temporal effort, particularly in fitting models with interactions between Year, Month and Zone (Table 2). To improve on the reliability of the model, a combined data model (using *Dolphin Watch* presence-absence data and the Scientific vessel data) that included only Month and Zone was fitted. While the deviance explained in this model (6.33%, Table 5) is less than that including Year, Month, and Zone (20.7%, Table 2), the reliance on very few data in some combinations of Zone, Month, and Year justified this more precautionary approach to modelling dolphin groups.

The resulting model indicated greater expected relative sightings upriver around Perth Water and the upper Canning River in the summer, downriver of the estuary (within the Inner Harbour) and in the Canning River between early autumn and early-mid winter, upriver around Matilda Bay and Narrows Bridge in winter, and towards Freshwater Bay in early autumn (Table 5 and Figure 8).

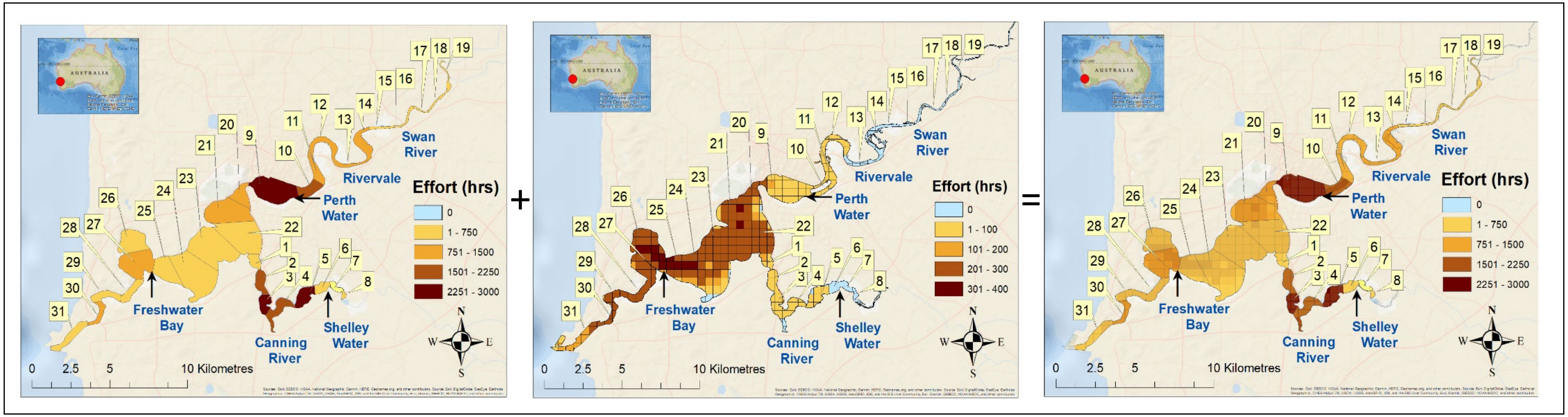
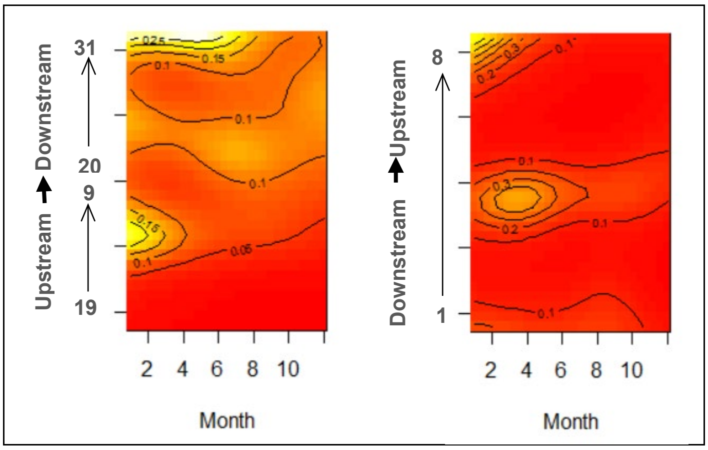


Figure 7. The spatial extent and resolution of the combined *Dolphin Watch* and Scientific vessel survey effort over the period between 2011 and 2020 in the Swan Canning Riverpark, Western Australia.

Table 5. The most reliable Binomial (cloglog link) Generalized Additive Model predicting dolphin group sightings for combined Scientific vessel and *Dolphin Watch* surveys that always recorded presence and absence with Month and Along-river Zone Location by Region as explanatory variables. Results include parametric coefficient estimates, standard error, t-value, and p-value and approximate significance of smooth terms including effective degrees of freedom estimated (edf), reference degrees of freedom (Ref. df), Chi-sq -value, and p-value.

Parametric terms	Estimate	Std. Error	Chi-sq value	p-value
(Intercept)	-0.90	0.14	-6.26	<0.001***
Region (Swan Estuary)	-0.07	0.15	-0.43	0.667
Smooth terms	**edf**	**Ref. df**	**F-value**	**p-value**
s(AlongRiverZoneLocation,Month):Canning River	20.00	23.77	160.50	<0.001***
s(AlongRiverZoneLocation,Month):Swan Estuary	22.46	26.03	249.50	<0.001***

Notes: Formula: Dolphins.Sighted.Y.N ~ River + s(ZoneSeq, Month, by = River, k = 15) + offset(log(Survey.duration..hours.))
Signif. codes: <0.001 = '***', 0.01='**', 0.05='*', 0.1 = '•'
R-sq.(adj) = 0.1063, Deviance explained = 6.33%
UBRE = -0.031, Scale est. = 1, n = 8,292



Note: the y-axis zone numbers are those allocated during development of Dolphin Watch (illustrated in Figure 1). For the Swan Estuary, zone numbers ordered from upstream to downstream are: Zones 19 to 9 (i.e., counting backwards from 19, 18, 17...) corresponding to the upper-most zone in the Swan River to Perth Waters, and Zones 20 to 31 (i.e., 20, 21, …) corresponding to Matilda Bay to Fremantle Inner Harbour. Consequently, at Narrows Bridge there is a jump from Zone 9 (Matilda Bay) to Zone 20 (Perth Water). The y-axis scale places Swan Estuary zones in order from Upstream to Downstream, regardless of the zone numbers, thus the y-axis label has both zone numbers and direction relative to upstream/downstream.

