Investigating the Bottlenose Dolphins in the Swan Canning Riverpark Using Two Research Methods:

A Comparison between Citizen Science and Professional Science

Murdoch
UNIVERSITY

A thesis presented for the degree of Bachelor of Marine Science Honours.

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Western Australia

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June 2015

Declaration

I declare that this thesis is a true and accurate account of my research. The main content contained in this work has not been previously submitted for a degree at any other tertiary educational institution.

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Shona Wharton

Abstract

Since 2011 the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) community in the Swan Canning Riverpark in Perth, Western Australia has been studied simultaneously through a citizen science project (Dolphin Watch) and a professional science project (the Dolphin Population Assessment Project). The two projects share a common aim – to collect scientific information that supports the conservation of dolphins and their habitat – but use different methodologies.

This thesis examined how the two projects approach the study of a wildlife population and evaluated how citizen science and professional science projects can complement each other, leading to better outcomes than if one approach is applied in isolation.

Using the example of the Dolphin Watch and Dolphin Population Assessment Project; data over a one-year period was analysed. These projects ecological outcomes were assessed through: (1) quantity of sampling; (2) spatial and temporal distribution of dolphin sightings; and (3) dolphin group dynamics (group size/ sighting size). Additionally, the volunteer's motivations and level of contribution was discussed in the context of Dolphin Watch. The main goal of this thesis was to investigate the extent of these projects' ability to produce complementary ecological outcomes.

Firstly, Dolphin Watch collected a higher quantity of data than the Dolphin Population Assessment Project. Volunteers recorded a total of 2682.3 hours of sampling effort in contrast to the 64.2 hours recorded by professional scientists. Dolphin Watch volunteers recorded over 15 times more effort hours per zone than the professional scientists (Dolphin Watch = 81.28 hours/ zone; Dolphin Population Assessment Project = 5.35 hours/ zone). The higher quantity of data collected through Dolphin Watch was reflected throughout the study area and included the common monitoring zones (zones 20-31).

Data collected through Dolphin Watch was able to indicate the dolphin community in the Swan Canning Riverpark occupied all monitoring zones, which included approximately 58 kilometres of river ways. Dolphins were sighted in both the upstream Swan and Canning rivers and the downstream zones near Fremantle throughout the study period; this indicated that dolphins range throughout the Riverpark year-round. The Dolphin Population Assessment Project supported these findings by identifying the dolphin community exhibited characteristics of a resident population.

The two research projects recorded dolphin group dynamics in different ways that meant they were not directly comparable. The differences in data collection originate from the inability to uniformly identify dolphin group sizes using a specific criterion over multiple observers. Therefore, Dolphin Watch volunteers recorded the total number of dolphins within each sighting; whereas the Dolphin Population Assessment Project identified the group size based on the 100-metre chain rule.

Finally, this thesis identified examples of distinct differences between a citizen science and professional science project that studied the same dolphin community. This study supported the concept that 'the type of research question asked will influence a project's design'. Dolphin Watch and the Dolphin Population Project approached empirical research on the dolphin community differently; where their differences allowed them to complement each other and support each other's claims.

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Acknowledgements

Firstly, I would like to thank all the Dolphin Watch volunteers who contributed many hours monitoring for dolphins and submitting your surveys. I am grateful I could work with such a passionate volunteer community who are committed to caring for the dolphins in the Swan Canning Riverpark. My personal thanks go to all the staff at the Swan River Trust who makes Dolphin Watch possible: Dr Kerry Trayler, Jason Menzies, Marnie Giroud, Linley Brown, Rachel Hutton, and Carol Logue. Not only are you constantly working to keep volunteers motivated and sharing the latest dolphin news to all the volunteers; you have been encouraging and supportive to me personally throughout this research project.

Thank you to Jennie Hunt, a Dolphin Watch volunteer who worked behind the scenes to collate all survey records. You are invaluable to Dolphin Watch and were important in making my project possible. Another, invaluable Dolphin Watch volunteer who I would like to thank is Robert Broadway. The work you did to create the data management program and the recent work to integrate the smartphone app records into the Dolphin Watch database has been critical in processing the results for this thesis.

I would like to acknowledge the staff at Gaia Resources; in particular Piers Higgs and Alex Chapman. You were instrumental in designing and maintaining the Dolphin Watch smartphone app throughout the study. Your technical support was vital; from helping train volunteers in using the Dolphin Watch app to finding technical solutions to glitches that appeared after software updates.

I would like to thank Catherine Baudains for your support and knowledge of conducting surveys. Although a lot of the work that we did together could not be included into the final thesis. You were instrumental in sharing practical advice and skills in the early stages of data processing and analysing.

Thank you to Chandra Salgado-Kent whose support was crucial in processing data from Dolphin Watch and learning about how Dolphin Watch data has been analysed in the past.

Thank you to Delphine Chabanne who shared data she collected for the Dolphin Population Assessment Project. Throughout this study you have taken time to share advice, knowledge and have helped me learn about how your professional science project operated. You taught me how to analyse data through new software and shared shapefiles that were helpful in creating the many maps that were critical to present data throughout this thesis.

I would like to thank my two supervisors: Lars Bejder and Hugh Finn. You have shared your academic advice and knowledge that has been invaluable in creating this thesis and the journey that has brought me to this point. You have encouraged me to learn, grow and strive to produce my best work over the past two years. And most importantly you have believed in me throughout it all.

Personal Acknowledgements

I would personally like to thank my family and friends for their encouragement and support throughout my honours project. You have helped me keep a balanced and healthy life while letting me grow and prosper into the person who I have now become as a result of this adventurous journey that begun two years ago. A special thanks to the HillSide Youth team; who have been invaluable friends and who have shared many memorable times. Thank you to my two mentors Chrissie and Craig who have supported me through everything.

Statement on the Contribution of Others

This research was possible by the following organisations, educational institutions, industry partners and financial supporters:

Supporters of the Coastal and Estuarine Dolphin Project/ Dolphin Population Assessment Project

Curtin University

Murdoch University

Swan River Trust

Dolphin Watch

Supporters of Dolphin Watch

Murdoch University Cetacean Research Unit

Curtin University Centre of Marine Science & Technology

River Guardians

Department of Parks and Wildlife

Fremantle Ports

Supporters of the Dolphin Watch Smartphone App

Gaia Resources

Swan River Trust

River Guardians

Department of Parks and Wildlife

Government of Western Australia

Supporters/ Funders of the Coastal Walkabout App *(the citizen science app that the Dolphin Watch app was designed after)*

Marine Ventures Foundation

Duke University

Murdoch University

Gaia Resources

Lotterywest

Murdoch University Cetacean Research Unit

Marine Conservation Ecology

1. Introduction

Empirical scientific studies collect information from the environment. This information can be collected through a variety of methods and processes. Two basic approaches are ‘professional science’ and ‘citizen science’. These two modes of research, and the potential for the two approaches to complement each other, were investigated in this thesis.

‘Professional science’ and ‘citizen science’ have been compared previously in scientific literature (e.g. Evans *et al.* 2000, Bell 2007, Cox *et al.* 2012). However, these studies have tended to focus on qualitative comparisons. The few quantitative comparative studies have focused on validating and assessing the accuracy of data collected by citizen scientists and by professional scientists (Darwall & Dulvy 1996, Cox *et al.* 2012). For example, Darwall and Dulvy (1996) reported that volunteer divers can collect reliable data for baseline reef fish surveys, including estimating fish lengths with 80% accuracy after three training dives. Volunteers are able to collect community level algae and invertebrate data within the range of variation seen in data colelcted by professional researchers (Cox *et al*. 2012).

This thesis undertook a quantitative and qualitative comparison of ‘professional science’’ and ‘citizen science’. In particular, this study investigated the methods used, data collected and results obtained for two separate research projects, one applying a ‘professional science’ approach and the other involving a large-scale ‘citizen science’ program. Both projects have the same aim – to obtain information about a local population of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) so as to inform management and conservation actions. The central argument of this thesis was that both approaches have strengths and weaknesses but, if applied together, the two approaches can complement each other and lead to outcomes that would not have been possible if they had been applied in isolation.

This chapter reviews the terms ‘professional science’ and ‘citizen science’ and describes the study and study population. It then discusses the two research projects that the study evaluates and develops a conceptual framework for how to compare professional science and citizen projects. The chapter concludes by presenting the overall aims of the thesis.

1.1 Terminology

The term ‘professional science’ is used in this thesis to describe the mode of data collection that is used by trained professional researchers who objectively study a specific topic within a research discipline (Strand 2003). This term is used in scientific literature as a comparative term to ‘citizen science’. For example, Conrad and Hilchey (2011) uses the term ‘professional scientists’ to describe people who conduct research within the context of disciplined task-orientated research. Additionally, the term ‘professional expert’ is used to describe research scientists who collect data for the purpose of developing specific knowledge on a research topic (Fischer 2000). In this thesis, the term ‘professional science’ was used to describe the type of research that is conducted through rigorous methods that conform to methods associated with the field of research.

In contrast, the term ‘citizen science’ is used in this thesis to describe the mode of data collection that sources information from a large and diverse range of people who volunteer within a community program (Reynolds 2009). This term is used in scientific literature among other terms such as ‘community based monitoring’ (Conrad & Hilchey 2011). Additionally, the term ‘amateur scientists’ has been used to describe people who participate in citizen science project (Henden 2011, Gura 2013).

1.2 Study Area and Population

Previous research has identified the presence of Indo-Pacific bottlenose dolphins in the Swan Canning Riverpark in Perth, Western Australia (115^{o}48’E, 32^{o}04’S) (Finn 2005, Chabanne *et al.* 2012). These studies indicate a resident dolphin community comprised of individuals who range within the estuary waters, are present year-round, and maintain stable associations with other members of the community. The population abundance from 2001 to

2003 was estimated at 17 or 18 individuals (excluding calves) (Finn 2005, Chabanne *et al.* 2012). These studies also indicate that dolphins observed within the Riverpark also use adjacent coastal waters.

The study area for this study encompassed the Swan Canning Riverpark and the Inner Harbour of the Port of Fremantle, which is located at the mouth of the Swan Canning Estuary and which is adjacent to the City of Fremantle (Fig 1). The length of the Inner Harbour is ~2.6 km from where the Harbour joins the Indian Ocean to the start of the Riverpark. The study area covers ~55 km of the waterways, including the Upper Swan and Canning River.

The Swan Canning Riverpark was gazetted in 2006 as the name for a river and estuarine reserve encompassing both the Swan and Canning Rivers. The Swan-Canning Estuary is a tidal estuary that is open to the Indian Ocean. The Inner Harbour was not gazetted as part of

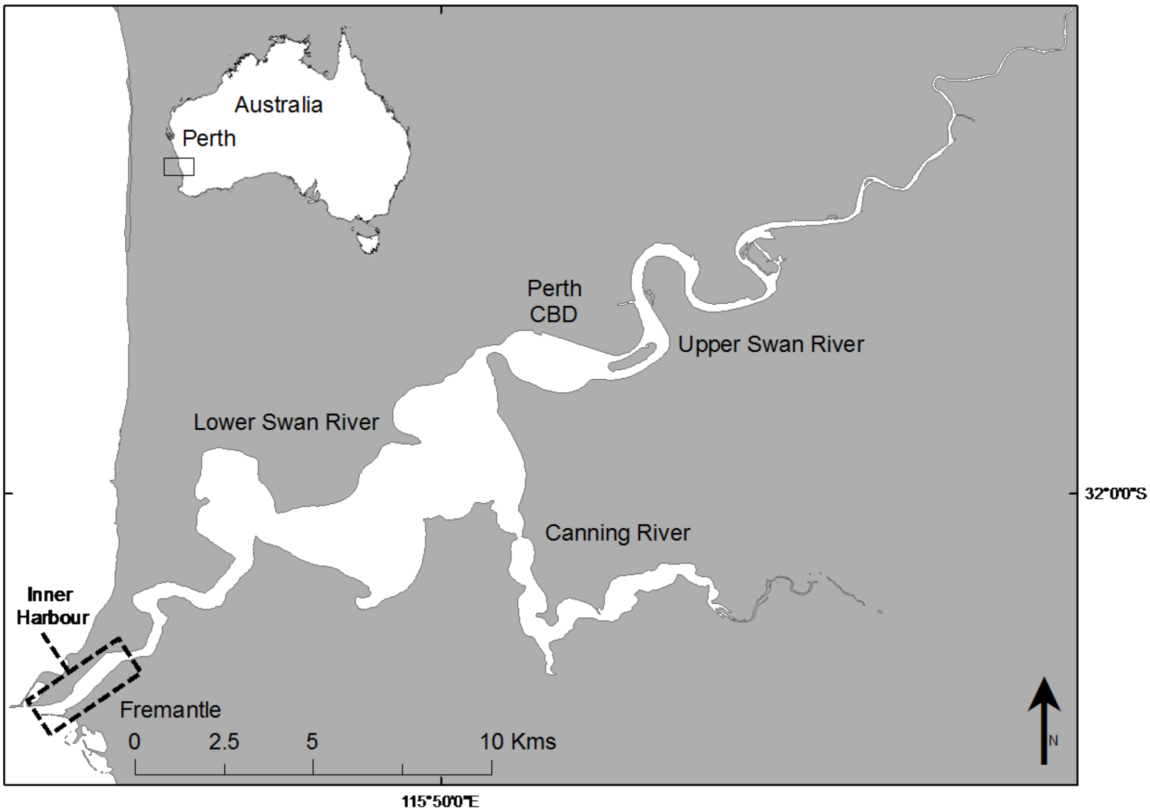


Figure 1.1 Map of the study area, showing the spatial extent of the Swan Canning Riverpark and the Inner Harbour.

the Riverpark. The Inner Harbour is part of the Port of Fremantle which is the major shipping port that services Perth, the state capital of Western Australia.

1.3 Seasons

For this thesis, data analyses were restricted to data collected over a period of one year: March 2014 until February 2015. It was necessary to restrict analyses to one year of data because of changes in the data collection methodology for the citizen science project investigated (Dolphin Watch), notably the introductions of smartphone application in March 2014 (see Chapter 2).

Data was partitioned and summarised the across four austral seasons: autumn (March–May), winter (June–August), spring (September–November) and summer (December–February). The same seasons were used for data collected through both citizen science and professional science projects.

1.4 Citizen Science – Dolphin Watch

This thesis investigated the Dolphin Watch citizen science project. Dolphin Watch involved trained volunteers who collected observational on bottlenose dolphins in the Swan Canning Riverpark within the Perth metropolitan area.

Registered and trained volunteers (hereafter also referred to as ‘Dolphin Watchers’) collected information on the presence and absence of dolphins within the study area. Dolphin Watchers were able to collect and submit their dolphin observations via two different data submission modes. Volunteers could either choose to submit their data through an online monitoring form on the projects website or submit data via the custom-developed Dolphin Watch smartphone application (or ‘app’).

Dolphin Watchers submitted data by completing a standardised survey form which contained specific questions designed to collect targeted information.

Similar data were collected through both the online submission form and the Dolphin Watch app; however the process and structure of how the information was collected varied. The website relied on Dolphin Watchers to manually complete all data fields whereas the smartphone app automatically recorded information sourced from the smartphones features. For example, the spatial location of dolphin sightings were automatically determined using the smartphone's Global Positioning system (GPS).

The Dolphin Watch study area was divided into 33 monitoring zones (Figure 2). Dolphin Watchers used these monitoring zones to indicate their location within the Riverpark; data can be collected from all of these zones.

1.5 Professional Science – Dolphin Population Assessment Project

This thesis investigated the 'Dolphin Population Assessment Project' that studied the bottlenose dolphins around Perth, Western Australia using a professional scientific approach. This project is run by PhD candidate Delphin Chabanne who is collecting data on the Perth dolphin population as part of her PhD. This research is conducted as a part of the Murdoch University Cetacean Research Unit (MUCRU), which aims to evaluate the ecology and population structure of dolphins in coastal and estuarine waters (MUCRU 2014). This research project is part of a larger, more extensive research collaboration that aims to assess the health of the dolphins in the Perth region, which includes the Swan Canning Riverpark. The Coastal and Estuarine Dolphin Project incorporates professional research conducted by two local universities, Curtin and Murdoch universities. The data used in this thesis originates from this project.