Figure 8. Generalized Additive Model (binomial) partial plots for combined Scientific vessel & Citizen science *Dolphin Watch* decadal (2011-2020) dolphin groups recorded during presence and absence surveys in the Swan Canning Riverpark, Western Australia. Contour plots with values are on a scale of 0 to 1, which represents the odds of the presence of groups.

4 Discussion

Citizen science (*Dolphin Watch*) and traditional science vessel-based (*Scientific vessel*) surveys in this study contrasted in their strengths and weaknesses, and thus complemented each other to fill gaps in knowledge that would have existed if only one survey platform had been used. In addition, combining data from both platforms improved the power of statistical models to detect spatial and temporal patterns in dolphin groups sighted.

Each of the survey platforms provided unique insight regarding patterns in dolphin group sightings. *Dolphin Watch* surveys outperformed Scientific vessel surveys in the spatial extent and temporal resolution of resulting data, while Scientific vessel surveys outperformed *Dolphin Watch* surveys in the spatial resolution and consistency of survey effort over the area covered. From *Dolphin Watch* surveys, dolphins' ranging patterns were identified as extending from the Inner Harbour into the upper reaches of the Swan and Canning Rivers – the upstream extent of which was not available from Scientific vessel surveys. From the Scientific vessel surveys, however, specific locations within monitoring areas where there were relatively high group sightings were identified. These locations coincided with narrow areas within the estuary (e.g., near the Fremantle bridges, the Narrows Bridge and the entrance of the Canning River) and locations that likely have structure in which prey may occur in greater densities (yacht clubs). The Fremantle Inner Harbour has been documented as a hotspot or core area for the Swan Canning Riverpark's resident dolphins in previous research (Moiler 2008; Marley et al. 2017; Chabanne et al., 2017; Salgado Kent et al. 2018a), with high intensity of foraging behaviour coinciding with the time mullet (sea mullet and yellow-eye mullet; *Mugil cephalus* and *Aldrichetta forsteri*, respectively) migrate out to sea in high numbers to spawn (Salgado Kent et al. 2018a). The study conducted by Salgado Kent et al. (2018a) suggested that within the Fremantle Inner Harbour, it is likely that the narrow channel at the location of the bridges concentrates high numbers of schooling fish, and dolphins may take advantage of the location to achieve high foraging efficiency (i.e., greater catch success of prey per unit effort). It may be that this same logic applies to other narrow locations within the Swan Canning Riverpark. Notably, one of these locations, the Narrows, is also a known popular fishing spot for locals. High dolphin occupancy at sites where there is a disproportionately high probability of entanglement in discarded fishing line has direct implications for targeted beach clean-ups and promoting responsible fishing practices.

By combining presence-absence data from both survey platforms, the most reliable model of those tested in this study (e.g., *Dolphin Watch* surveys only, Scientific vessel surveys) was achieved. The most reliable model was not the one that explained the most deviance, rather, it was based on the available data across the spatial and temporal extents of the Swan Canning River (e.g., sample size at combinations of monitoring zone, month, and year) that would reduce the likelihood of overfitting (and consequently result in an unreliably high model deviance explained). Indeed, the temporal regime of the Scientific vessel surveys changed over time with surveys conducted more than five times per season between June 2011 to September 2013, then restricted to five surveys per season between October 2013 and August 2015, and then only three surveys per season thereafter with the majority run monthly (i.e., one survey per month). Based on this combined model, the probability of sighting dolphin groups in different areas of the Swan Canning Riverpark is expected to shift seasonally. In general, there appears to be a shift in the expected probability of sighting dolphin groups in the Canning River, Swan River, and lower and middle reaches of the estuary – from high probability further upriver in autumn and winter months shifting to further downriver in spring and summer months

(Figure 9). In regions of the Swan Canning Riverpark where there were sufficient surveys conducted to confidently infer over years, spatial and seasonal patterns appeared relatively stable over the years.

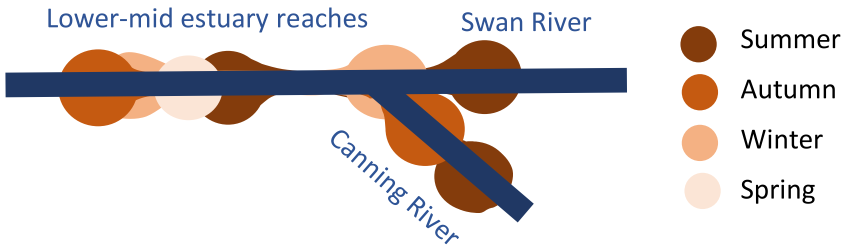


Figure 9. Conceptual model sketch of seasonal shifts in 'hotspots' of dolphin groups sighted in the Swan Canning Riverpark. Note: not to scale and locations of 'hotspots' are conceptual relative locations and not based on measured distances upriver.

While this study identifies seasonal and spatial predictors of expected probabilities in sighting dolphin groups, these represent a component of a range of drivers that influence locations of dolphin occupancy in different seasons. In general, it is likely that shifts in dolphin occupancy are linked to changes in abiotic and biotic conditions in the Riverpark. It is known that patterns in abiotic conditions, such as salinity, temperature, and dissolved oxygen (among many other attributes) are complex and vary over seasons and years (Hipsey et al., 2016), as are the distribution and abundance of dolphins' prey and biotic conditions that their prey rely on (e.g., their food source) (McCluskey et al., 2016; Tweedley et al., 2021). Abiotic conditions may directly influence dolphins' preferred locations of occupancy or indirectly through their influence on dolphin prey. While indirect effects through changes in distribution and abundance of dolphin prey are most intuitive, a recent study documented dolphin mortality events due to 'freshwater skin disease' at a time of a marked drop in salinity due to rainfall in the estuary (Duignan et al., 2020). It is not known, however, whether there might be any direct link between dolphin habitat occupancy and freshwater input into the system.

Two studies (an honour thesis and a conference presentation; Beidatsch 2012 and Salgado Kent et al. 2018b, respectively) have tested several approaches to model links between *Dolphin Watch* sightings and abiotic variables. These studies resulted in varying model performance due to the scale and resolution of abiotic conditions and *Dolphin Watch* data and how well they matched each other. Despite these limitations, a range of variables were identified as partially explaining patterns in dolphin group sightings, including monitoring zone, rainfall, salinity, temperature, dissolved oxygen, distance upriver. The latter study (Salgado Kent et al. 2018b) recommended that future research should use higher spatial and temporal resolution modelled abiotic conditions of the Swan Canning Riverpark if available, and to implement GPS position tracking of volunteer observers through a smartphone App to improve resolution of spatial *Dolphin Watch* data.

This study has demonstrated that the combination of citizen science and traditional scientific surveys provides a more complete and robust representation of dolphin ecology in the Swan Canning Riverpark that a single survey platform would. While citizen science surveys are more cost-effective than are traditional scientific surveys for the amount of data they produce and have the added benefit of educating and increasing environmental awareness in the community, importantly scientific surveys provide a validation tool for citizen science programs and a mechanism for quality control and improvements in citizen science programs. It is also important to highlight that by combining both survey platforms, progress towards filling gaps in ecological and behavioural knowledge is vastly improved, and thus so is progress towards fulfilling management strategy objectives.

We provide a range of recommendations for the next decade of the *Dolphin Watch* program below and suggest a framework for their joint integration into research and conservation management programs.

5 Recommendations

This report evaluated patterns in spatial and temporal dolphin group sightings in the Swan Canning Riverpark – key knowledge for ongoing monitoring and management of dolphins and their threats in a highly urbanised environment. Notably, the work here uses data from a decade-long Citizen Science program complemented with traditional Scientific vessel surveys. The significant decadal milestone provided an opportunity to report on broad ranging patterns of Riverpark dolphins over a significant period of time, and to plan for the next decade of the *Dolphin Watch*. Based on findings here, we recommend that over the next decade, *Dolphin Watch* in the Swan Canning Riverpark:

- **Continue to monitor broad ranging patterns of dolphins** as an integral part of ongoing dolphin management and detection of broad-scale changes in the Swan Canning Riverpark environment.
- **Make presence-absence surveying a standard** for trained *Dolphin Watch* citizen scientists. *Dolphin Watch*ers, in this survey mode, record presence-absence data by conducting formal 'surveys', regardless of whether they see dolphins or not. These surveys require that the start time of the survey be recorded the moment searching for dolphins begins and the end time when searching for dolphins ends, rather than opportunistically reporting dolphins when sighted while not conducting a formal survey. The result will be vastly increased power to detect shifts in spatial and temporal occupancy and significant pressures at particular locations within the Riverpark. Data from all *Dolphin Watch* sightings (opportunistic and presence-absence reports) in this study were key to defining the minimum spatial extent in which the Swan Canning Riverpark dolphins' range. Some results from modelling this type of data, however, contrasted with *Dolphin Watch* presence-absence and Scientific vessel survey model results (both of which agreed with each other where sample sizes were sufficiently robust). This outcome means that the inclusion of opportunistic data in such models results in less reliable models. The GAMs approach used here assumes bias-free data, of which opportunistic sightings are far from being. Future analyses using models designed for opportunistic presence-only data such as Maxent habitat suitability may improve model results over the long term, however Salgado Kent et al.'s (2018b) preliminary Maxent models suggest that there are still limitations to achieving good model fit, regardless. In general, presence-absence models such as GAMs (and Generalized Estimating Equations) are recommended for future analyses as they are often more robust and provide direct information on density distribution rather than habitat suitability that is generated from Maxent models (see Salgado Kent et al. 2021). We suggest that with the use of a smartphone App, it may be possible to make conducting formal surveys easier and more accessible to *Dolphin Watch* citizen scientists.

- **Obtain high resolution *Dolphin Watch* spatial data.** With a smartphone App that allows tracking, high resolution spatial information will be possible.
- I**ncreased spatial coverage of *Dolphin Watch* effort**, including from kayaks and boats, be incentivised. Survey coverage in areas not normally surveyed and away from the riverbank where many *Dolphin Watch*ers focus effort will increase equal coverage probability over the broad area (Lacy et al. in press).
- **Scientific vessel surveys continue to be undertaken** to gain insight into additional attributes within the dolphin community, and to provide complementary knowledge and a validation tool for the Citizen science program. While we could not estimate error rates from *Dolphin Watch* surveys directly in this report, by comparing *Dolphin Watch* survey model results with those from Scientific vessel surveys, a level of validation of citizen science surveys was provided. Due to limitations in the presence-absence sample sizes, we recommend that Scientific vessel surveys continue and after adjusting *Dolphin Watch* surveys according to recommendations here, modelling be undertaken to track reduction in biases in effort. Additionally, vessel surveys are the primary source of photo-identification, which is required to monitor the ongoing demographics of the population and change in the community size. We suggest that a population viability analysis be undertaken in the future, when a sufficiently long-term population demographic data set is in hand (Lacy et al. in press).

More generally, we recommend that a framework for integrating citizen science and traditional scientific surveys include:

- The implementation of both survey modes at the beginning of a program for validation of citizen science surveys and identification of limitations and complementarity, and
- Where a Citizen science program does not provide a full representation of the attributes of a system being studied, but provides valuable data that is cost-effective and improves on what is achievable otherwise, that the two survey modes be undertaken in tandem to address management needs.

Only through such an approach can meaningful monitoring, that would otherwise be too expensive to undertake, be sustained over many decades – and through this, allow us to detect and act on serious changes in the environment, and predict future scenarios such as those anticipated with a changing climate.