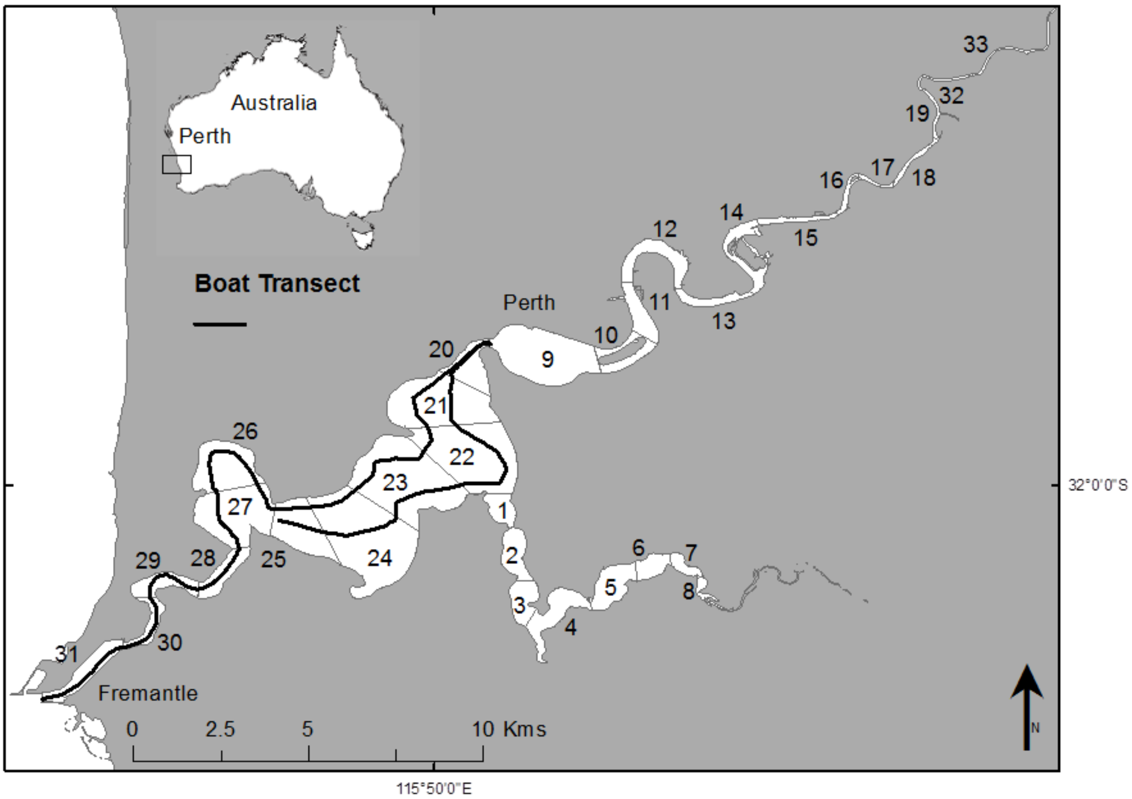


Figure 1.2 Map depicts the 33 monitoring zone that were used for the Citizen Science Dolphin Watch project. In contrast, a pre-determined boat transect route (dark solid line) was repeated surveyed for dolphins in the Professional Science Dolphin Population Assessment Project.

The Population Assessment Project collected dolphin data along a pre-determined boat transect route that covers 12 of the 33 Dolphin Watch monitoring zones, covering 68% (27.73 km^2) of the total area covered through Dolphin Watch (40.77 km^2, Figure 2). These zones are in the lower reaches of the Swan River and are closest to the river mouth.

The Population Assessment Project aimed to collect professional scientific knowledge to relevant government organisations and industry corporations to aid in the conservation of the local bottlenose dolphin population (MUCRU 2014). This was achieved by sharing the acquired knowledge with the general community as well as the wider scientific community. The lead professional researcher involved in this project communicated knowledge obtained with the Dolphin Watch citizen science community through training and upskilling events.

1.6 Observational Wildlife Research

1.6.1 Data collected in Field Studies of Wildlife

Field studies of wildlife typically collect data through visual or (less frequently) acoustic observations of free-ranging animals. An individual encounter is often referred to as a ‘sighting’ and various data may be collected during the course of a sighting. While specific research questions will vary, the main over-arching research questions associated with field studies generally relate to quantifying the abundance, spatial distribution, and temporal patterns of wildlife (e.g. Durden *et al.* 2011, Gnone *et al.* 2011)(Table 1). Research projects that cover multiple species may also collect data related to species identification. The two research projects investigated in this thesis collected data on a single species – the Indo-Pacific bottlenose dolphin.

The research questions driving a field study will determine the types of data that are collected. For example, to investigate the spatial distribution of a species the location of sightings is often recorded (e.g. Bruce *et al.* 2014). To study what times the species is present in certain locations, sighting data is associated with a time period, such as date, month or season. Exploring species density in a study area requires sighting data such as group counts (or group size) and total individual counts (e.g. Barlow & Forney 2007, Davidson *et al.* 2014).

Table 1.1 Overview of the types of data and results associated with typical research questions within observational wildlife research studies.

Research Questions	Data Collected	Examples of Outcomes from Analyses
Spatial patterns	Location of sightings Presence/absence of species at locations	eographic Extent/ Range esidency abitat use ovements depending on environmental characteristics (e.g. temperature or salinity) ollution Impact (spread from point source)
Temporal patterns	Date and time of sighting	easonal Changes nnual Movements el patterns ogressive Change ehabilitation ollution Impact (rate of contamination)
Abundance	Number of Individuals Number of Group Sightings	otspots opulation Size obability of Sighting oup Size
Individual Identity	No. of species present Individuals present in group Individual Identification	Diversity Social Association Survival Genetic Associations

To reliably assess the number of individual dolphins that reside in a study area it is helpful if individual animals can be reliably identified over time, either through natural marks or some method of placing tags on individuals (Connor *et al.* 2000, Whitehead *et al.* 2000a). Individual identification data can then be used to produce sighting histories for each individual. Research that records the individual identities of the target species allows a wider range of potential analyses (Mann 2000). In dolphins, for example, research that identifies individuals can study dolphin association patterns (e.g. Smolker *et al.* 1992, Lusseau *et al.*

2003), relationships between habitat and foraging behaviour (e.g. Hastie *et al.* 2004), estimate their age and reproductive condition (Wells 1998).

1.6.2 Research Questions

Field research typically aims to support wildlife conservation through developing an understanding of the components that build a community, its structure, and the features that impact the target species.

Describing the geographic extent of wildlife can define effective conservation boundaries and areas of impact to a community. Spatial information is critical in investigating a community's residency pattern or its use of space. Determining whether a community occupies its geographic extent constantly or exhibit movement patterns is important to implementing management strategies. Additionally, geographic data linked to environmental data can provide insight to the use of habitat. For example, Smith (2012) investigated habitat frequented by dolphins in Bunbury, Western Australia.

Quantifying a wildlife community with data such as abundance measures is instrumental in evaluating the population size and the locations where large quantities are observed. Identifying hotspots and the number of individuals that frequent these hotspots is critical to inform decision makers about the spatial locations where conservation strategies will be most effective. For example, Bruce *et al.* (2014) identified sheltered coastal waters as critical conservation hotspots for migrating humpback whales along the eastern coast of Australia.

Identifying individuals within a wildlife community is necessary when exploring the associations and survival probability (Whitehead *et al.* 2000a). These components are important when assessing the social structure, the health of a wildlife community and how it can be managed effectively.

1.7 Thesis Context

Citizen Science and Professional Science have the potential to collect similar types of data (e.g. spatial and temporal patterns), but with different levels of accuracy, degrees of details, or intensities of data collection. Some research questions will be better answered through the results generated through a professional science project (e.g. Vermeulen & Cammareri 2009, Durden *et al.* 2011), whereas some questions will be better answered through a citizen science project (e.g. Sullivan *et al.* 2009, Ries & Oberhauser 2015).

Sometimes the two approaches are thought of as competing approaches to answer the same or very similar problems (e.g. the geographic extent of a species). They may also involve separate studies of the same population or species seeking answers to different questions.

1.8 Aims of Thesis

This thesis took a different perspective – it examined how the two approaches could be applied in synergy, with each approach collecting different data but in the pursuit of a common or integrated purpose. Specifically, this thesis investigated how the two approaches could produce complementary results for the same wildlife population – *i.e.* the Indo-Pacific bottlenose dolphin community in the Swan Canning Riverpark. Both the Population Assessment Project and Dolphin Watch aimed to increase knowledge about the dolphin community and thereby support the conservation of dolphins and their habitat, though the methods they used for collecting data differed in important ways. Thus, at the heart of this thesis is the proposition that professional science and citizen science ought properly to be understood in the context of each other and in the context of broader conservation objectives, with the two approaches having different but often mutually supporting capacities for the collection of information about wildlife and their environment.

The second and third chapters assessed the two empirical research projects – Dolphin Watch and the Dolphin Population Assessment Project. The common areas these projects investigated include: (1) spatial and temporal distribution of dolphin sightings; and (2) the number of dolphins present in dolphin sightings. The Dolphin Population Assessment Project, by virtue of its more rigorous scientific methodology and – in particular – the ability of researchers to identify individual dolphins, was also able to investigate the ecology of the dolphin in greater detail. In addition, this thesis looked at Dolphin Watch as a model citizen science program through which it was possible to investigate several issues of general interest in citizen science, including trends in volunteer contribution in response to training events and the introduction of novel reporting technologies.

The final chapter compared the two modes of research. This investigation identified three key overlapping areas and how the same kind of data could produce different ecological outcomes. The ecological outcomes produced through Dolphin Watch were to describe basic environmental patterns related to the dolphin community. The Dolphin Watch project produced outcomes relating to: (1) the spatial extent of the dolphin community; (2) variability and commitment of volunteers; and (3) the impact of volunteer's motivations. The ecological outcomes produced through the Dolphin Population Assessment Project described the dolphin community. The Dolphin Population Assessment Project produced outcomes covering: (1) abundance; (2) movement patterns; (3) probability of survival; and (4) sighting frequency. These different outcomes are explored in this final chapter to show how these two research modes can work together where their outcomes are complementary to each other. The chapter show that by combining the information gathered from citizen science volunteers and the professional science researchers the depth and speed that knowledge can be integrated into conservation increases.

2. Using Citizen Science to Collect Quantitative Information on Bottlenose Dolphins in the Swan Canning Riverpark

2.1 Introduction

Citizen science projects obtain scientific knowledge by using volunteers to collect data. This knowledge can then be used to inform environmental management and conservation strategies (Thiel *et al.* 2014). For a citizen science project to successfully contribute to conservation strategies, the project typically must collect a large quantity of data to decrease the effects of biases during data collection (Tonachella *et al.* 2012). Previous citizen science studies have aided wildlife conservation by collecting data on the migratory patterns of humpback whales (Bruce *et al*. 2014), the distribution and relative abundance of cetaceans (Davidson *et al.* 2014), and the location of spatial hotspots for reef fishes (Pattengill-Semmens & Semmens 2003). Additionally, Sequeira *et al.* (2014) identified suitable habitat for koalas, and Branchini *et al.* (2015) described the biodiversity and spatial variations of Egyptian coral reefs.

Ultimately, the ability of a citizen science project to contribute to wildlife conservation depends on the project's capacity to collect sufficient data to obtain accurate conclusions to specific research questions. For example, Davies *et al.* (2012) analysed photographs of whale sharks taken by citizen scientists to obtain an abundance estimate through mark-recapture that was similar to findings by professional scientists. Another citizen science project provided evidence that humpback whales prefer warm, shallow and relatively protected waters for their breeding grounds, making the project a valuable management resource for monitoring whale distribution and abundance around Maui, Hawai'i (Davidson et *al.* 2014).

Generally, citizen science projects focus on collecting data relating to wildlife abundance and distribution (e.g. Sequeira *et al.* 2014, Thiel *et al.* 2014). Abundance and distribution data has been collected for a wide range of species, including koalas (*Phascolarctos cinereus*) (Sequeira et al. 2014), invasive species of crabs (Delaney *et al.* 2007), cetaceans (Davidson *et al.* 2014), and whale sharks (Davies *et al.* 2012). Additionally, citizen science projects have collected data at a broad range of spatial and/or temporal scales (Bonney *et al.* 2009, Sullivan *et al.* 2009, Dickinson *et al.* 2012). For example, Ries and Oberhauser (2015) documented the abundance and distribution of monarch butterflies across the North American continent, and Sullivan *et al.* (2009) identified how the data collected for the eBird citizen science project could be used investigations across several spatial and temporal scales.

Citizen science projects may have particular utility for wildlife species that occur over a large geographic area because a system of volunteer observers can collect observations at a broad spatial scale and for an extended time period (Bruce *et al.* 2014, Davidson *et al.* 2014). For example, the eBird project has demonstrated a sustained data flow since 2003 (Sullivan *et al.* 2009), and Ries and Oberhauser (2015)a citizen project in North and Central America records the migration of monarch butterflies over distances of up to 4500 km (Ries & Oberhauser 2015). Projects (including Dolphin Watch) that successfully incorporate smartphone technology into the data collection phase have an advantage of using GPS-enabled devices to validate spatial data (Elwood *et al.* 2012, Bruce *et al.* 2014, Sequeira *et al.* 2014). In contrast, observations by professional scientists may be limited to observations at a particular time and place, even if the quality or utility of the data recorded is greater.

Some cetaceans range over large spatial areas (Whitehead *et al.* 2000a), which poses challenges for management and conservation. Even cetaceans that are resident in coastal or estuarine areas may have home ranges that extend over dozens of square kilometres. Citizen science projects that collect ecological data for cetaceans can therefore have practical benefits for cetacean conservation (Davies *et al.* 2012, Embling *et al.* 2015).

2.2 Aims of Chapter

I used the presence and absence data collected by Dolphin Watch volunteers to assess the frequency of dolphin sightings and the geographic range for dolphin encounters. This chapter aimed to describe the basic ecological patterns relating to the dolphin community and discuss volunteer's contribution and motivations. The basic ecological outcomes were produced by investigating: (1) the spatial and temporal distribution of dolphin sightings; and (2) the number of dolphins present in dolphin sightings. The main goal of this chapter was to explore what outcomes can be produced by Dolphin Watch and the extent of limitations related to other citizen science projects.

2.3 Methods

2.3.1 Field Methods

The study area (the Swan Canning Riverpark and Fremantle Inner Harbour) was divided into 33 monitoring zones (Figure 2.1) in which Dolphin Watch participants recorded the presence or absence of dolphins. Data was collected from 1 March 2014 until 28 February 2015. A survey was defined as when a volunteer was actively looking for dolphins within a given zone, *i.e*. when they were "on effort" documenting dolphin presence or absence within a zone. The duration of a survey was the time spent monitoring for dolphins within a single zone. If the person moved to an adjoining zone, the preceding survey would end, and a new survey would be recorded for the new zone.

Surveys can be carried out whenever and for as long as the volunteer wishes. Surveys that ran for longer than 10 consecutive hours were omitted from the analysis. The duration of a survey was recorded in hours and was a required field for every survey. Volunteers also recorded the duration of sightings.

When a dolphin group was sighted, a sighting was recorded. A sighting recorded dolphin presence within one of the 33 monitoring zones. A dolphin sighting was defined as the presence of one or more dolphins. Each sighting was restricted to one monitoring zone and recorded the total time that the dolphin group was observed within that zone.

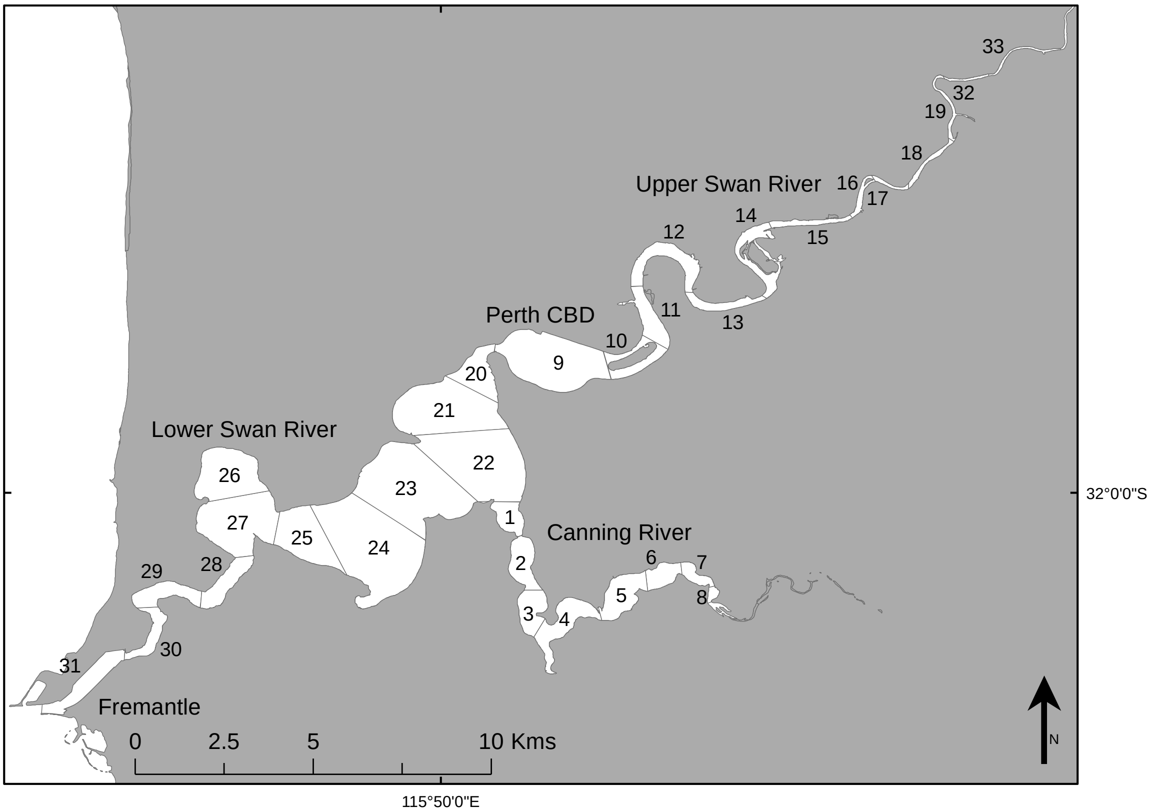


Figure 2.1 Dolphin Watch study area showing the 33 monitoring zones.