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Appendix A

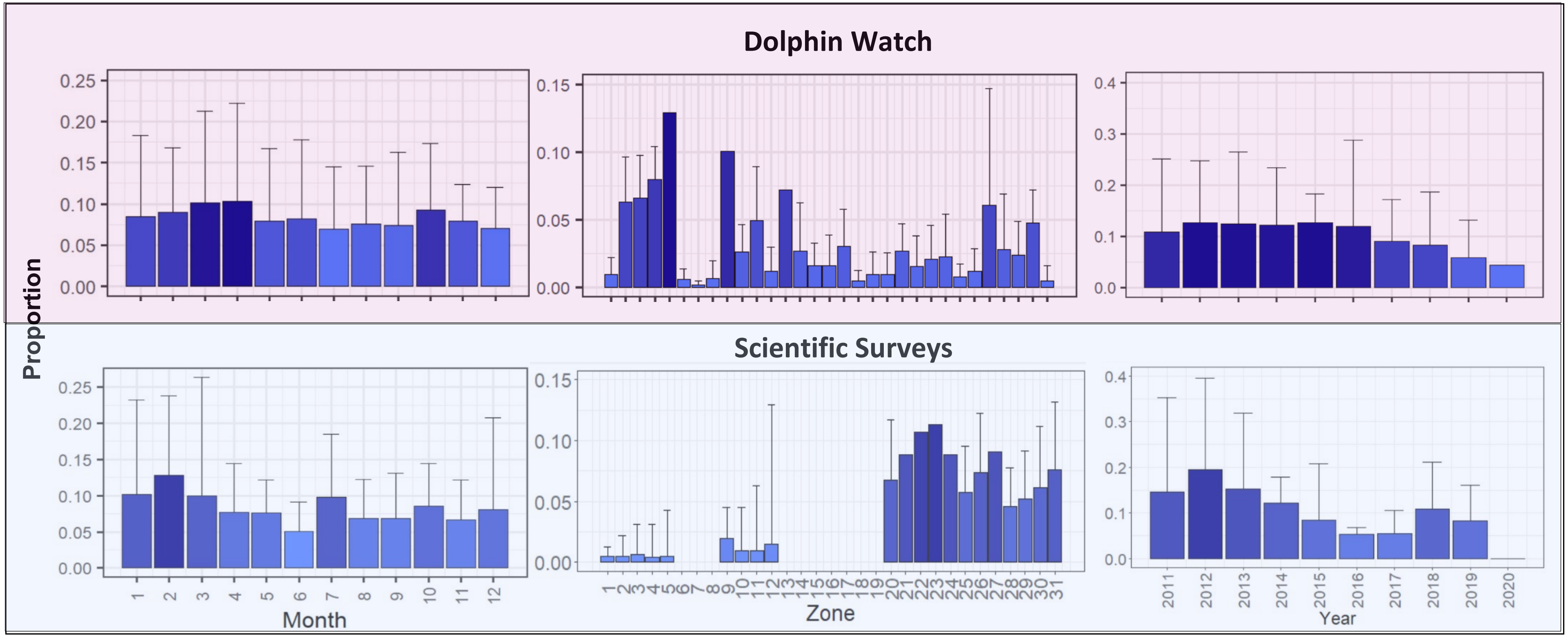


Figure 10. Survey effort over months, years, and zones for *Dolphin Watch* and Scientific vessel survey platforms over the period between 2011 and 2020 in the Swan Canning Riverpark, Western Australia.

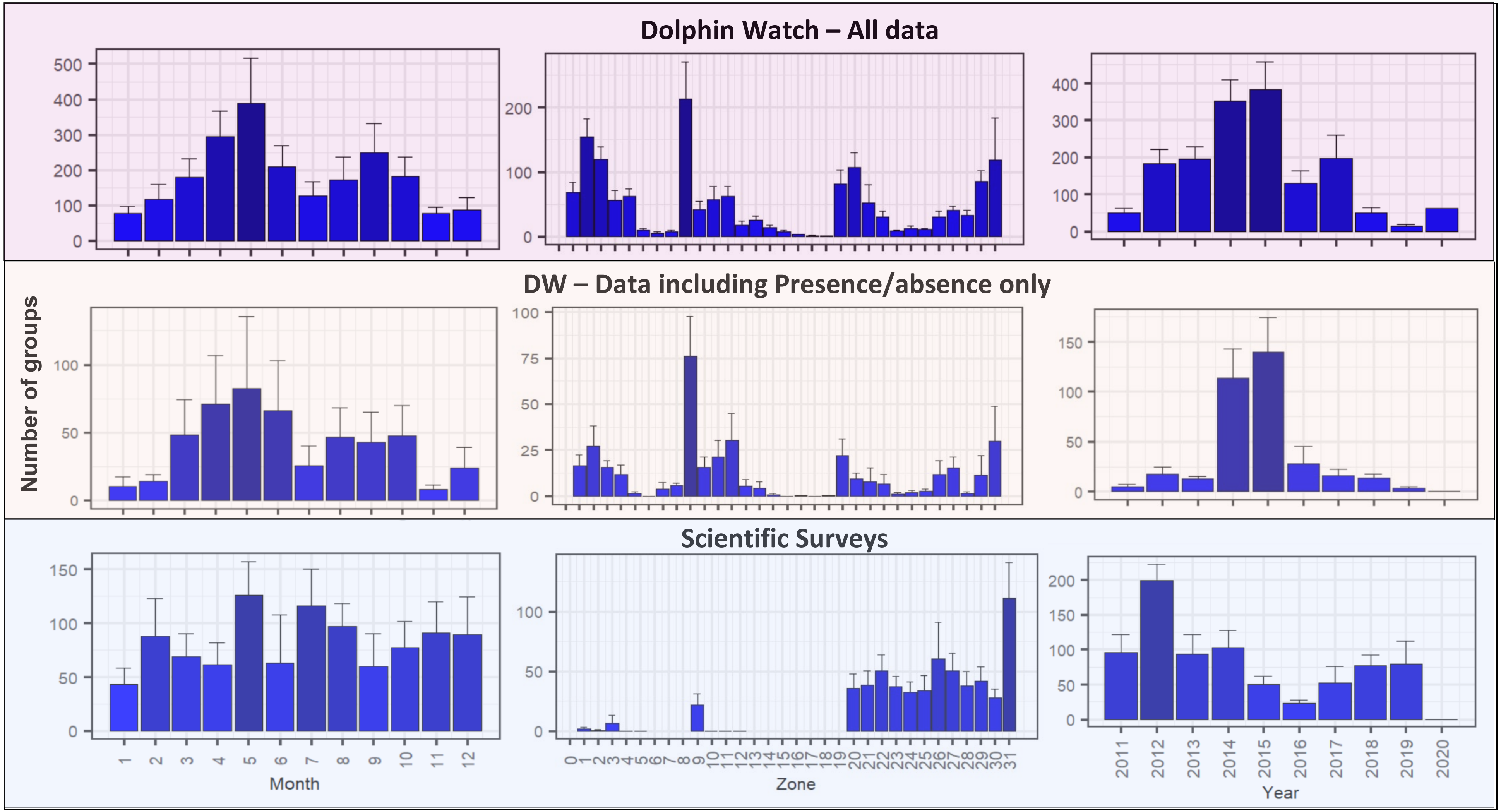


Figure 11. Number of dolphin groups sighted over months, years, and zones for *Dolphin Watch* and Scientific vessel survey platforms over the period between 2011 and 2020 in the Swan Canning Riverpark, Western Australia.

Appendix B

Table 6. Binomial (cloglog link) Generalized Additive Model predicting dolphin group sightings for combined Scientific vessel and *Dolphin Watch* surveys that always recorded presence and absence with Month, Year and Along-river Zone Location by Region as explanatory variables. Results include parametric coefficient estimates, standard error, chi-sq value, and p-value and approximate significance of smooth terms including effective degrees of freedom estimated (edf), reference degrees of freedom (Ref. df), F-value, and p-value.

All DW data:

Parametric terms	Estimate	Std. Error	Chi-sq	p-value
(Intercept)	-1.61	0.05	-34.36	<0.001***
Sector (Swan)	-0.27	0.06	-4.39	<0.001***
Smooth terms	**edf**	**Ref. df**	**F-value**	**p-value**
s(AlongRiverZoneLocation,Year,Month):Canning	63.03	78.26	450.60	<0.001***
s(AlongRiverZoneLocation,Year,Month):Swan	97.38	105.75	1131.60	<0.001***

Notes: Formula: Dolphins.Sighted.Y.N ~ River + s(ZoneSeq, Year, Month, by = River, k = 15) + offset(log(Survey.duration..hours.))
Signif. codes: <0.001 = ‘***’, 0.01=‘**’, 0.05=‘*’, 0.1 = ‘.’
R-sq.(adj) = 0.017, Deviance explained = 9.97%
UBRE = -0.229, Scale est. = 1, n = 27,272

Scientific vessel Survey data:

Parametric terms	Estimate	Std. Error	Chi-sq	p-value
(Intercept)	-475.20	1652157.10	0.00	1.00
Sector (Swan)	475.00	1652157.10	0.00	1.00
Smooth terms	**edf**	**Ref. df**	**Chi-sq**	**p-value**
s(AlongRiverZoneLocation,Year,Month):Canning	9.00	9.00	0.00	1.000
s(AlongRiverZoneLocation,Year,Month):Swan	28.02	37.80	96.70	<0.001***

Notes: Formula: Dolphins.Sighted.Y.N ~ River + s(ZoneSeq, Year, Month, by = River, k = 15) + offset(log(Survey.duration..hours.))
Signif. codes: <0.001 = ‘***’, 0.01=‘**’, 0.05=‘*’, 0.1 = ‘.’
R-sq.(adj) = -0.082, Deviance explained = 5.21%
UBRE = -0.142, Scale est. = 1, n = 3,001

DW Presence/Absence combined:

Parametric terms	Estimate	Std. Error	t-value	p-value
(Intercept)	305.50	301781.30	0.00	0.999
Sector (Swan)	-282.80	373276.10	0.00	0.999
Smooth terms	**edf**	**Ref. df**	**F-value**	**p-value**
s(AlongRiverZoneLocation,Year,Month):Canning	73.99	77.29	197.60	<0.001***
s(AlongRiverZoneLocation,Year,Month):Swan	67.02	78.07	284.80	<0.001***

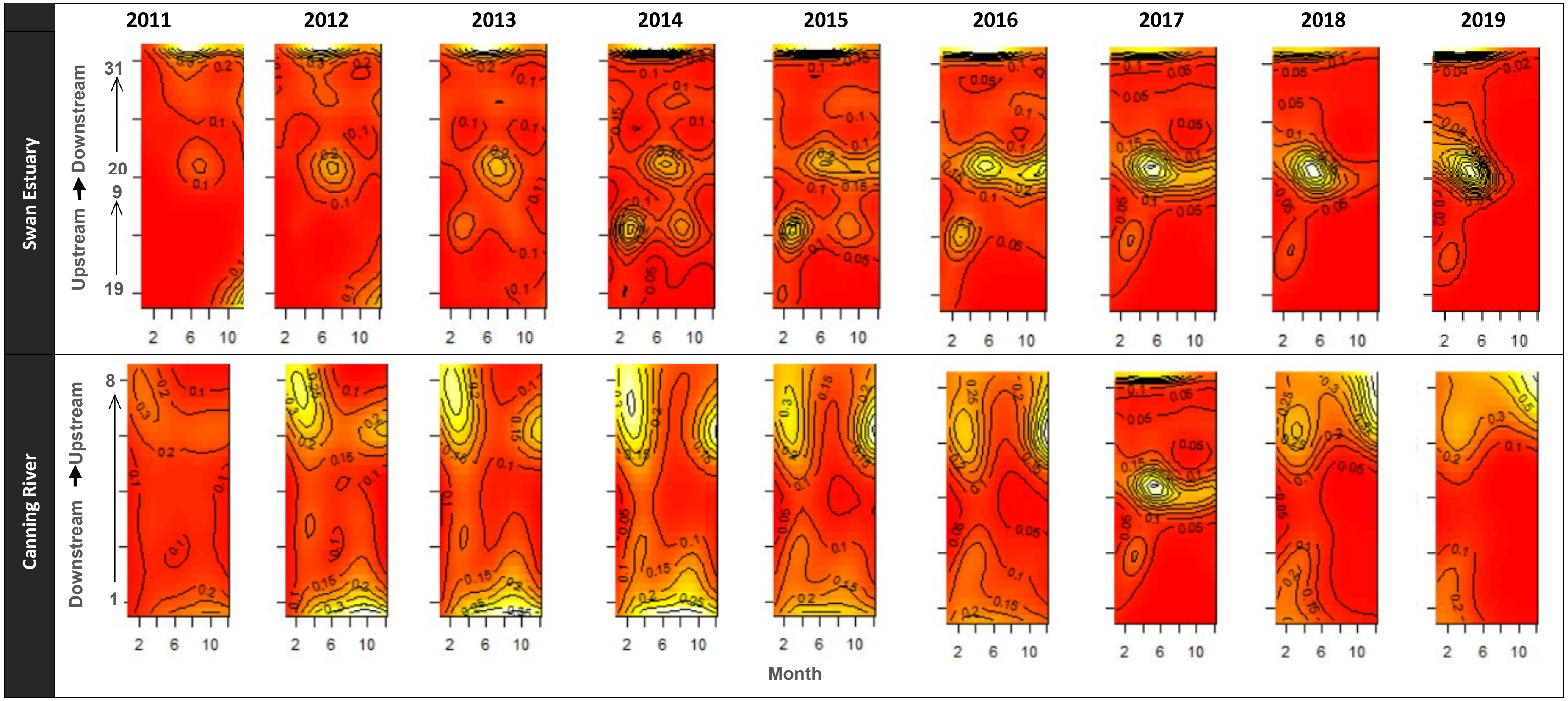
Notes: Formula: Dolphins.Sighted.Y.N ~ River + s(ZoneSeq, Year, Month, by = River, k = 15) + offset(log(Survey.duration..hours.))
Signif. codes: <0.001 = '***', 0.01='**', 0.05='*', 0.1 = '•'
R-sq.(adj) = 0.31, Deviance explained = 32.6%
UBRE = -0.253, Scale est. = 1, n = 5,291