Monitoring Zones

The monitoring zones were designed for the Dolphin Watch project and allowed participants to record their spatial location without the need of a device to obtain a GPS coordinates. Monitoring zones vary in size from 0.08 km^2 to 5.10 km^2. The middle of the estuary is the widest part and the monitoring zones in this region have the largest spatial area. The zones in the upper reaches of the Swan and Canning rivers are much narrower and have a smaller spatial area. The average area for a monitoring zone is 1.17km^2 (SE± 0.22).

Submitting Observational Data

Dolphin Watch volunteers could log information on dolphins via one of two modes (online form or Dolphin Watch app), each of which consisted of a monitoring form that contained a series of specific questions. Specifically, the forms asked for information pertaining to each survey, including information about the participant, time of the survey, zone being surveys and any dolphin present (Figure 2.2). In the event that no dolphins were sighted during a survey, participants were asked a minimum of 10 questions. A total of 18 questions were asked when dolphins were sighted. Participants answered these questions through the Dolphin Watch website at any time after conducting their survey or immediately following a survey through the DW app. Both collection methods recorded the same information. However, there were differences in how information was collected.

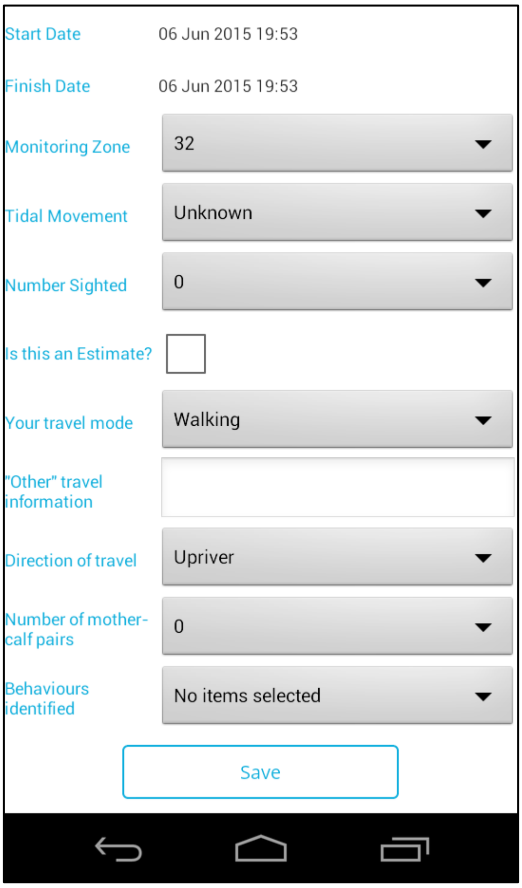


Figure 2.2 The monitoring form from the Dolphin Watch app that is volunteers competed after every survey. Additional to this information; the identity of the volunteer would be recorded when they logged into the app or website using their unique identification code and password. (Android version shown)

Where all the information was entered manually through the online monitoring form, some information was automatically recorded when using the DW app. For example, the DW app automatically recorded information about the date, start time, end time, and monitoring zone. When a survey was submitted through the DW app, up to eight questions were automatically completed such as time, GPS location, start and finish times for surveys and sightings, and monitoring zones.

Additionally, the process from participants completing the monitoring form and the information being loaded onto the database was different between the online monitoring form and the app. Once a participant completed the online monitoring form, the data was directly included in the database. However, once a participant completed the monitoring form through the DW app, it was only saved onto their smartphone, and the participant separately uploaded the data via the internet. The records from smartphones were stored separately and processed twice each week before being loaded to the database.

Whether submitted from the website and from the app, all records were subject to quality control procedures. Records with inconsistencies were removed from the database before analysis. Inconsistent records included: records where the participant did not attended the initial training event; a survey covering multiple zones; a survey with the dolphin observation time outside of the survey time; and a survey with inconsistent start and finish dates.

Quality Control Checks

All survey entries were inspected for inconsistencies, technical and human errors. All entries that did not pass all quality control checks were deleted and omitted from analysis. Surveys were deleted if they: (1) recorded more than 10 hours continuous effort; (2) if the total effort recorded was less than one minute; (3) the dolphin sighting time was outside of the survey time; (4) the survey was not conducted by a trained volunteer; and (5) the survey recorded effort in multiple monitoring zones.

Provenance of the data

Two dates were recorded for each survey; the date the survey was conducted and the date the submission was uploaded onto the Dolphin Watch database. Often there was a time lapse between these two dates. The time lapse is defined as the length of time between a survey's finish time and the date/ time the record is uploaded onto the Dolphin Watch database. For submissions made through the website, this occurs when the form is completed and submitted online. The upload date/ time for smartphone records occurs after three steps; volunteers have completed the monitoring form on their smartphones, they uploaded the record where it was stored in a separate data-storage, before being loaded into the Dolphin Watch database twice a week.

Time lapse data was transformed by $\log_{10}$ to achieve normalcy which was assessed through Anderson-Darling Test. A student t-test was used to make comparisons between the time lapse between Dolphin Watch records that recorded absence only and records with dolphin presence.

Volunteer Training

Volunteers were trained through an information and registration evening. Training consisted of a 2.5 hour presentation where volunteers learn about dolphins in the Swan Canning Riverpark and how they can record dolphin sightings. The dolphin population was described by either a Murdoch or Curtin University researcher, who shared general facts about the Swan Canning Riverpark dolphins that had been derived from current professional research and past results from Dolphin Watch. Information given to volunteers included: how to identify individual dolphins by comparing the dorsal fins, identifying behavioural characteristics, and current known population size.

Through the training Dolphin Watch volunteers were trained to conduct surveys that recorded the presence/ absence of dolphins within defined zones in the Swan Canning Riverpark and the Inner Harbour of the Port of Fremantle. Volunteers were instructed how to identify the presence of a mother-calf pairs. Volunteers recorded the number of dolphins observed and the number of mother-calf pairs present, though volunteers had the option of recording “unknown” as a response for these abundance measures.

2.3.2 Statistical Analysis

Survey data was analysed to quantify the number of dolphin sightings, total dolphin counts, and the survey effort. Dolphin data was quantified for each monitoring zone. The total number of dolphins encountered by volunteers was derived from the number of dolphin sightings and the recorded group size.

The effort hours recorded in each monitoring zone was transformed by square-root to achieve normalcy, which was tested through an Anderson-Darling test. A one-way ANOVA was used to compare the quantity of effort and the number of surveys recorded between the monitoring zones.

The volunteer effort corresponding to the time of day was analysed; where a day was broken into 1-hour time periods. The total number of surveys was used to compare effort. If a survey was conducted over more than one time period then the survey was broken into one hour segments to account for these long surveys. For example, if a survey was conducted from 6am - 8am, this survey would be counted twice as it covered two hours.

Volunteer data was analysed to quantify: the number of volunteers who joined Dolphin Watch; the date when they were trained; the date when they began recording surveys; and how many surveys volunteers contributed across the study period. Two categories of volunteers were recognised; (a) existing volunteers who had already joined Dolphin Watch prior to the start of this study (i.e. before March 1st 2014) and (b) new volunteers who joined during the study (i.e. between March 2014 and February 2015).

Uptake

The uptake rate was defined as the number of volunteers who started ‘actively’ submitting surveys during the study period. Volunteers were classified as active after they had submitted their first survey. The volunteer uptake was determined by the date a trained volunteer began ‘actively’ submitted surveys. For existing volunteers, they may have contributed to Dolphin Watch previously before the study began in March 2014 but these previous considerations were not taken into consideration for this study.

Level Volunteer Contribution

Volunteer contribution was defined as how long a volunteer would continue to contribute surveys to Dolphin Watch. This was calculated by categorising each individual volunteer as an ‘active volunteer’ or an ‘inactive volunteer’ for each day throughout the study. An ‘active volunteer’ was defined as an individual who had: (a) recorded a survey previously during the study period, and (b) had recorded a survey sometime in the future during the study period. This meant that each individual volunteer only had one period of time that they were classified as ‘active’ (Figure 2.3). The level of volunteer contribution on any given day was calculated by the number of volunteer who were classified as active.

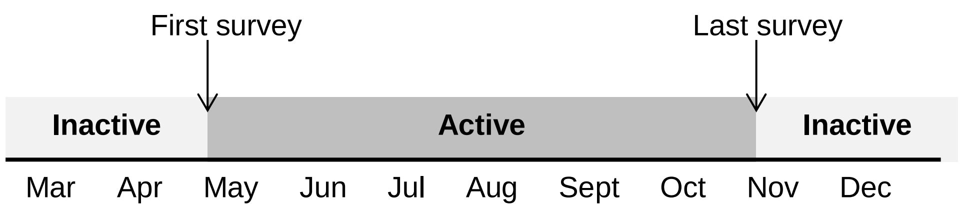


Figure 2.3 Example of the time frame that a volunteer would be classified as ‘active’ and ‘inactive’ during the one-year study.

2.4 Results

Summary Statistics

Dolphin Watch volunteers recorded surveys throughout the study period. A total of 5100 surveys were submitted between March 2014 and February 2015. At least one survey was submitted on every day (n = 365 days) of this period except for 21 February 2015.

Only 4330 surveys were considered for statistical analysis, with 875 (17%) being excluded after failing to pass a quality control check (Table 2.1). Of these 4330 surveys, 2841 (66%) were recorded through the online form on the website and 1489 (34%) were recorded through the DW app.

Sampling effort differed across seasons, with autumn (March – May) recording the highest combined sampling effort hours with 762.8 hours monitoring for dolphins throughout the Swan Canning Riverpark (Table 2.1). The most surveys were recorded in spring (1463, 34%) which also saw the highest number of volunteers (93 individuals out of the total 164 volunteers who were active sometime during the study). Summer recorded the lowest number of volunteer with only 60 individuals recording a survey (Table 2.1).

More volunteers submitted their surveys through the website monitoring form than those who used the DW app (Table 2.1). For both the website and DW app submission methods, the number of individual volunteers decreased across the study.

Table 2.1 Summary statistics for data collected through the Dolphin Watch website, Dolphin Watch smartphone app, and both methods combined.

	Website					App					Combined				
	AUT	WIN	SPR	SUM	TOTAL	AUT	WIN	SPR	SUM	TOTAL	AUT	WIN	SPR	SUM	TOTAL
Number of Surveys	820	593	934	494	2841	282	291	529	387	1489	1102	884	1463	894	4330
Number of Sightings	155	123	74	98	450	32	48	43	45	168	187	171	117	143	618
Sightings Per Hour	0.24	0.27	0.14	0.17	0.20	0.28	0.40	0.31	0.52	0.34	0.25	0.30	0.17	0.22	0.23
Number of Dolphins	406	332	201	248	1187	73	127	89	79	368	479	459	290	327	1555
Effort Hours	649.4	458.4	540.7	572.9	2221.5	113.4	120.7	140.8	86.0	460.9	762.8	579.2	681.4	658.9	2682.3
Number of Volunteers	80	66	66	43	135	27	23	19	19	63	91	81	93	60	164
Sighting Size	2.6	2.7	2.7	2.6	2.6	2.6	2.8	2.3	1.9	2.4	2.6	2.7	2.6	2.4	2.6
Standard Error	*0.09*	*0.12*	*0.10*	*0.12*	*0.05*	*0.18*	*0.18*	*0.14*	*0.12*	0.08	*0.08*	*0.09*	*0.09*	*0.09*	*0.04*

Number of Surveys records the total number of times that a volunteer monitored for dolphins; this includes both presence and absence.
Number of Sightings records the total number of times that a volunteer sighted dolphins within a survey; this indicates presence only surveys.
Number of Dolphins is the accumulative number of dolphins that are sighted, irrespective of their individual identities.
Effort Hours is the quantitative measure that records the length of time that volunteers spent monitoring for dolphins; this includes both presence and absence.
Number of Volunteers is the number of individual volunteers that recorded surveys. This does not take into consideration the volunteers who recorded multiple times.
Sighting Size is the total number of dolphins recorded within a sighting.

A larger quantity of surveys, dolphin sightings, and effort hours was submitted through the website. A total of 450 (73%) of dolphin sightings were recorded through the website, whereas there were 168 (27%) of sightings through the DW app. A total of 618 dolphin sightings were recorded, with 1555 dolphin encountered during surveys (Table 2.1).

The average sighting size was consistent over the whole study period with the average sighting size was 2.6 (SE ± 0.04) dolphins. Most of the dolphin sightings (n = 485, 75%) reported a sighting size between one and three dolphins (Figure 2.4). Only 66 (11%) of sightings reported over five dolphins present.

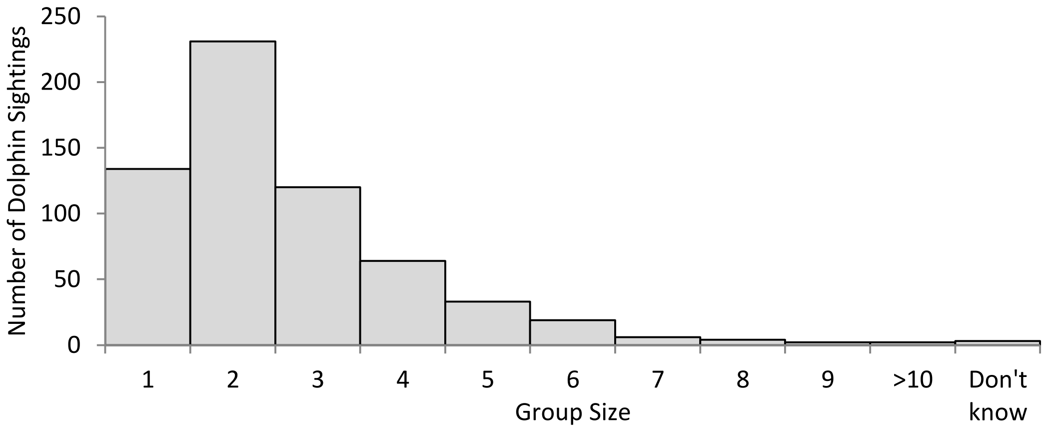


Figure 2.4 Frequency of sighting sizes recorded by volunteers.

Geographic Extent and Intensity of Survey Effort

During the study period, all 33 zones were surveyed for dolphins (Figure 2.5). The average effort hours spent in each zone was 81.3 hours (SE ± 15.4). Survey effort varied across the monitoring zones throughout the study (one-way ANOVA; df = 32; F = 22.41, P <0.01). The amount of survey effort for a zone varied from 4.2 hours (Zone 7 – Canning River) to 428 hours (Zone 5 – Canning River).

Temporal Distribution of Effort

The most popular time period for volunteer to monitor for dolphins was between 7am and 9am (2874 surveys; 44%) (Figure 2.6). The majority of effort was recorded between 6am and 6pm (6506 surveys; 99%). A small peak was also seen from 4pm-6pm (921 surveys; 14%).

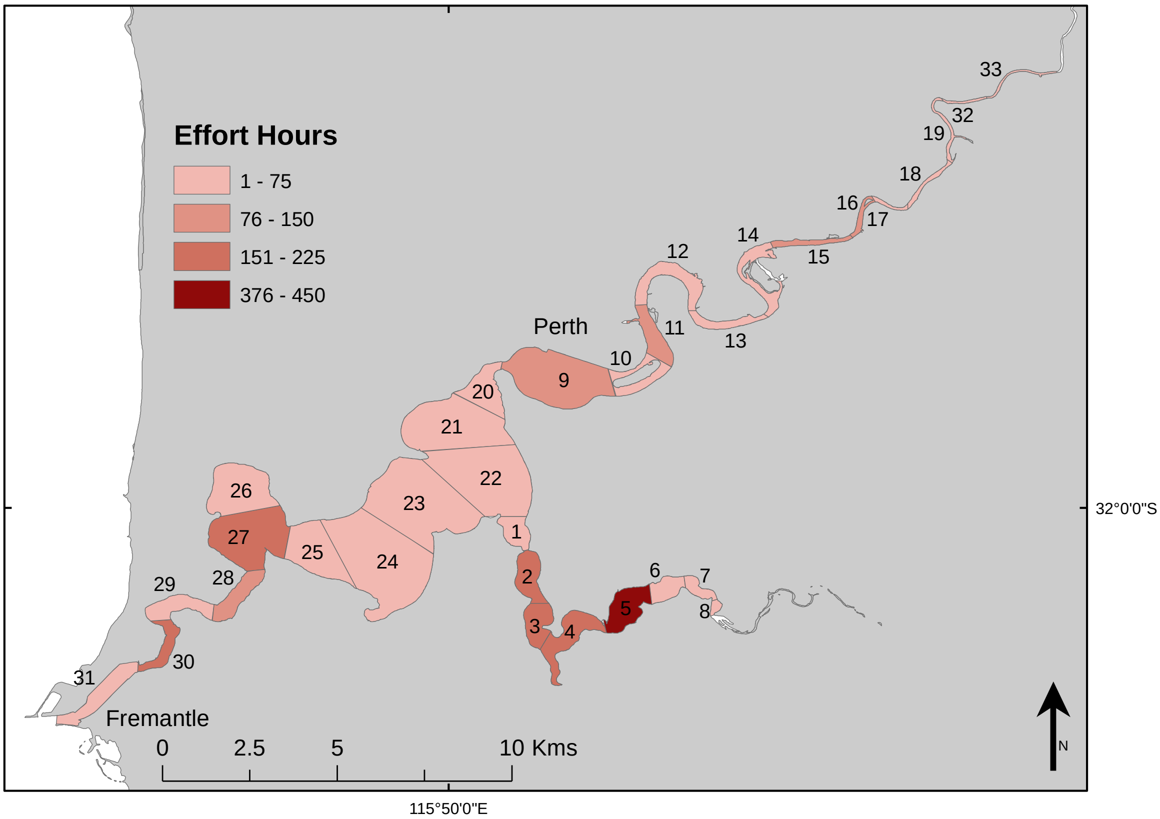


Figure 2.5 Number of hours that Dolphin Watch volunteers spent surveying for dolphins within the 33 zones of the study area.