Scientific vessel Survey and DW Presence/Absence combined:

Parametric terms	Estimate	Std. Error	t-value	p-value
(Intercept)	-51.36	139.08	-0.37	0.712
Sector (Swan)	50.31	139.08	0.36	0.718
Smooth terms	**edf**	**Ref. df**	**F-value**	**p-value**
s(AlongRiverZoneLocation,Year,Month):Canning	90.90	94.25	328.90	<2e-16***
s(AlongRiverZoneLocation,Year,Month):Swan	93.96	103.30	981.30	<2e-16***

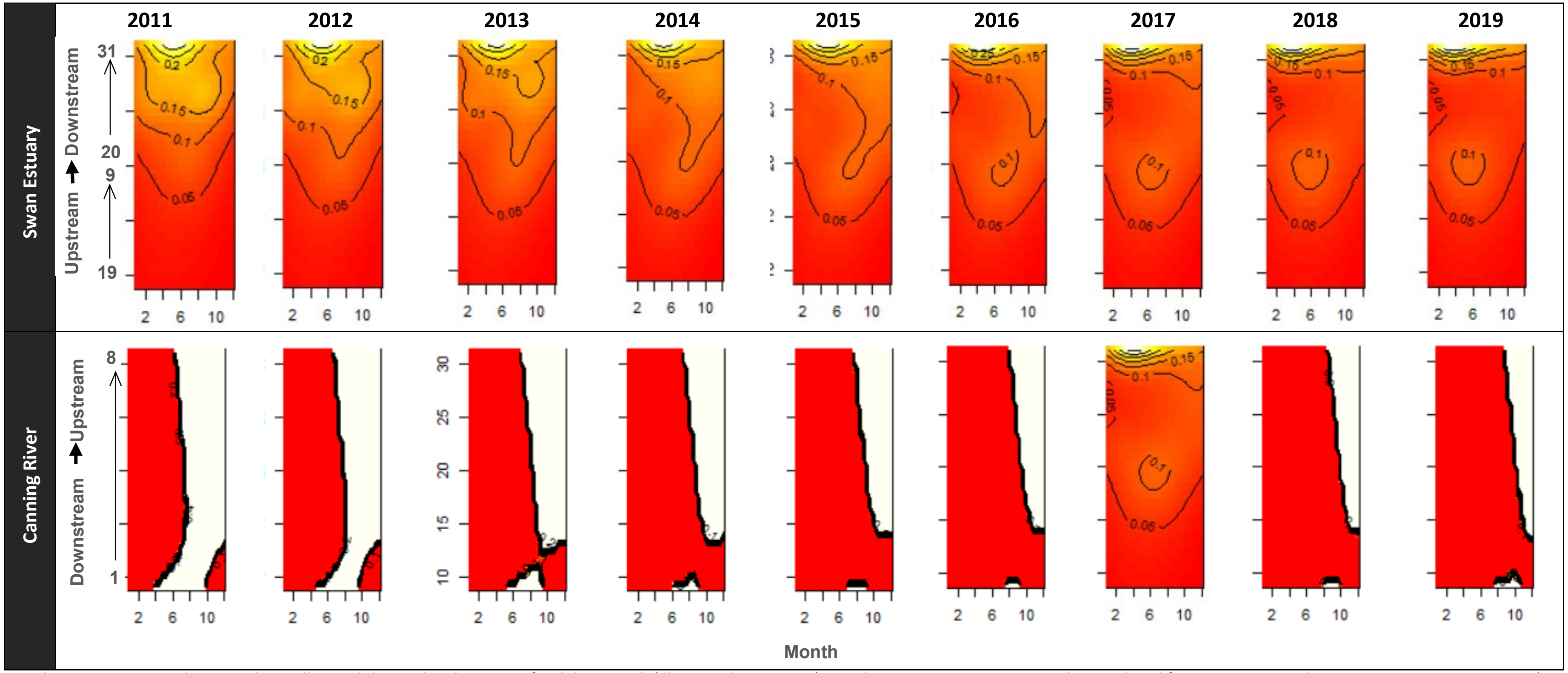
Notes: Formula: Dolphins.Sighted.Y.N ~ River + s(ZoneSeq, Year, Month, by = River, k = 15) + offset(log(Survey.duration..hours.))
Signif. codes: <0.001 = '***', 0.01='**', 0.05='*', 0.1 = '•'
R-sq.(adj) = 0.103, Deviance explained = 20.7%
UBRE = -0.144, Scale est. = 1, n = 8,292