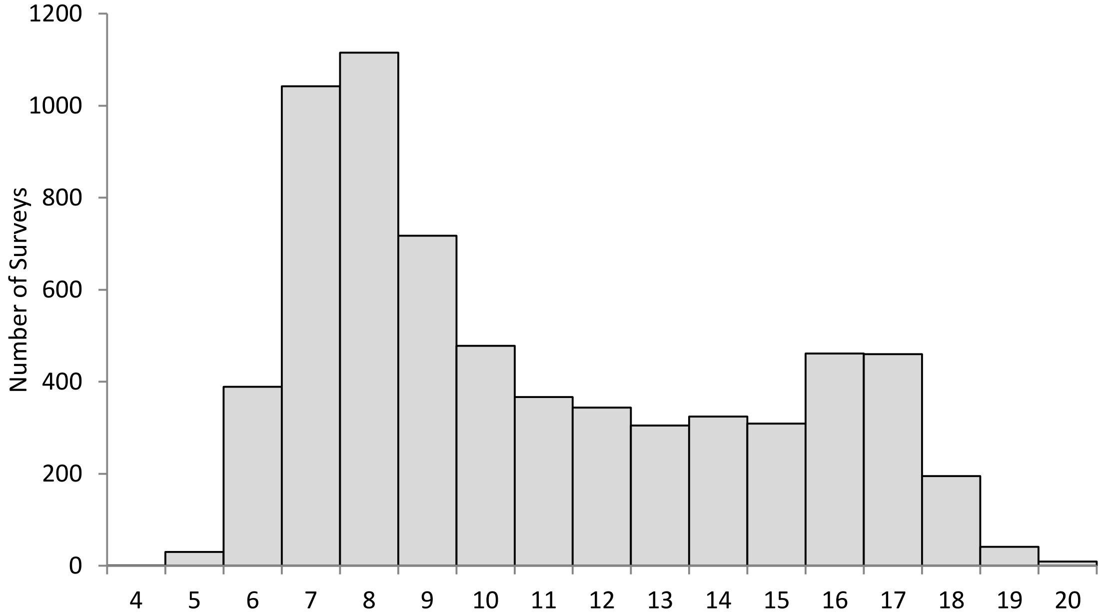


Figure 2.6 The total number of surveys being conducted during each hour time period.

Surveys

The number of surveys submitted in each monitoring zone varied greatly throughout the study area (Figure 2.7). The number of surveys conducted in each monitoring zone varied through the study (one-way ANOVA; df = 32; F = 22.41; P <0.01). All zones recorded at least eight surveys over the study period, with zone 7 recording the least surveys. Zone 2 had the highest number of surveys with 376 surveys recorded. The most surveys recorded in one zone within a single season were from Zone 9 during the spring season with a total of 162 surveys within the three-month period (September – November).

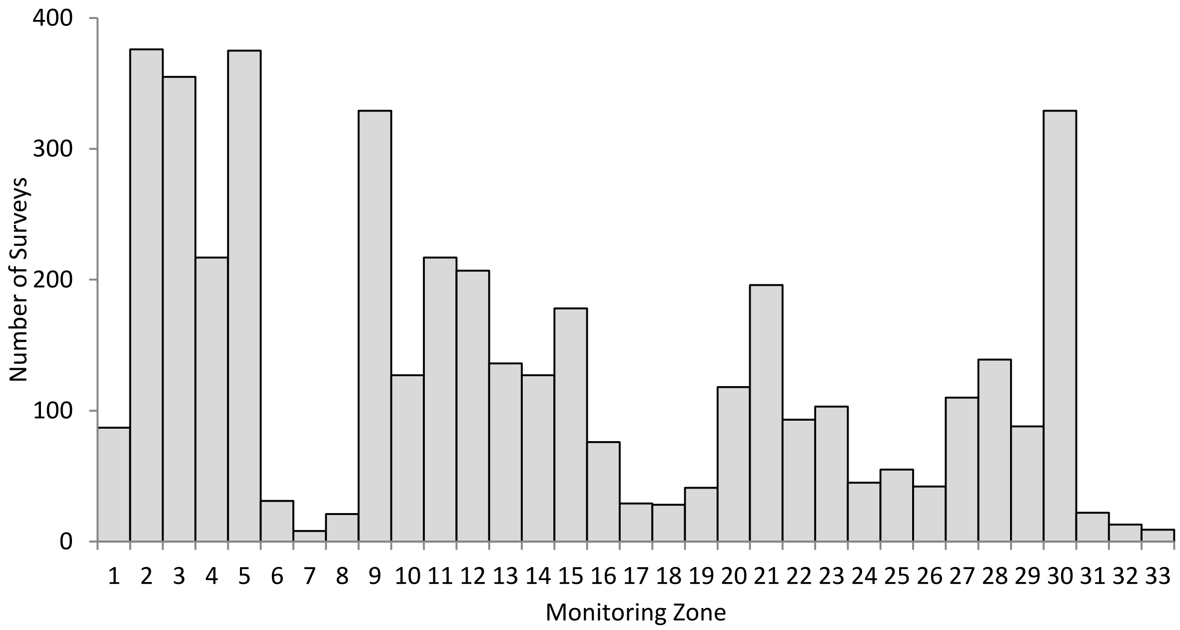


Figure 2.7 Number of surveys recorded in each monitoring zone. Zones 1-8 are located in the Canning River, zones 9-19 and 32-33 are located in the upper Swan River, and zones 20-31 are located in the lower Swan River.

Number of submitted surveys

The number of surveys submitted per day fluctuated from no surveys (21 February 2015) to the maximum of 17 surveys (14 September 2015). On average, there were 7.3 (SE ± 0.15) surveys submitted each day. The 30-day moving average showed two distinct peaks in the number of surveys submitted each day (Figure 2.8). The first peak was at the end of April 2014, and the second was at the beginning of November. The moving average dropped to the lowest point at the beginning of August 2014.

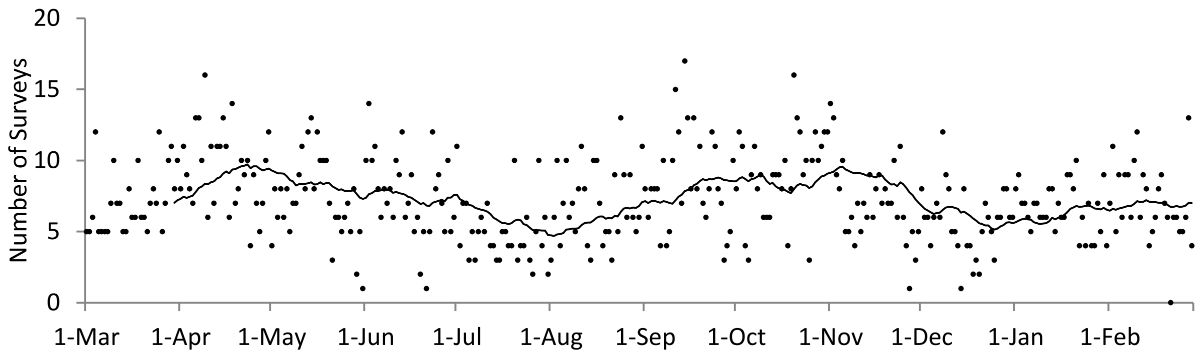


Figure 2.8 Number of surveys recorded each day throughout the one year study period. The trendline shows a 30-day moving average.

Dolphin Sightings

Dolphins were documented in 31 of the 33 zones, with no dolphins sighted in zone 7 (Canning River) and zone 33 (Upper Swan River) (Figure 2.9). The highest number of dolphin sightings per hour was in zone 31 (Inner Harbour), with 2.4 dolphins sightings per hour (Figure 2.9).

There were two other zones (Zone 1 in the Canning River and Zone 14 in the Upper Swan River) that also showed higher dolphin sighting rates than the remaining zones. On average, approximately four hours effort needed to be recorded within a monitoring zone before a dolphin sighting was recorded (SE ± 0.04). The zones that did not have any dolphin sightings were zones that had few effort hours (4.2 hours in zone 7 and 6.1 hours in zone 33).

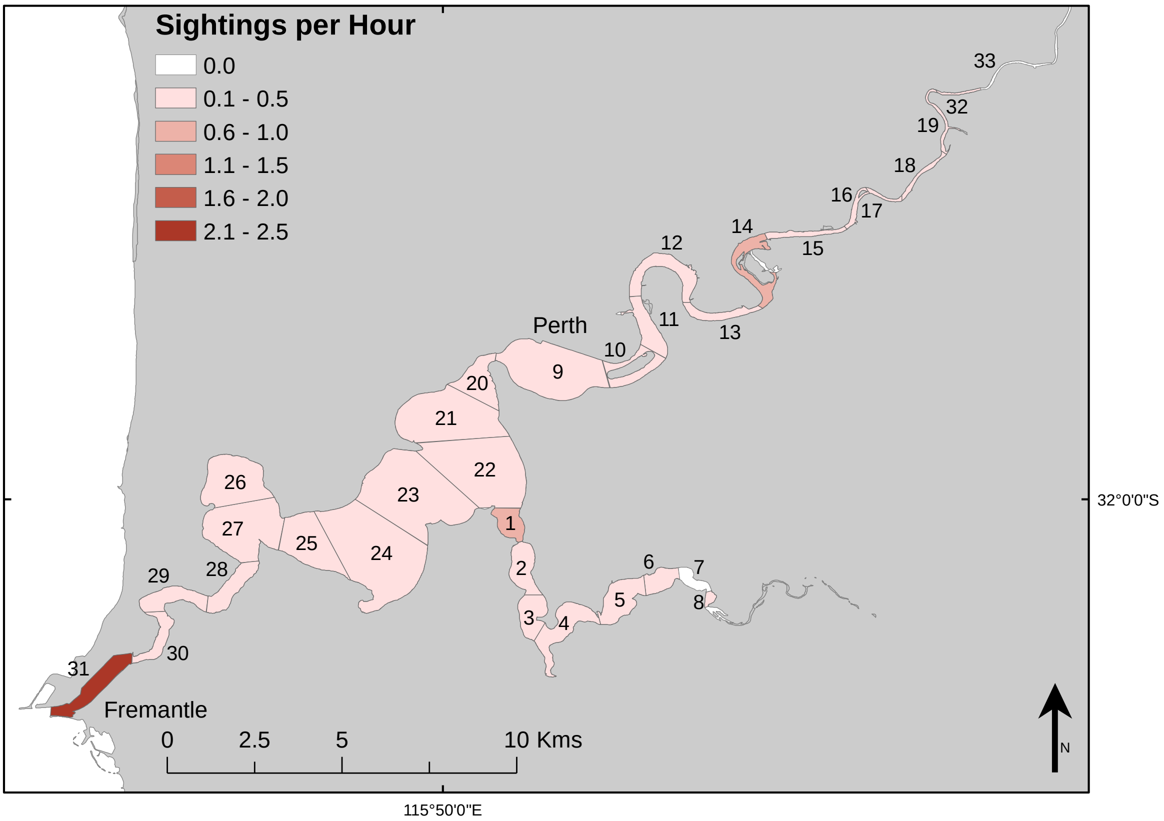


Figure 2.9 The number of dolphin sightings per effort hour across the Swan Canning Riverpark.

Dolphin Watch volunteers

The number of volunteers that conducted surveys varied differed across zones (Figure 2.10). Zone 9 was the most popular zone, with 53 volunteers reporting surveys. Other popular zones that drew many volunteers were zones 21 and 11. Other locations with a high number of volunteers recording surveys were in the lower Swan River (zones 20-30) and part of the Canning River (zones 2-5). On average a volunteer submitted a survey once every three days.

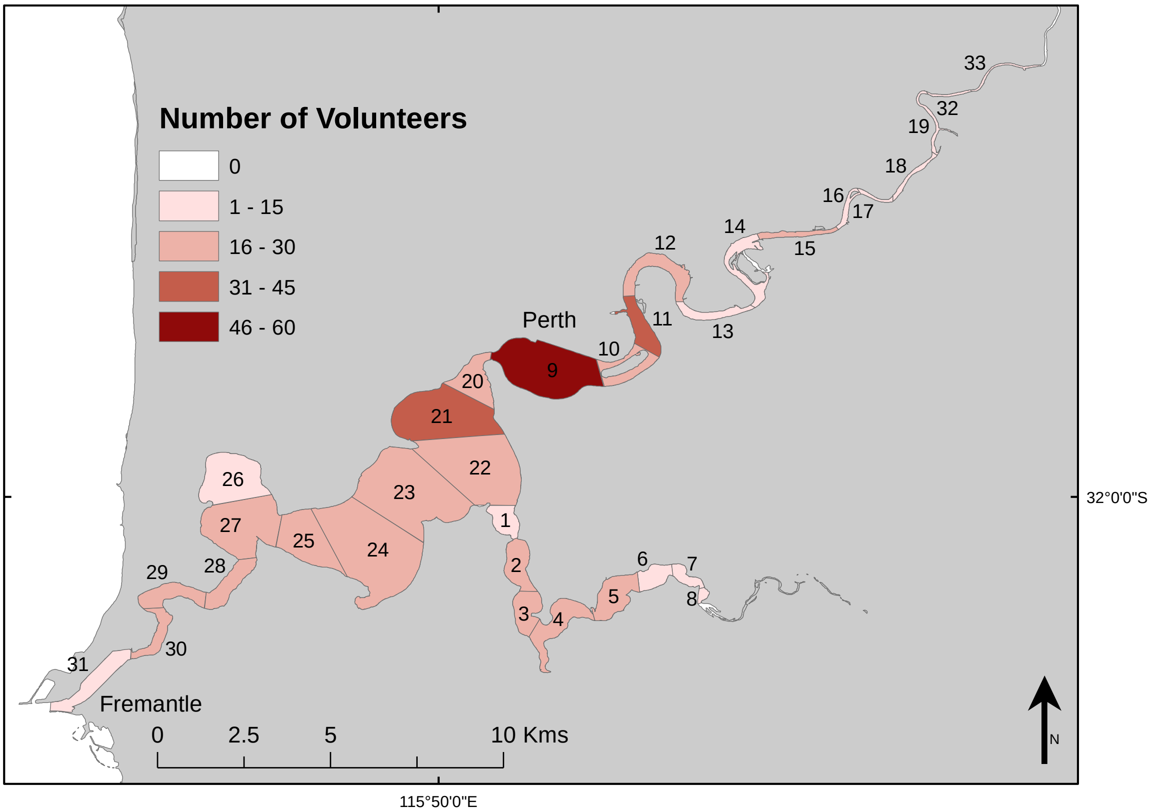


Figure 2.10 The number of volunteers who recorded surveys in each monitoring zone.

Recruitment

There were three dates that a new volunteer could have joined Dolphin Watch during the year. These were the recruitment and initial training evenings that were held on 26 March 2014, 20 August 2014, and 25 February 2015. Prior to the initiation of this study, there were 595 trained Dolphin Watch volunteers. Out of these existing volunteers, 84 (15%) recorded a survey during the study period. A further 80 volunteers who were trained during the study period submitted at least one survey. The majority of these “new” (i.e. inducted during the time period of this study) volunteers contributed their first survey within the first month after the March 2014 or August 2014 training events (Figure 2.11). In addition, there were 10 volunteers who reported a survey for the first time (during the study period) in the October 2014; these volunteers included new recruits and existing volunteers. Among the existing volunteers, 46 individuals (28%) submitted a survey within March (first month of the study period).

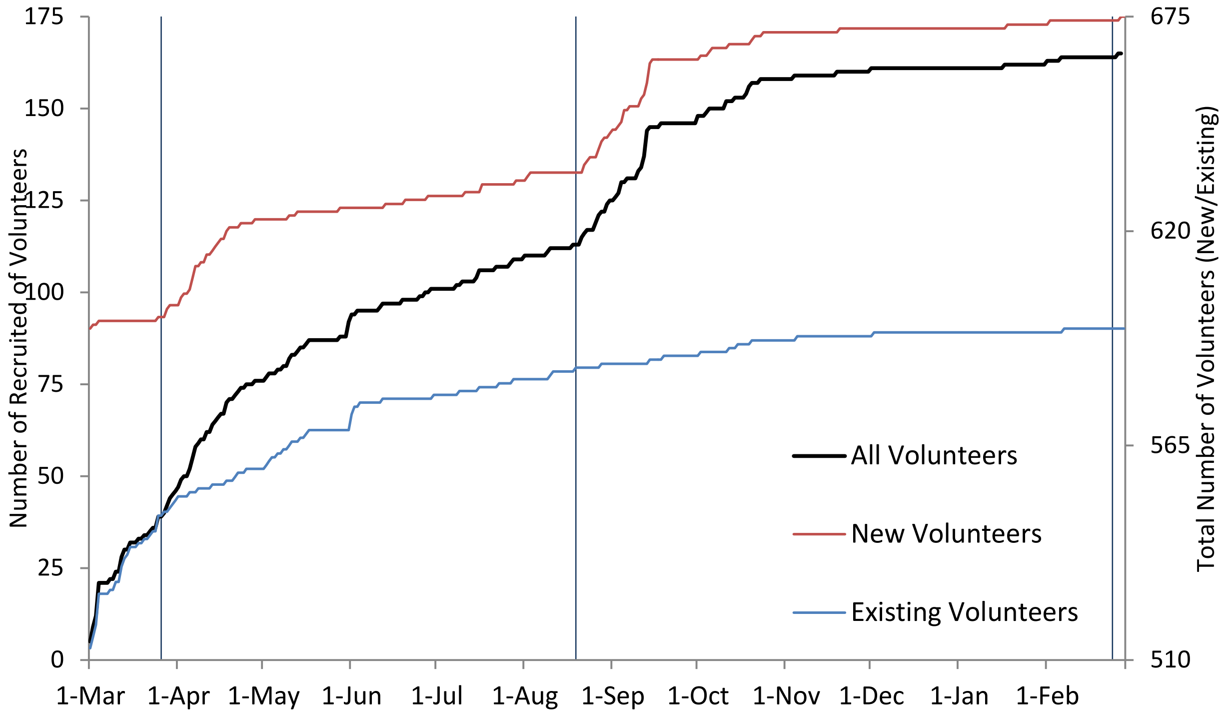


Figure 2.11 The recruitment of volunteers throughout the year (n = 164).
Blue line (secondary axis): The cumulative number of existing volunteers who recorded a survey during the study period (n = 84).
Red line (secondary axis): the cumulative number of new volunteers who submitted a survey (n = 80).
The vertical lines indicate when training events occurred throughout the study.

Dolphin Watchers Contribution over Study Period

The average number of days that a volunteer was classified as an 'active' volunteer was 120 days. The shortest time period for a volunteer to be classified as 'active' was one day; and the maximum time period was 364 days. The majority of individual volunteer were 'active' for less than one month, which was a total of 65 volunteers (39%) (Figure 2.12).

A larger number of new volunteers (those who were trained during the study period) were seen to have a shorter 'active' time period (Figure 2.12). There was approximately equal number of new and existing volunteers who had an 'active' time of less than one month. Approximately 48 volunteers were classified 'active' for more than half of the year-long study period; 77% of these (37 volunteers) had been volunteers before the study period.

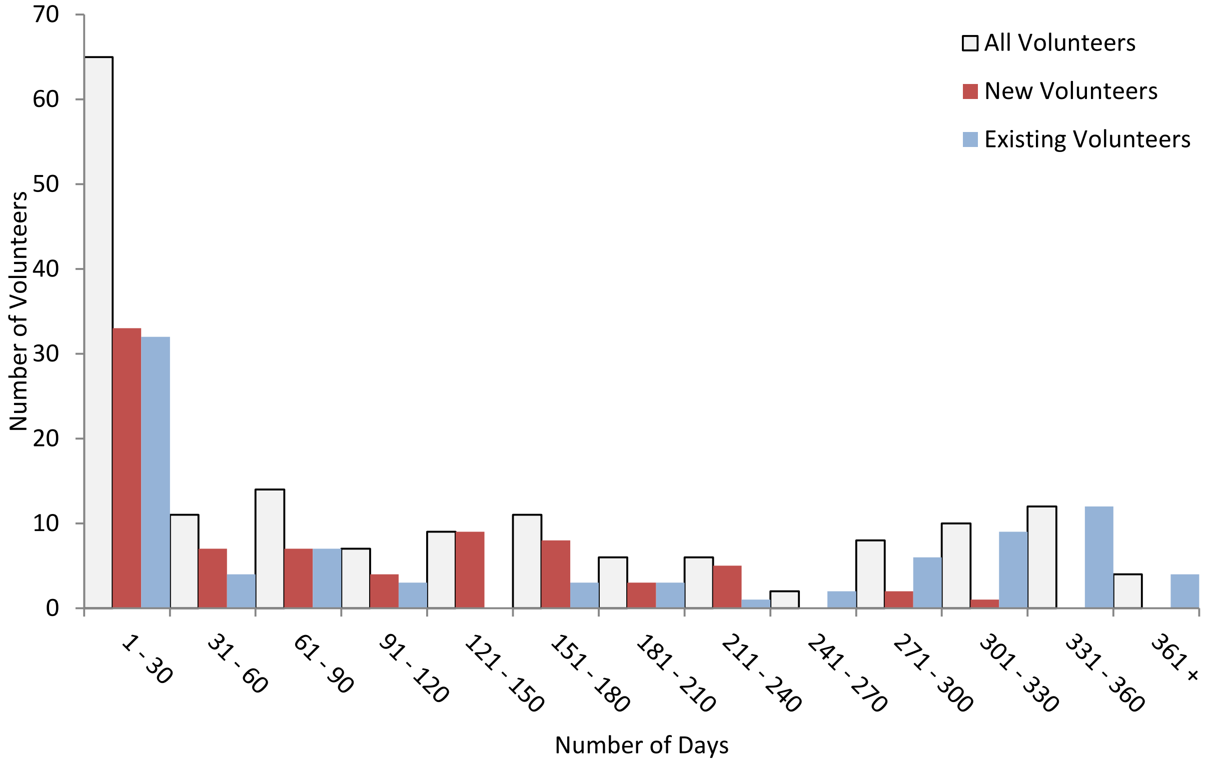


Figure 2.12 The frequency of individual volunteers who were classified as 'active' during the study.

2.5 Discussion

2.5.1 Ecological Patterns:

Dolphin Encounter Range

Dolphin Watch observations indicated that dolphins range throughout the Swan Canning Riverpark. The presence of dolphins was noted from the Fremantle Inner Harbour to the furthest upstream monitoring zones in the Swan and Canning Rivers. Observations in the two most upstream zones suggest that individuals in the dolphin community will travel at least as far as these zones. Citizen science can collect large quantities of data that can determine the spatial extent of a community, and can determine the absence/presence of an animal in less frequent locations (Bruce *et al.* 2014, Ries & Oberhauser 2015). The example Ries and Oberhauser (2015) looks at a citizen science project that successfully recorded the distribution and spatial extent of migrating monarch butterflies.

Hotspot locations

This study identified two types of hotspots that can be discovered through the Dolphin Watch project; i.e. a spatial concentration. The two types of hotspots are: (a) dolphin hotspots; and (b) volunteer monitoring hotspots.

Identifying animal hotspots is important for wildlife conservation (Harwood 2010). For example, (Bruce *et al.* 2014) identified mother and calf pairs were encountered more freuently closer to the coast and protected waters. Dolphin Watch identified zone 31 (Inner Harbour) as the strongest dolphin sighting hotspot. However, the location of hotspots from Dolphin Watch data does not necessarily accurately describe the spatial distribution of dolphins in the Swan Canning River. The spatial distibution of wildlife is influenced by many environmental factors; for example: the probabiltiy of detection, man-made infastructure that increases human activity (i.e. boat ramps, jetties, marinas, etc…) (Kelly *et al.* 2004), and temperature (e.g. Sequeira *et al.* 2014). Data excludively collected by Dolphin Watch volunteers would not be able to determine the spatial distribution of dolphins in the Swan Canning Riverpark.

The most popular zone among volunteers was identified as zone 9, which is the zone associated with the Perth CBD. Other popular areas which drew the most Dolphin Watchers include the lower Swan River (between Fremantle and Perth CBD) and the East Perth area. Highly populated locations are known to attract citizen scientists (Thiel *et al.* 2014). The majority of surveys were conducted from the shoreline, and so zones with an easily accessible shoreline are also likely to be popular among volunteers. Future research can utilise volunteer hotspots when evaluating the effect of observer variability within each monitoring zone.

Variable Effort

Variability could be seen in three different ways in the data collected by volunteers: (1) spatially through monitoring zones; (2) temporally dependent on the month; and (3) temporally dependent on the time of day.

Recording effort in citizen science projects is critical to assessing the accuracy and reliability of the results (Matthiopoulos & Aarts 2010). This is particularly important where, as was the case in this study, volunteer effort is not consistent across the study area. However, by recording effort along with sightings, the number of sightings could be standardised across the study area. The sampling effort in a critical part of each survey, both presence and absence. Recording effort quantifies the time volunteers are monitoring form dolphins.

Throughout the study, there was greater survey effort in some monitoring zones than others. Location bias is a common issue in citizen science projects and has been noticed in studies on koalas (Sequeira *et al.* 2014) and humpback whales (Bruce *et al.* 2014). The most popular zones were located between Fremantle and Perth CBD and the zones surrounding the CBD. The most popular marine citizen science projects to date have been in locations that are easily accessible for the targeted participants (Thiel *et al.* 2014). Pattengill-

Semmens and Semmens (2003) collected data on reef fishes by designing the data collection process to work with recreational snorkelling and diving. Due to the nature of volunteering, the amount of effort collected in any given zone cannot be predicted and it cannot be assumed that this will stay constant.

Volunteer effort varied throughout the study year. One predictable trend was the increase in effort recorded in the month after a training event. An increase could be seen in both: (a) the number of individual volunteers; and (b) the number of surveys per day. Volunteers are highly motivated after they first join Dolphin Watch, which is consistent with other citizen science projects. For example, Roggenbuck *et al.* (2000) investigated the recruitment and retention of Save Our Streams volunteers; where volunteers were found to loose interest in the project for reasosns such as not believing the data they collected was contributing to management and conservation. The spike in volunteer contributions after a training event indicated that these events encouraged recruitment and motivated volunteers. Although the volunteer contributions could be expected to increase following a training event, the extent of increase could not be predicted.

The time between 7am-9am was the most popular time for volunteers to conduct a survey. Beidatsch (2012) study of Dolphin Watch data from 2009-2012 identified a spike in volunteer contributions later in the morning (9am-11am) and also in the late afternoon (5pm-6pm). A common result from both studies was that the majority of volunteer contributions were conducted during the day (6am-6pm) (Beidatsch 2012). Although volunteer contributions can be predicted to occur during the day; the hours most popular with volunteers fluctuate over a longer tme period (multiple years).

2.5.2 Volunteers

Length of Volunteer Involvement

Citizen science projects will have various volunteer retention rates that can depend on the design of the project (Alexandra *et al.* 2014). The majority of volunteers who recorded surveys during this study were short term volunteers. This trend was similar in both new and existing volunteers; although it was more pronounced with the new volunteers.

Two types of volunteers contributed to Dolphin Watch: short-term and long-term volunteers. Short-term volunteers contributed surveys in the initial time period after joining the project. Long-term volunteers continued to contribute surveys over many years. If a volunteer is associated with a citizen science project for a longer time, that person is the more likely to increase their data collection (Thiel *et al.* 2014). Therefore, there is a benefit in retaining volunteers within a citizen science project, as the contributions from long-term volunteers increase the quantity of data collected (Thiel *et al.* 2014). This concept was supported in the Dolphin Watch volunteer community; with the majority of volunteers that recorded surveys over an extended length of time had been involved in Dolphin Watch before this study began.

Communication

The number of surveys Dolphin Watchers submitted on a daily basis was influenced by the training events. Training events are one of the Dolphin Watch's major forms of communication and hence motivation (Thiel *et al.* 2014). Additionally, the uptake rate of new volunteers implies that an individual is highly motivated to contribute just after they join the project. To maintain participation within a citizen science project, it is necessary to communicate with the volunteers (Chu *et al.* 2012) and to motivate volunteers to contribute to a project for; educational learning (Ryan *et al.* 2001, Bruyere & Rappe 2007, Measham & Barnett 2008), protecting the environment (Ryan *et al.* 2001, Caissie & Halpenny 2003, Bruyere & Rappe 2007), personal satisfaction (Caissie & Halpenny 2003, Thiel *et al.* 2014), and public recognition (Thiel *et al.* 2014).

Reaction to New Smartphone App

A third of all surveys were submitted through the Dolphin Watch app making it a successful method for collecting observation data. The use of the smartphone app increased immediately after the initial training events were held. Additionally, app use increased as a result of the DW app training event held on the 2nd October 2014. The link between the DW app uptake rates and the training events suggest that volunteers will be more confident to use the app to record their surveys once they have attended a training event.

2.5.3 Limitations

Dolphin Detection

Volunteers were asked to record the number of dolphins observed in each sighting. The results indicated a small sighting size (average = 2.6 dolphins; SE ± 0.04) with very small standard error. A previous study investigated the probability of Dolphin Watch volunteers detecting dolphins and suggested that they could be influenced by: (1) whether the dolphin is in range; (2) the dolphin is detectable i.e. the dolphin is at the surface; and (3) the volunteer must be looking in the right place (Beidatsch 2012). Beidatsch suggested that the detectability of dolphins would impact the number of absence records submitted. The concept of dolphin detectability could also impact the number of dolphins recorded in presence sightings accounting for the small dolphin sighting sizes. Gerrodette *et al.* (2002) indicated that volunteers working in the eastern tropical Pacific Ocean were underestimating the average dolphin sighting size as much as 26%.

There was no emphasis during training to instruct volunteers how to measure dolphin sighting size. Therefore, the accuracy of dolphin sighting size cannot be guaranteed. Volunteers may under or overestimate sighting sizes; however the results from this study suggest that Dolphin Watch volunteers are more likely to underestimate dolphin sizes.

Technology Challenges

The use of smartphone technology in citizen science projects has increased, and incorporating this technology provides many advantages (Teacher *et al.* 2013). Previous studies have successfully incorporated smartphone technology into the data collection process (Dickinson *et al.* 2012, Newman *et al.* 2012, Davidson *et al.* 2014). For example, Davidson *et al.* (2014) incorporated smartphones to collect GPS tracking data when conducting surveys. Teacher *et al.* (2013) discussed several ways smartphones can be used to collect data through an increase in technology and by linking to external sensors, for example collecting data via Bluetooth to record information from animal tags. Despite the advantages that a smartphone app brought to the Dolphin Watch project, there were some significant disadvantages. In the final four months of the study, many records made through the smartphone app did not record all the necessary information, as incomplete records submitted from an iPhone device with the iOS 8.0 operating system. These records they did not record a start date and/or start time. This problem began with the new operating system update at the end of September and was rectified at the end of February. The constant updates and operating system changes in smartphones could cause potential problems for data collected through smartphones in the future. Although the problem was being repaired, it affected records for over four months. Smartphones can make data collection easier to submit and automatically record information, but working with new technology comes with its own series of unforseen challenges.

3. Quantitative Information Collected Through a Professional Scientific Approach to Studying Bottlenose Dolphins in the Swan Canning Riverpark

3.1 Introduction

In conservation biology, professional science typically uses systematically collected data to help find effective avenues to conserve wildlife, which usually involves identifying populations at risk, determining a cause of decline in abundance or distribution, or developing mitigation strategies (Read 2010). In and near urban areas, dolphins are vulnerable to human activities, and conservation efforts aimed to decrease impacts are important (Read 2010). Marine mammals are particularly susceptible to impacts, such as population declines, due to their low reproductive rates and are particularly vulnerable to disturbance in costal and urban waters (Whitehead *et al.* 2000b). Evaluating the abundance, habitat use, areas of importance, social relationships and critical behaviours are important in developing appropriate conservation strategies for dolphin populations (Connor *et al.* 2000).

Researching dolphin population dynamics is best achieved through long-term studies that identify individual dolphins (Mann 2000, Whitehead *et al.* 2000a). There are three main methods for dolphin identification: photographic identification, physical tagging and genetic sampling (Whitehead *et al.* 2000a). Photo-identification sampling is one form of mark recapture method that allows for the identification of individuals (e.g. Chabanne *et al.* 2012, Nicholson *et al.* 2012, Smith *et al.* 2013), and has been successfully employed for every cetacean species that has a dorsal fin (Whitehead *et al.* 2000a).

Previous dolphin research in the south-west of Western Australia has taken advantage of photo-identification sampling to individually identify dolphins (Chabanne *et al.* 2012, Smith *et al.* 2013). Smith *et al.* (2013), for example, used photo-identification to investigate the seasonal abundance, temporary emigration and survival of dolphins in a coastal environment near Bunbury, while Chabanne *et al.* (2012) used historical photo-identification data to assess community size, emigration, and association patterns for dolphins in the Swan-Canning Estuary near Perth.