Appendix C



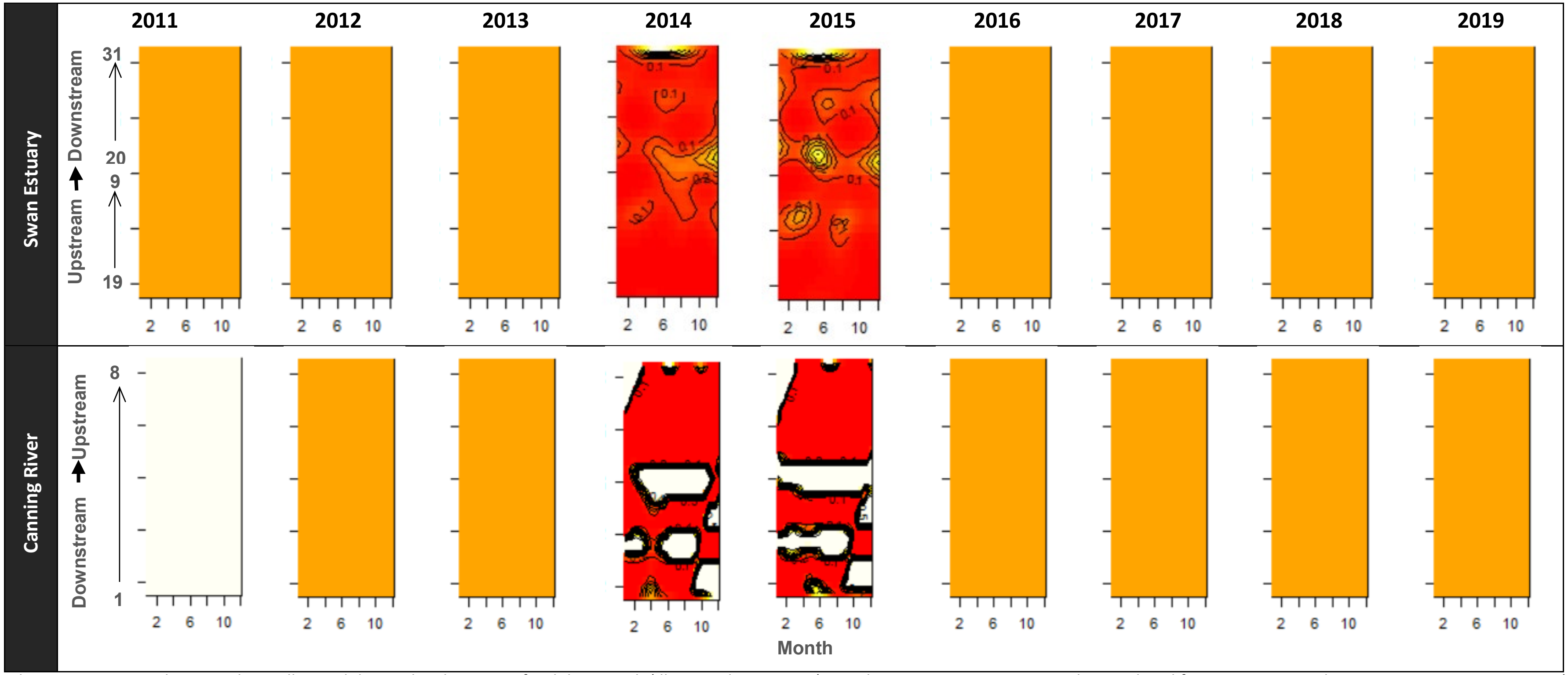
Note: the y-axis zone numbers are those allocated during development of Dolphin Watch (illustrated in Figure 1). For the Swan Estuary, zone numbers ordered from upstream to downstream are: Zones 19 to 9 (i.e., counting backwards from 19, 18, 17...) corresponding to the upper-most zone in the Swan River to Perth Waters, and Zones 20 to 31 (i.e., 20, 21, ...) corresponding to Matilda Bay to Fremantle Inner Harbour. Consequently, at Narrows Bridge there is a jump from Zone 9 (Matilda Bay) to Zone 20 (Perth Water). The y-axis scale places Swan Estuary zones in order from Upstream to Downstream, regardless of the zone numbers, thus the y-axis label has both zone numbers and direction relative to upstream/downstream.

Figure 12. Generalized Additive Model (binomial) partial response plots for *Dolphin Watch* decadal (2011-2020) dolphin groups recorded during all surveys in the Swan Canning Riverpark, Western Australia. Contour plots with values are on a scale of 0 to 1, which represents the odds of the presence of groups. Note that colour scales differ among the Canning River and Swan Estuary sectors and the values in the contour plots should be referred to for values corresponding to the colour scales.