For photo-identification, dolphins can be individually identified through natural markings, although the longevity and changeability of markings is crucial for identification and to maintain equal probability of capture (Würsig & Jefferson 1990). Dorsal fin scars are considered to last the life of an individual, however additional marks near or over previous marks can obscure identification (Würsig & Jefferson 1990). The most useful feature of the dorsal fin for photo-identification is the trailing edge, where permanent markings and abrasions appear easily (Würsig & Jefferson 1990). Other features that make an individual identifiable include: dorsal fin shape, shading of dorsal fin and upper body, scratches, scrapes and wound marks, and patterns in pigmentation (Würsig & Jefferson 1990).

Short-term photo identification sampling is useful in collecting data relating to movement patterns, population size and dynamics. Long-term photo identification studies can investigate calving intervals, age of sexual maturity, life history parameters, life span and social structure (Würsig & Jefferson 1990, Whitehead *et al.* 2000a).

Studies of dolphin abundance and distribution are integral to management and conservation strategies (Mann 2000). Professional science projects often investigate dolphin abundance and distribution and have, for example, demonstrated: the presence of a localised resident community (Chabanne *et al.* 2012); spatial and temporal patterns of habitat use (Smith *et al.* 2013); and the cumulative impacts on the survival of juveniles and calves resulting in lower recruitment levels (Currey *et al.* 2011). These studies relied on the collection of photo-identification data over multiple years and over spatial scales encompassing dozens of kilometres of coastline (e.g. Currey *et al.* 2011, Chabanne *et al.* 2012, Smith *et al.* 2013).

Although a wide range of questions can be answered through long-term photo-identification studies, my study covered a time period of one-year, which limits the results that can be obtained (Whitehead *et al.* 2000a). Therefore, this study investigated abundance estimation, population emigration and migration of bottlenose dolphins with a one-year period using a professional scientific approach.

3.2 Aims of Chapter

I described the Swan River dolphin's ecology through professional science methods exhibited by the Dolphin Population Assessment Project. Ecological outcomes focused on describing the dolphin community. This was achieved by investigating the dolphin community's: (1) abundance; (2) movement patterns; (3) probability of survival; and (4) sighting frequency. The main goal of this chapter was to explore what outcomes can be produced by the Dolphin Population Assessment Project and what were the limiting factors that restrict the amount of outcomes that can be produced through a professional science project.

3.3 Methods

3.3.1 Field Methods

Sampling was conducted by professional scientist Delphine Chabanne from June 2011 and concluded in May 2015 (Chabanne 2015a). Equal sampling effort was allocated across four austral seasons: autumn (March–May), winter (June–August), spring (September–November) and summer (December–February). Surveys that were conducted from March 2014 until February 2015 were examined.

Boat-based photo-identification surveys for dolphins were conducted along pre-determined transect routes systematic route within the study area, the Swan Canning Riverpark (Figure 1). Previous and current dolphin research have used these single line or zig-zag transects routes to structure sampling effort (e.g. Nicholson *et al.* 2012, Smith *et al.* 2013). These studies covered coastal open waters, which accommodate line transects effectively. Smith *et al.* (2013) conducted zigzag transects in the open-ocean portion of their study in Bunbury, which was adapted to a single path transect within the shallow waters of the harbour and inlet. Following this example, the surveys conducted in this study followed a pre-determined single transect route that accommodated the changes in river depth and various widths of the Swan Canning Riverpark (Figure 3.1).

A survey was defined as the “on-effort” time monitoring dolphin within a monitoring zone. Once the boat reached the edge of a monitoring zone the preceding survey finished and a new survey begun in the next zone. Some zones (zones 20-25) recorded two surveys per transect because the line transect doubled-back on itself in the wider sections of the river.

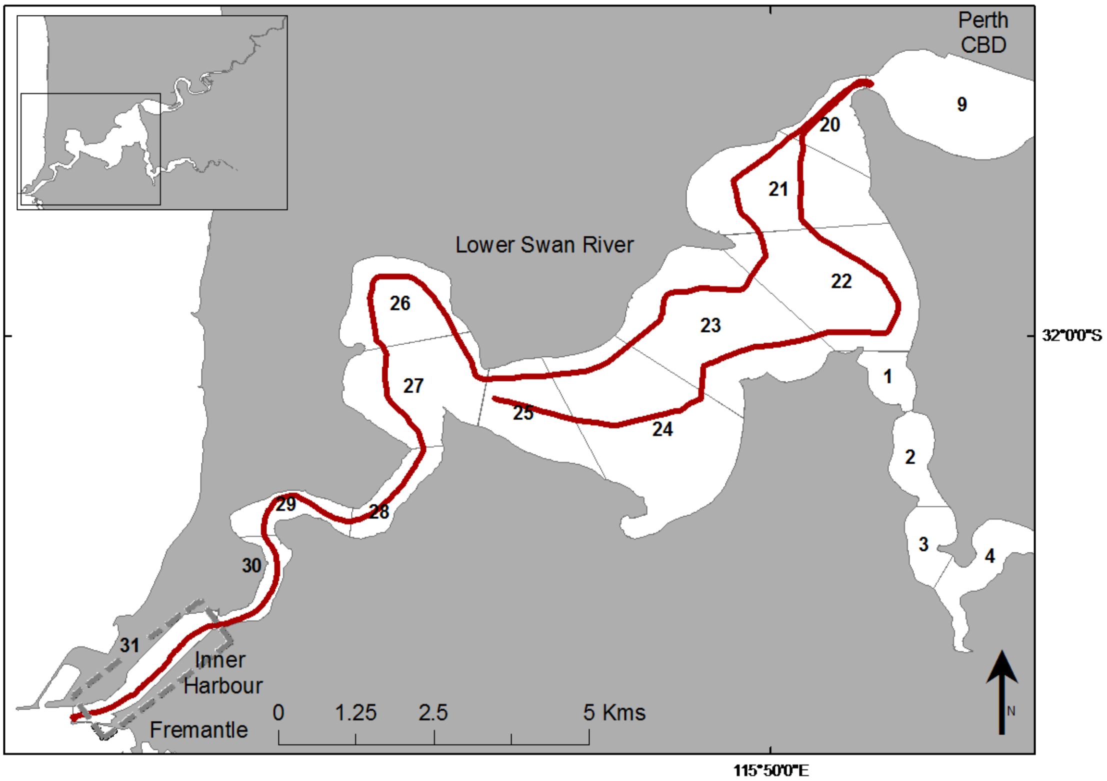


Figure 3.1 Study area for the Dolphin Population Assessment Project with line transect route.

Two to five observers were on the boat during each transect (median = 3). On effort data collection was conducted in the second and third months of each season and created segregated sampling between each "primary sampling period" (see explanation below). A primary sampling period described the period of time in which sampling occurred. In this study, a primary period referred to a season (each of three month duration). One primary sampling period, contains five, "secondary sampling periods". Secondary sampling periods describes how many surveys were conducted within a single season, i.e. each survey was defined as one, secondary sampling period. In this investigation there were a total of 20 secondary sampling periods that were evenly distributed among four primary sampling periods.

To maintain a consistent and high probability of capture, surveys were only conducted during favourable weather conditions in sea state conditions of Beaufort (sea state scale) 3 or less. In the event that the weather deteriorated and became unfavourable during the survey, the survey was terminated, and data collected were not used in quantitative analysis.

Mark Recapture

Research was conducted through a boat-based photo-identification mark recapture method now widely used for small cetacean species (e.g. Currey *et al.* 2011, Nicholson *et al.* 2012, Smith *et al.* 2013). This method of capture is unobtrusive towards the individual dolphins as there is no need for human-dolphin physical contact. Photographs of dolphin's dorsal fins were taken to individually identify each dolphin. Lasting and distinctive features on a dolphin's dorsal fin include scars, indentations, and the overall shape of the fin allowing for long-term identification (Wells & Scott 1990, Smolker *et al.* 1992). During a survey dolphins were observed in groups (i.e. one or more dolphins), referred as a sighting. Dolphins were defined in the same group using a 100m chain rule and when individuals have the same behaviour. Group sizes were transformed by square-root to compare between the seasons.

An individual dolphin is defined as a "capture" when it is observed and identified for the first time during the study period. Other observations of the same individual during the study period are defined as a "recapture".

A high-quality photo that allowed for individual identification was required for each repetitive capture. A photograph grading process ensured that photographs were of a high quality, and encounter histories were created for each identified dolphins.

Photograph Grading Process

The photographic grading process used throughout this study was used extensively in previous dolphin research (Chabanne *et al.* 2012, Nicholson *et al.* 2012, Smith *et al.* 2013). This process was modified and developed from research conducted at the Saratosa Dolphin Research Program (Urian *et al.* 1999). All photographs taken during the surveys were graded for image quality. The quality of the photo was determined using five parameters: clarity/focus; contrast; camera angle (ideal angle is perpendicular to camera); whether the dorsal fin was fully visible in the picture; and the proportion of the frame that was filled by the dorsal fin. Only excellent and good quality photos were included in the capture histories of each individual dolphin. The capture histories of individual dolphins were used to estimate abundance and survival rates of the dolphin population.

3.3.2 Robust Design

There are two types of population models that can describe a dolphin community: open and closed models. Closed population models describe a dolphin population assuming that there is no recruitment, immigration, emigration and/or mortality. Whereas, open population models will assume that dolphins can permanently move to and from the study area.

The Robust Design method that was used for this investigation incorporated both open and closed population models (Kendall 2010). The model allows for an open population model between primary periods. However, the population is closed within primary period and between the respective secondary periods. Therefore, creates created the assumption that recruitment, immigration birth and/or mortality should only occur between the sampling seasons and was assumed that these events do not occur within the seasons. This method allowed for limited and restricted movement into and out of the study area.

Multiple movements in and out of the study area were described as temporary emigration. There are two ways that temporary emigration can be described within Robust Design models: (1) Random and (2) Markovian, in which the detection probability in a primary sampling period depends on whether the animal was present within the study area or absent (Kendall 2010).

To assume equal probability of captures, only dolphins with distinctive fins (i.e. excluding clean fin or fins with too little marks for which misidentification could occur). In addition, calves were excluded because of their dependency with their mother.

Model Assumptions

All population models made the following assumptions (Pollock 1982, Pollock *et al.* 1990, Williams *et al.* 2002):

1) distinctive features are not lost during the study;
2) distinctive features are correctly recognised on re-capture;
3) individual dolphins are instantly released after being captured; no survey (i.e. no capture);
4) intervals between season are longer than the duration of the season (i.e. primary period);
5) all individual dolphins observed in a given sighting have the same probability of surviving until the next sighting;
6) the study area does not vary;
7) homogeneity of capture probabilities, i.e. that all animals in a sighting have the equal probability of being captured.

The Robust Design models allows for immigration and emigration between the sampled seasons. The models estimate the probability of first capture ‘p’, the probability of re-capture ‘c’, and the number of animals that are in the sampling area ‘N(i)’. Additionally, the models also estimate the probability of seasonal survival ‘S(i)’. Two temporary emigration parameters were calculated and described the probability that the dolphin captured emigrated from the study area between sampling periods ‘γ”(i)’, and the probability that a dolphin not captured stays away from the study area between sampling periods ‘γ’(i)’.

All 14 models (Table 1) were ranked on their Akaike Information Criterion (AIC) values. The best model (with the lowest AICc value) described the population and accounted for the temporal variation of dolphin abundance (Akaike 1974, Burnham & Anderson 2004). Models with AICc value of less than two were considered to describe the population well.

Table 3.1 Robust Design models used to analyse the population of Swan River dolphins.

Markovian	S. γ''(t) γ'(t)	
	S. γ''(t) γ'.	
	S. γ''. γ'(t)	
	S. γ''. γ'.	
	S(t) γ''(t) γ'.	$\gamma_k'' = \gamma_{k-1}''$, $\gamma k' = \gamma_{k-1}'$
	S(t) γ''(t) γ'(t)	$\gamma_k'' = \gamma_{k-1}''$, $\gamma k' = \gamma_{k-1}'$
	S(t) γ''. γ'(t)	$\gamma_k'' = \gamma_{k-1}''$, $\gamma k' = \gamma_{k-1}'$
Random	S. γ''. γ'.	$\gamma'' = \gamma'$
	S. γ''(t) γ'(t)	$\gamma'' = \gamma'$
	S(t) γ''. γ'.	$\gamma'' = \gamma'$
	S(t) γ''(t) γ'(t)	$\gamma'' = \gamma'$
	S(t) γ''(t) γ'(t)	$\gamma'' = \gamma'$, $\gamma_k'' = \gamma_{k-1}''$, $\gamma_k' = \gamma_{k-1}'$
No Movement	S. γ''. γ'.	$\gamma'' = 0$, $\gamma' = 0$
	S(t) γ''. γ'.	$\gamma'' = 0$, $\gamma' = 0$

Capture probability was allowed to remain time variable between primary sampling periods. Mark and recapture probabilities were assumed equal. The notation '.' Indicates that a given parameters was kept constant and (t) indicates the parameter was allowed to be time variable.
S denotes Survival
γ'' denotes Emigration
γ' denotes Immigration
Subscript k-1 denoted Markovian emigration/immigration
Markovian means that the probability an individual being a temporary emigrant in time *i* is dependent on whether a dolphin was present/absent in the study area at time *i*-1

3.3.3 Dataset

Dolphin encounter histories are converted to binary code and loaded into MARK (7.2). The primary and secondary sampling periods are manually defined. For all models, the probability of first capture and probability of recapture were assumed equal (assumption was validated by only keeping distinctive fins and good quality photos). Since the process of capturing dolphins was unobtrusive, the probability of recapturing the same individual did not decrease over time. A total of 14 models were applied to the data and ranked based on how well the data fit to the model.

Proportion of distinctly marked individuals in the population

The abundance estimation calculated was scaled based on the distinctiveness of fins in the population. The distinctiveness of fins was calculated from the capture histories of individuals. Each of the captures for individual dolphins was quality-graded based on the best photograph taken of each individual during that sighting. The distinctiveness (θ) of a fin was calculated as the ratio of the number of high quality photographs with highly distinctive finds to the total number of high quality photographs taken.

$$\theta = \frac{\text{number of high quality photographs with highly distinctive fins}}{\text{total number of high quality photographs taken}}$$

Total population size

The abundance estimates from the models were created only from the distinctive animals. Therefore, the estimated number of dolphins was scaled to the proportion to the individuals that have highly distinctive features. To correct for the entire population (i.e. including non-distinctive dolphins), the estimated total abundance of dolphins was divided with the distinctiveness rate of the dolphin in the population:

$$N_{total} = \frac{Nm}{\theta}$$

Where N_{total} is the estimated abundance for all individuals (both distinctive and non-distinctive) identified during the study, Nm is the abundance estimate of the highly distinctive individuals, and θ is the proportion of distinctive individuals.

The variance for the total estimated abundance was calculated using the delta method (Williams *et al.* 2002):

$$SE\,(N_{total}) = \sqrt{N_{total}^{2}\left(\frac{SE\,(Nm)^{2}}{Nm^{2}} + \frac{1-\theta}{n\theta}\right)}$$

Where n is the sample size. Log-normal 95% confidence intervals were calculated as follows (Burnham & Anderson 2004):

$$\text{Lower 95\% confidence} = \frac{N_{total}}{C}$$

$$\text{Upper 95\% confidence} = N_{total}C$$

Where:

$$C = \exp\left(1.96\sqrt{\ln\left(1+\left(\frac{SE\,(N_{total})}{N_{total}}\right)^{2}\right)}\right)$$

(Nicholson *et al.* 2012, Tyne *et al.* 2014).

3.4 Results

3.4.1 Survey Effort and Summary Statistics

During the four-season study period between March 2014 and February 2015, 20 transects were conducted, which totalled 64.2 hours on-effort in the Swan River. A total of 41 dolphin groups were sighted throughout the study area (Figure 3.2), with an average of three group sightings per monitoring zone.

A total of 232 dolphins were encountered (Table 3.2). Across the study 39 individuals were individually identifiable, of which 25 were adults (64.1%), 3 were juveniles (7.7%), and 11 were calves (28.2%) (Table 3.2).

Only 67.5% (n = 27) of the 39 identified dolphins were used in analysis. The remaining dolphins were excluded because: (a) they were calves; (b) their dorsal fins were 'clean' (i.e. lacking any distinguishing marks); and/or (c) the quality of photo capture could not be used to accurately confirm their identity (i.e. unidentified dolphins). Only three individuals (7.5%) were unidentified. The proportion of distinctly marked individual captures throughout this study was 57.6%.

Sightings were concentrated in lower portion of the river near Fremantle, particularly zones 31 and 29 (Figure 3.2). The highest group sighting frequency also occurred in these locations (Figure 3.3), with zone 31 recording 1.03 dolphin group sightings per hour and zone 29 recording 1.45 group sightings per hour. The zones which recorded the least group sightings per hour were 20, 22-24, and 30, with zone 20 having the lowest group frequency (0.23 dolphin groups per hour).

On average, a dolphin sighting (i.e. an encounter of an individual or group) occurred 2.2 (SE ±0.17) times per transect (i.e. for each complete survey of the entire transect route).

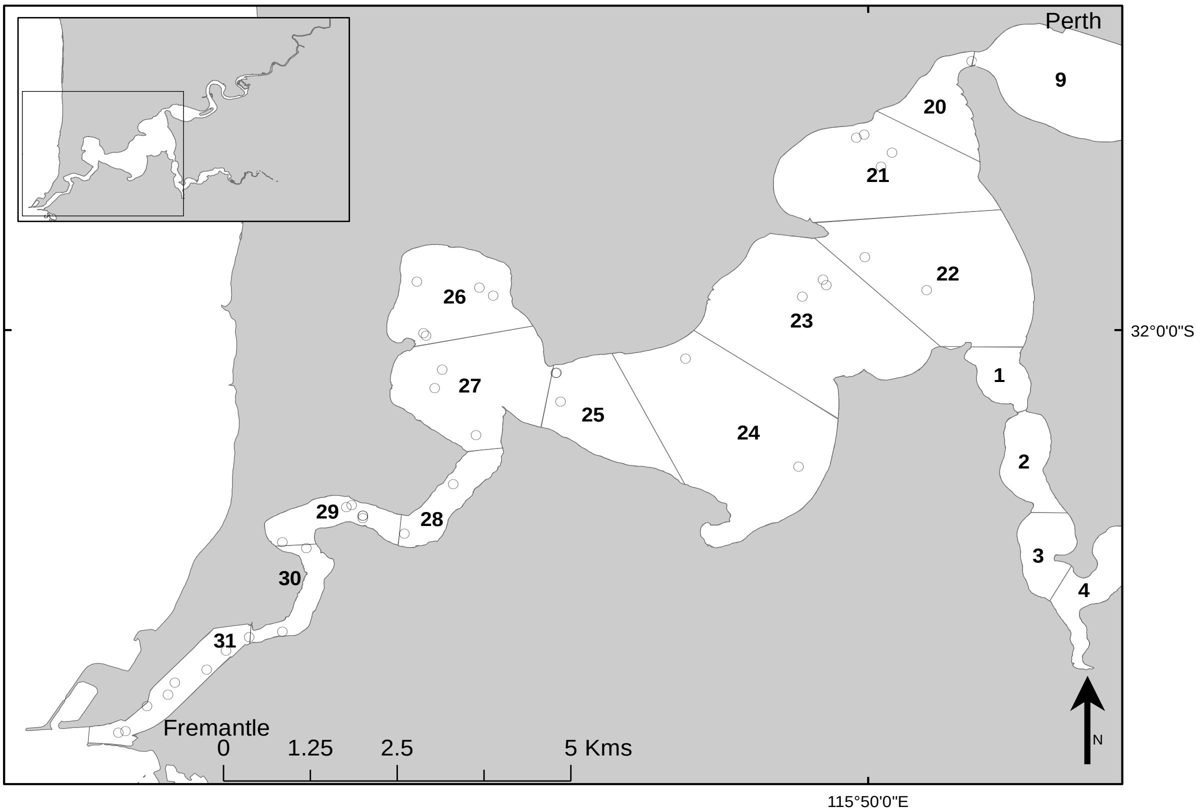


Figure 3.2 Dolphin sighting locations in Lower Swan River (zones 20-31). Each circle represents a single dolphin group sighting.

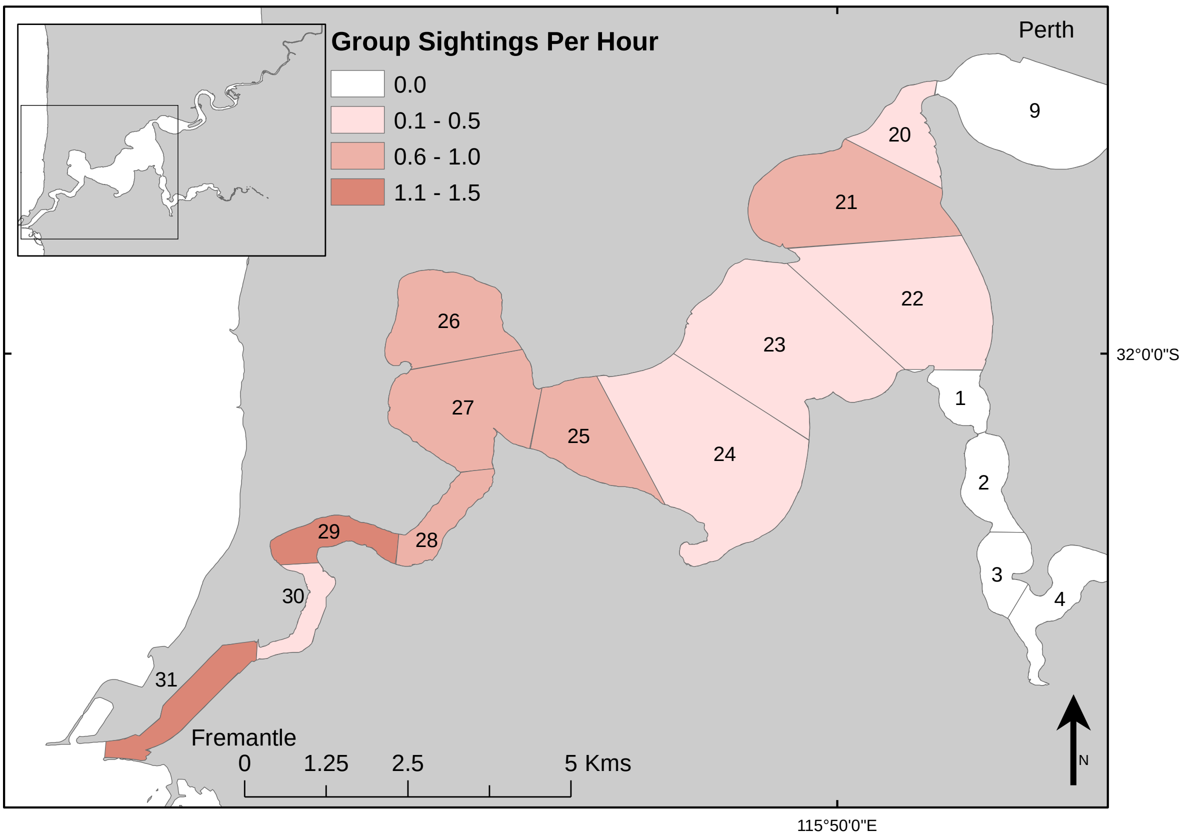


Figure 3.3 Dolphin group sightings per effort hours in the lower Swan River (zones 20-31).

Group Sizes

Dolphin group sizes ranged from 1–19 dolphins (Figure 3.4). The average group size across the study period was 5.7 (SE± 0.65) dolphins per group sighting. By inspection, the average group size in autumn was smaller than in all other seasons (Table 3.2). However, the difference of average group size was not significantly different when comparing all the seasons through an ANOVA test (df = 3; F = 1.1108; P = 0.36).

Table 3.2 Summary Statistics for the dolphin population in the Swan River.

	Autumn	Winter	Spring	Summer	Total
Number of Transects	5	5	5	5	20
Number of Surveys	95	95	95	95	380
Total Hours Effort	15.17	15.55	16.20	17.28	64.2
Number of Dolphin Group Sightings	10	12	10	9	41
Dolphin Group Sightings Per Hour	0.66	0.77	0.62	0.52	0.64
Total Number of Dolphins	37	74	63	58	232
Number of Dolphins Per Hour	2.44	4.76	3.89	3.36	3.61
Mean Group Size (SE±)	3.7 (0.83)	6.2 (1.15)	6.3 (0.86)	6.44 (2.26)	5.7 (0.65)
Number of Individuals analysed *	11	15	17	14	20
Number of Individuals observed (total)	*22*	*25*	*31*	*31*	*39*
Calves	*3*	*4*	*7*	*9*	*11*
Juveniles	*3*	*2*	*3*	*3*	*3*
Adults	*16*	*19*	*21*	*19*	*25*

* The total number of Individuals that are analysed in the Robust Design Model. These individuals have highly distinctive fins. No calves are included in this number.

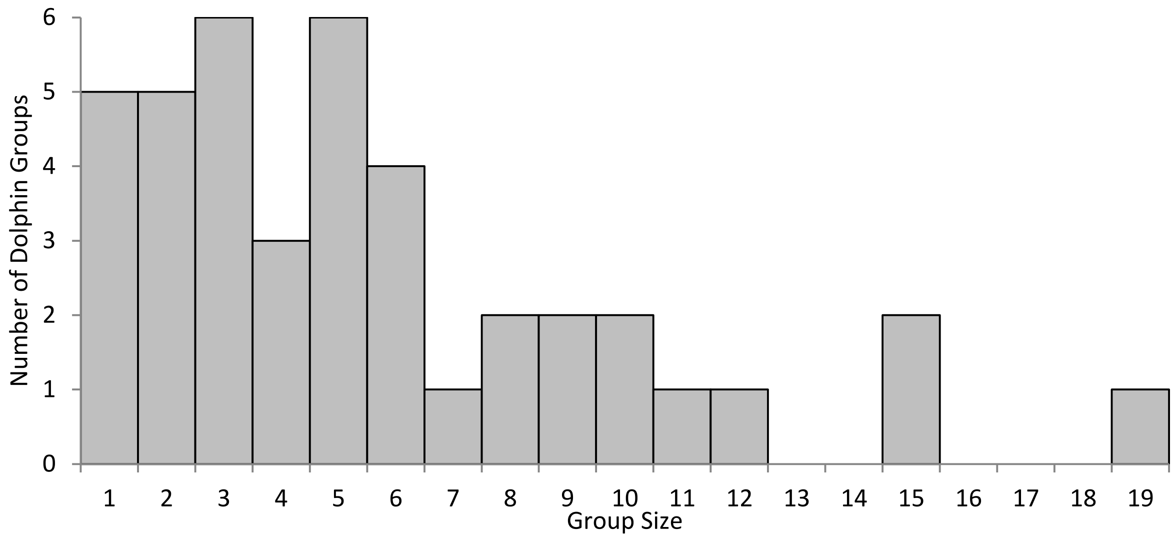


Figure 3.4 Frequency distribution of the observed dolphin group sizes encountered while on photo-identification transects (41 groups).

3.4.2 Sighting frequency of individual dolphins

On average, an individual was sighted 1.82 times (SD ± 0.21) every season. The maximum number of times an individual was identified was in ten separate group sightings (Figure 3.5). Eight individuals (40%) were recorded in all four seasons and in at least 7 sightings (Figure 3.5). The individual sighting frequency appeared highest in winter (2.13 SD ± 0.74) and the lowest in autumn (1.67 SD ± 0.52). Eighteen (90%) of individuals were sighted in multiple seasons, with 11 individuals (55%) seen in three or more seasons (Figure 3.5).

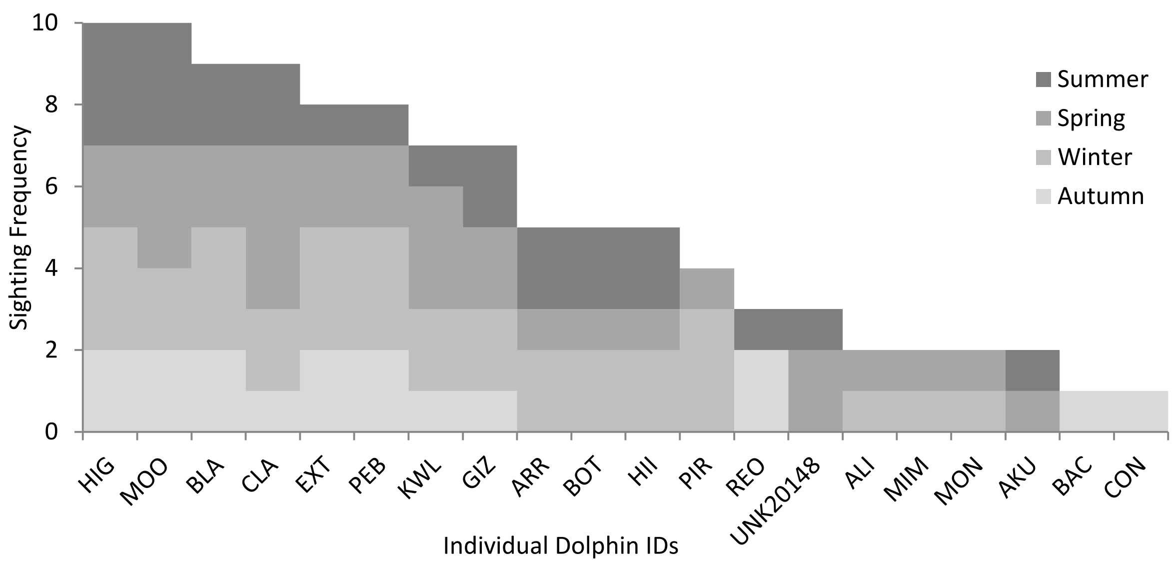


Figure 3.5 Sighting Frequency for each individual identified dolphin (no calves, no clean fins). Colour depicts which season the sighting was observed. Dolphin IDs recorded on this graph are three letter acronyms of the individual dolphin IDs used during the research.

3.4.3 Model Selection

The best fitting population model in the analysis of abundance, immigration and survival was the no-movement model with constant survival (ΔAICc < 2; Table 3.3). A no-movement population model assumes that the dolphin community experienced no immigration or emigration between primary or secondary sampling periods. Additionally, this best fitting population model assumed that the rate of survival was constant throughout the year of this study.

Table 3.3 Population model outcomes for all 14 models.

Model Parameters	Model Restrictions	Δ AICc	Deviance
S. γ". γ'.	**γ" = 0, γ' = 0**	**0.0000**	**228.0113**
S(t) γ". γ'.	γ" = 0, γ' = 0	2.9219	224.1986
S. γ". γ'.	γ" = γ'	3.0880	227.7746
S. γ". γ'(t)		3.1025	224.3792
S. γ". γ'.		4.4915	225.7682
S. γ"(t) γ'.		6.1934	220.3810
S(t) γ". γ'.	γ" = γ'	6.3691	224.1473
S. γ"(t) γ'(t)		8.3852	218.8865
S(t) γ". γ'(t)	γ_k" = γ_{k-1}", γ_k' = γ_{k-1}'	8.9102	223.0979
S. γ"(t) γ'(t)	γ" = γ'	9.1952	226.9734
S(t) γ"(t) γ'(t)	γ" = γ'	9.4614	223.6490
S. γ"(t) γ'(t)	γ" = γ', γ_k" = γ_{k-1}", γ_k' = γ_{k-1}'	9.4614	223.6490
S(t) γ"(t) γ'.	γ_k" = γ_{k-1}", γ_k' = γ_{k-1}'	10.0471	220.5485
S(t) γ"(t) γ'(t)	γ_k" = γ_{k-1}", γ_k' = γ_{k-1}'	10.0471	220.5485

Capture probability was allowed to remain time variable between primary sampling periods. Mark and recapture probabilities were assumed equal. The notation '.' Indicates that a given parameters was kept constant and (t) indicates the parameter was allowed to be time variable.
S denotes Survival
γ" denotes Emigration
γ' denotes Immigration
Subscript k-1 denoted Markovian emigration/immigration

Seasonal Survival and Probability of Capture

The no-movement (best fitting) model estimated a constant survival rate of 0.92 (SE± 0.05, 95% CI = 0.75-0.98) and assumed that no dolphins immigrated or emigrated between primary sampling periods, therefore this estimated value was zero.

The probability of capture varied over the course of the study period, with the probability of capture lowest in autumn (25% SE± 6%). The capture probability was highest in summer with a chance of 51% likelihood of capture in a transect (SE± 4%). The average probability of capture over all four seasons was 38% (SE± 4%).

Abundance measures

The population models estimated the dolphin abundance for each season throughout the study. Twenty individual dolphins were included in the abundance estimation analysis. This sub-set of individuals was used because they had highly distinctive fins and were not calves. The number of highly distinctive individuals (excluding calves) encountered in each season fluctuated from 11–17.

The best fitting model also estimated the dolphin abundance (N_{total}) in the Swan River ranged between 24 and 32 individuals (Table 3.4). The lowest abundance estimation was found in autumn, and the highest abundance was in spring.

Table 3.4 Estimates for each of the seasons during the study. Where, Nm is the estimated number of individual dolphins according to the population model. N_{total} is the estimated number of individual dolphins corrected with the percentage of distinctive fins recorded during sampling.