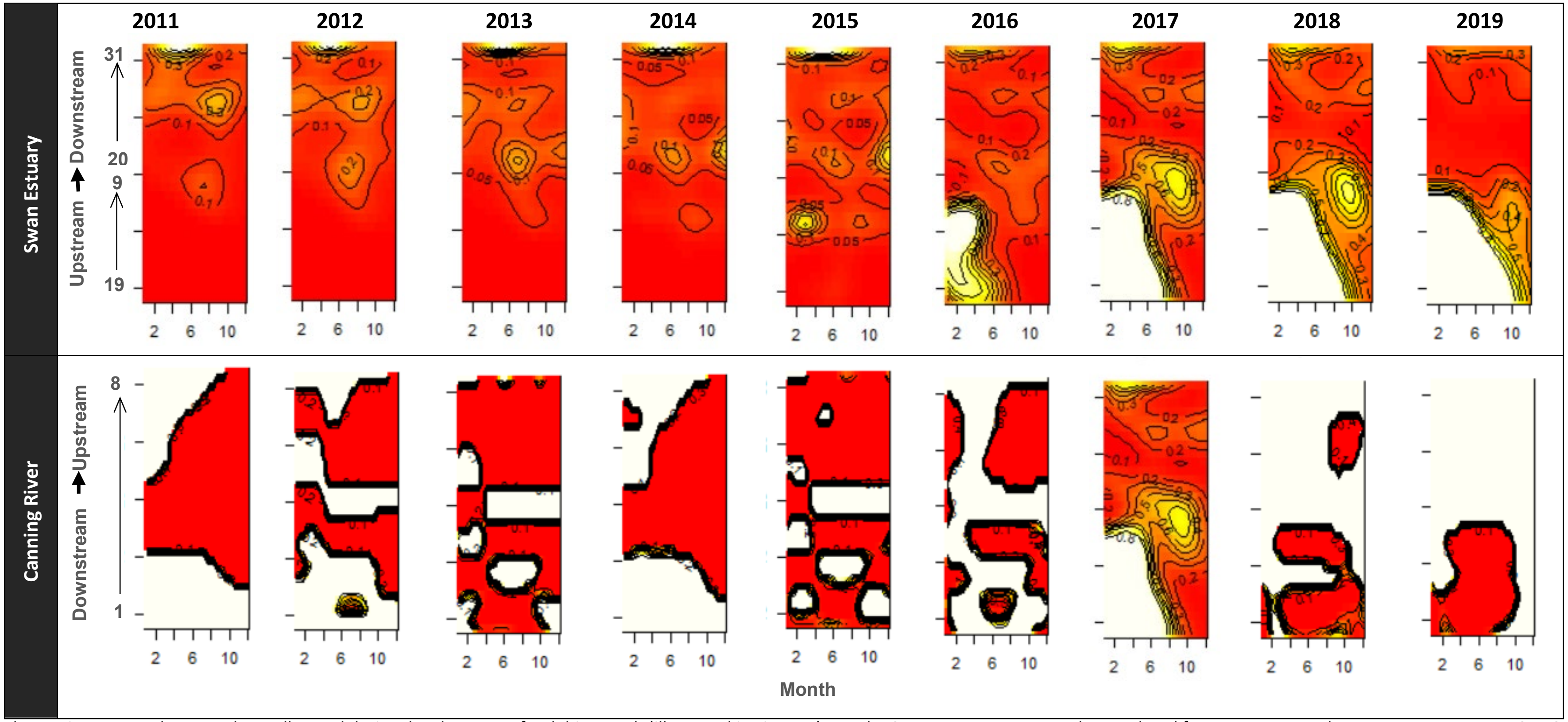
Note: the y-axis zone numbers are those allocated during development of Dolphin Watch (illustrated in Figure 1). For the Swan Estuary, zone numbers ordered from upstream to downstream are: Zones 19 to 9 (i.e., counting backwards from 19, 18, 17...) corresponding to the upper-most zone in the Swan River to Perth Waters, and Zones 20 to 31 (i.e., 20, 21, …) corresponding to Matilda Bay to Fremantle Inner Harbour. Consequently, at Narrows Bridge there is a jump from Zone 9 (Matilda Bay) to Zone 20 (Perth Water). The y-axis scale places Swan Estuary zones in order from Upstream to Downstream, regardless of the zone numbers, thus the y-axis label has both zone numbers and direction relative to upstream/downstream.

Figure 13. Generalized Additive Model (binomial) partial response plots for Scientific vessel decadal (2011-2020) dolphin groups recorded during surveys in the Swan Canning Riverpark, Western Australia. Contour plots with values are on a scale of 0 to 1, which represents the odds of the presence of groups. Note that colour scales differ among the Canning River and Swan Estuary sectors and the values in the contour plots should be referred to for values corresponding to the colour scales.



Note: the y-axis zone numbers are those allocated during development of Dolphin Watch (illustrated in Figure 1). For the Swan Estuary, zone numbers ordered from upstream to downstream are: Zones 19 to 9 (i.e., counting backwards from 19, 18, 17...) corresponding to the upper-most zone in the Swan River to Perth Waters, and Zones 20 to 31 (i.e., 20, 21, ...) corresponding to Matilda Bay to Fremantle Inner Harbour. Consequently, at Narrows Bridge there is a jump from Zone 9 (Matilda Bay) to Zone 20 (Perth Water). The y-axis scale places Swan Estuary zones in order from Upstream to Downstream, regardless of the zone numbers, thus the y-axis label has both zone numbers and direction relative to upstream/downstream.

Figure 14. Generalized Additive Model (binomial) partial response plots for Citizen science *Dolphin Watch* decadal (2011-2020) dolphin groups recorded during presence and absence surveys in the Swan Canning Riverpark, Western Australia. Contour plots with values are on a scale of 0 to 1, which represents the odds of the presence of groups. Note that colour scales differ among the Canning River and Swan Estuary sectors and the values in the contour plots should be referred to for values corresponding to the colour scales.



Note: the y-axis zone numbers are those allocated during development of Dolphin Watch (illustrated in Figure 1). For the Swan Estuary, zone numbers ordered from upstream to downstream are: Zones 19 to 9 (i.e., counting backwards from 19, 18, 17...) corresponding to the upper-most zone in the Swan River to Perth Waters, and Zones 20 to 31 (i.e., 20, 21, ...) corresponding to Matilda Bay to Fremantle Inner Harbour. Consequently, at Narrows Bridge there is a jump from Zone 9 (Matilda Bay) to Zone 20 (Perth Water). The y-axis scale places Swan Estuary zones in order from Upstream to Downstream, regardless of the zone numbers, thus the y-axis label has both zone numbers and direction relative to upstream/downstream.

Figure 15. Generalized Additive Model (binomial) partial response plots for combined Scientific vessel & Citizen science *Dolphin Watch* decadal (2011-2020) dolphin groups recorded during presence and absence surveys in the Swan Canning Riverpark, Western Australia. Contour plots with values are on a scale of 0 to 1, which represents the odds of the presence of groups. Note that colour scales differ among the Canning River and Swan Estuary sectors and the values in the contour plots should be referred to for values corresponding to the colour scales.