							95% interval	
	n	Nm	SE(Nm)	N_{total}	SE(N_{total})	C	Lower	Upper
Autumn	11	13.693295	3.044781	23.77308	8.109416	1.916074	12.40718	45.55099
Winter	15	15.375794	1.160725	26.69409	6.247379	1.57241	16.97655	41.97404
Spring	17	18.279373	1.691543	31.73502	7.227229	1.553847	20.42352	49.31135
Summer	14	15.333256	1.845037	26.62024	6.893483	1.647636	16.15662	43.86046

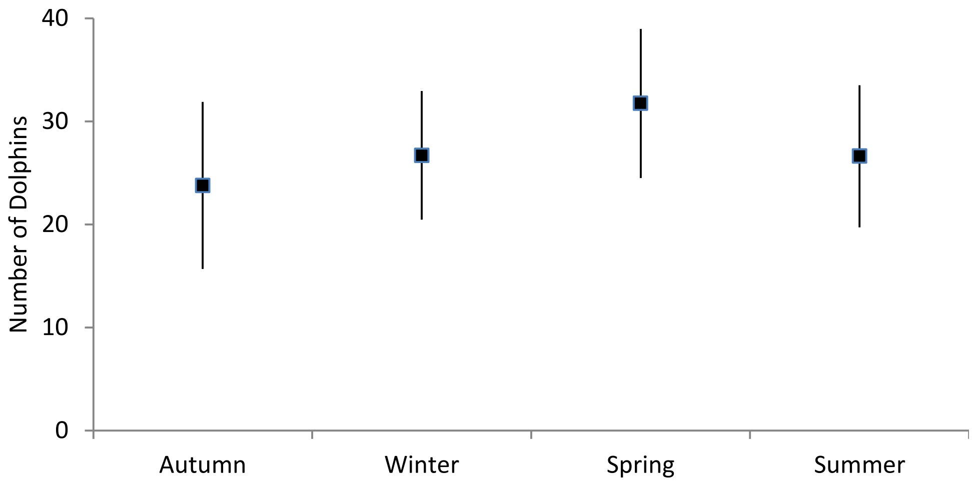


Figure 3.6 Dolphin abundances from autumn 2014 to summer 2015 (excluding calves). 95% confidence intervals indicated by vertical bars.

3.5 Discussion

3.5.1 Swan River Dolphin Ecology:

Seasonal Population Size Estimates

The estimated abundance of dolphins ranged from 24 to 32 individuals throughout the year, with a slight increase during spring season. The stability of the abundance estimate in this study suggested an accurate representation of the true resident population size. A previous study conducted from 2001 – 2003 estimated 18 resident dolphins through individual sighting rates (Chabanne *et al*. 2012). Chabanne *et al.* (2012) defined resident dolphins as individuals sighted more than 30 times (>10%) over the 222 field days. The true number of dolphins that occupy the Swan Canning Riverpark had changed. In the time between these studies some fluctuations in individual dolphin numbers was noted; in particular when six dolphins died within six-months (Bell *et al.* 2009). It should be noted that given the short study time frame (one-year) for this study the evaluation of temporary emigration and immigration could not be completely tested.

Immigration/ Emigration

The population model that best fit the data collected over the study period assumed there were no movement patterns into or out of the study area. The fluctuations between seasons cannot be accounted for through temporary emigration, which would require data from multiple years, and the data used in this chapter was collected from another project with a four-year sampling period (Chabanne 2015a). A longer study would evaluate how the number of individual dolphins could be influenced by temporary emigration and transient dolphins.

Probability of Survival

The population model indicated that the estimated chance of survival was high and consistent throughout the study period (0.92, 95% CI = 0.75-0.98). This suggests that the dolphin community has low mortality rates in adults. The model assumed no movement and therefore did not consider immigration or emigration. However, the study by (Chabanne *et al.* 2012) indicated through sighting frequencies that there are nineteen (44.2%) transient dolphins and six (13.9%) dolphins that are occasional visitors that occupy the lower Swan River. This previous study supports an open population that includes temporary emigration (Chabanne *et al.* 2012). The 92% survival rate that the no-movement population model estimated would include those individual dolphins that would be better described as either transient or occasional visitors. However, the length of this study did not accommodate for analysis that would be needed to prove the existence of these animals.

3.5.2 Sighting Frequency

Average Group Size

The average group size recorded during this study (5.7 individuals SE± 0.65) was likely to be accurate. The average group size results in this study were similar to a previous study of coastal bottlenose dolphins in Bunbury (180 km south of Perth), where the mean group size is 5.5 (SD ± 0.17; Smith (2012)). However, a previous study on the dolphin community (conducted in 2001 – 2003) in the Swan River identified an average group size of 2.80 (SE ± 0.11) (unpublished data; Finn (2015)). There are three possible reasons why the group sizes from this study and the previous study were different: (1) the results show a real difference between group sizes; (2) the high frequency of recording dolphin groups foraging in the 2001 – 2003 study, which was the behavioural characteristic associated with the lowest mean group size; and/ or (3) the two researchers applied different criteria for defining a dolphin group (Finn 2015). To investigate these differences in group size within the Swan River dolphin community the study would need to consider the behavioural characteristics of group sizes currently; this would also require a larger dataset collected over a longer time period.

Individual Dolphin Sighting Frequencies

The seasonal individual sighting frequencies for this study were higher than a previous study in the Swan River from 2001 – 2003 (Chabanne *et al.* 2012). The previous study calculated seasonal sighting rates to reflect the number of seasons that a dolphin was sighted at least once divided by the total number seasons (n = 8) (Chabanne *et al.* 2012). Chabanne *et al.* (2012) calculated a mean seasonal individual sighting rate of 0.51 sightings per season (SD 0.06) compared to the mean seasonal sighting frequency of 1.82 sightings per season (SD 0.21). The larger standard deviation could be a result from the smaller dataset used in this study (2001 – 2003 study = 402 dolphin group sightings; this study = 41 dolphin group sightings). The lower seasonal mean sighting rate in Chabanne *et al.* (2012) study could be a result of the large number of group sightings of dolphins foraging, which behaviour exhibited the smallest mean group size (Finn 2015).

The individual sighting frequency in this study indicated the presence of a resident dolphin community. Additionally, the same individual dolphins occupied the river in all seasons, suggesting year-round residency. These findings were comparable to a study conducted in the Swan River from 2001 – 2003, that obtained similar conclusions (Chabanne *et al.* 2012). Although Chabanne *et al.* (2012) identified a resident population, transient and occasional visitors were also identified. This study's temporal study period was not long enough to investigate temporary emigration. However, the likelihood that they were present is high and would be identified in studies with a longer duration.

3.5.3 Limitations

Professional science projects are restricted by the costs involved in such a rigorous study. There are multiple costs involved with conducting a profession science study, for example: (1) financial cost; (2) disturbance to the target species and non-target species; and (3) environmental and cultural impacts. Professional scientists have an obligation and responsibility for these logistical cost when designing and conducting their research (Gales *et al.* 2010). The cost of a project increases as the project increases in size: spatial size, temporal size and scope/extent of topic.

Professional science projects require repeat sampling (Huntington *et al.* 2004). The number of repeat samples that can be collected is related to a project's time frame; for example a project that spans over one year will record less data than a project that runs for four years. The information collected through the Dolphin Population Assessment Project was a detailed and precise; resulting in the average transect to be longer than 3.2 hours. Because of the time it took to complete one transect, the number of repetitions was limited. Therefore, to collect enough data to run professional scientific analysis the spatial scale of the project needs to be restricted.

3.5.4 Conclusion

This study has highlighted many advantages of conducting a professional science project on this community of dolphins in the Swan Canning Riverpark, including: (1) abundance estimation; (2) survival probability; (3) group sizes; and (4) individual sighting frequencies. The Dolphin Population Assessment Project has successfully described the dolphin community over the year-long study period.

4. Comparison of a Citizen Science and Professional Science Projects Investigating a Dolphin Population in the Swan Canning Riverpark

4.1 Introduction

This thesis proposed citizen science and professional science have different capacities and limitations for collecting scientific information, but ought properly to be applied in ways that are complementary and mutually supporting. My aim was to compare the two modes of research which involved the same wildlife community and took place in the same time period and in the same area. This chapter looks at the two empirical research projects that have discussed in previous chapters: Dolphin Watch (chapter 2) and the Dolphin Population Assessment Project (chapter 3).

Research that investigates easily distinguishable species over large spatial and temporal scales, which focuses on collecting information that develops knowledge on basic ecological patterns and processes, is best achieved through citizen science. For example, in chapter 2, Dolphin Watch indicated that dolphins occupied the entire study area year-round and large scale patterns in dolphin frequency over the whole study area.

Research that investigates on a small scale assesses species/ individuals with obscure distinguishable features, which focuses on developing detailed knowledge on complex biological and ecological processes, is best achieved through professional science. For example, in chapter 3, the Dolphin Population Assessment Project described certain aspects of the dolphin community, such as: (1) abundance; (2) survival probability; (3) groups sizes; and (4) individual sighting frequencies.

Prior research has looked at these two research methods to compare them with the idea of determining which method works best in different research contexts. For example, studies have compared the same types of data collected by citizen scientists and professional scientists, where both groups of observers use the same collection methods outlined in the citizen science project (e.g.Matthews 1960, Darwall & Dulvy 1996, Evans *et al.* 2000). A citizen science project is specifically designed to accommodate the volunteers (Shirk *et al.* 2012). Projects are designed so that the skills needed to participate will be able to be learnt through the training provided. This poses the question that if valuable data cannot be extracted from a citizen science project then these issues could potentially be reduced by adapting the project's design and the expectations placed on volunteers.

An alternative way of investigating citizen science and professional science was to assess their capabilities of using their research strengths together. Professional science would focus on identifying individuals, describing the population, and understanding biological and behavioural characteristics observed. Citizen science would focus on the large scale research objectives that investigate the temporal and spatial occupancy and frequency of sightings. With each project focusing on a different aspects of the same community, the results produced help explain the mechanisms at work in each other's projects providing valuable supportive information (Huntington *et al.* 2004).

4.2 Aims of Chapter

I evaluated the extent that the Dolphin Watch and the Dolphin Population Assessment Project overlapped by comparing the possible ecological outcomes produce through either project. Data used to answer these three research questions included: (1) quantity of sampling effort; (2) spatial and temporal distribution of dolphin sightings; and (3) dolphin group dynamics (group size/ sighting size). This chapter aimed to assess the limiting factors influencing each project and investigate the ability for these modes of research to produce complementary ecological outcomes that relate to the dolphin community in the Swan Canning Riverpark.

4.3 Methods

The data presented in this chapter is drawn from the projects described in the previous two chapters: Dolphin Watch (Chapter 2) and the Dolphin Population Assessment Project (Chapter 3).

4.4 Results

4.4.1 Summary Statistics

Sampling Effort

The Dolphin Population Assessment Project recorded less monitoring hours than Dolphin Watch; where sampling effort total 2.4% of the effort hours recorded by Dolphin Watch volunteers (Table 4.1). A total of 2682.3 survey hours was recorded through the DW project, which surveyed 33 zones. The Dolphin Population Assessment Project recorded 64.17 hours in 12 zones (zones 20-31). The average effort recorded per zone was 81.3 hours/zone (SD ± 88.4) for Dolphin Watch and 5.4 hours/zone (SD ± 0.4) for Dolphin Population Assessment Project (Table 4.1).

Table 4.1 Summary of sampling effort recorded in Dolphin Watch and the Dolphin Population Assessment Project across the entire study area.

	Dolphin Watch	Dolphin Population Assessment Project
Total Effort (hours)	2682.3	64.17
Number of Zones	33	12
Average Effort (hours/zone)	*81.28*	*5.35*
Standard Deviation	*88.37*	*0.38*
Total Area (km^2)	40.77	27.73
Average Area (km^2)	1.24	2.31
Total River Length (km)	~58	~20

When comparing the effort recorded exclusively in the common monitoring zones (zones 20-31); the Dolphin Population Assessment Project recorded 7.6% of the hours recorded by Dolphin Watch volunteers. Dolphin Watch recorded 844.9 hours in the zones that were common to both projects (Table 4.2). In all but one of the common zones Dolphin Watch recorded more sampling effort; Zone 31 was the exception, where the Dolphin Population Assessment Project recorded 57 minutes more effort (Figure 4.2). Dolphin Watch recorded a higher number of dolphins, sampling effort hours, sightings, and surveys within the common monitoring zones (zones 20-31) (Table 4.2).The standard errors associated with the averaging effort, number of dolphins, sightings and number of surveys submitted was also higher in Dolphin Watch (Table 4.2).

Table 4.2 Summary statistics from the 12 common monitoring zones (zones 20-31).

	Dolphin Watch	Dolphin Population Assessment Project
Effort (hours)	844.88	64.17
Average Effort/ Zone	70.41	5.35
Standard Error	*(SE ± 15.13)*	*(SE ± 0.38)*
Number of Dolphins	568	232
Average Number of Dolphins/ Zone	47.33	19.33
Standard Error	*(SE ± 7.79)*	*(SE ± 3.83)*
Number of Surveys	1315	360
Average Number of Surveys/ Zone	109.58	30
Standard Error	*(SE ± 23.49)*	*(SE ± 3.02)*
Number of Sightings	226	40
Average Number of Sightings/ Zone	18.83	3.33
Standard Error	*(SE ± 3.04)*	*(SE ± 0.57)*

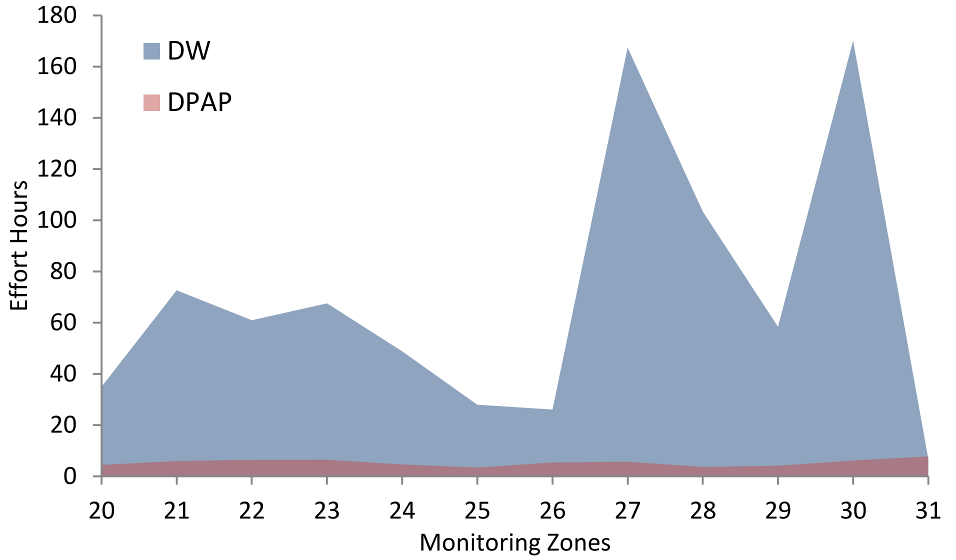


Figure 4.1 Effort hours recorded in the common monitoring zones between the two projects; Dolphin Watch, and the Dolphin Population Assessment Project.

Abundance estimation

An estimated abundance could only be calculated by data collected under the Dolphin Population Project. Analysis predicted the dolphin population fluctuated between 24 and 32 individuals throughout the study period; with a yearly average of 27.2 individuals (SE ± 1.7).

Proportion of Volunteers Recording Presence/ Absence

Dolphin Watch volunteers recorded both the presence and absence of dolphins in the Swan Canning Riverpark. However, 21% of volunteers only recorded dolphin presence. The majority of volunteers (55%) recorded a mixture of presence and absence surveys throughout the year. The remaining 24% of volunteers recorded surveys but never reported a dolphin sighting.

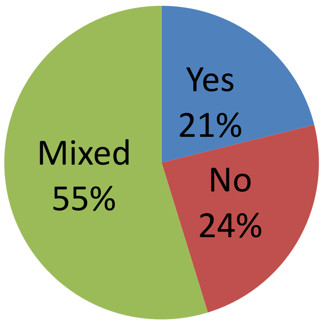


Figure 4.2 Proportion of volunteers who recorded presence only, absence only, and a mixture of presence/ absence surveys. This graph is based on the total number of volunteer (164 volunteers).

Time lapse

Records that reported a dolphin presence were more likely to be submitted quicker than records reporting absence. The average time lapse for Dolphin Watch records that record the absence of dolphins was 98.77 hours (SE ± 2.63). Whereas, the average time lapse when recording presence was 76.32 hours (SE ± 6.44). The time lapse was significantly different between absence surveys and presence records (student t-test: df = 834; T = 5.848; $P < 0.01$).

4.4.2 Distribution of Dolphin Sightings

Spatial Extent

The area covered by Dolphin Watch is 1.5 times larger than the area covered by the Dolphin Population Assessment Project. The total area covered by Dolphin Watch was 40.8 km^2 and the Dolphin Population Assessment Project covered 27.7 km^2 (Table 4.2). The average area of the 33 zones was 1.24 km^2 (SD ± 1.38). The average area for the 12 common zones was 2.31 km^2 (SD ± 1.62). The total river length covered by Dolphin Watch is ~58km and ~20km for the Dolphin Population Assessment Project.

Over 50% of Dolphin Watch effort was concentrated in six monitoring zones (zone 2-5, 27 and 30) (Figure 4.2). Zone 5 recorded the largest percentage (16%) of effort for Dolphin Watch (Figure 4.2). The zone with the largest proportion of effort recorded for Dolphin Population Assessment Project was zone 31 with 12% of the total effort recorded.

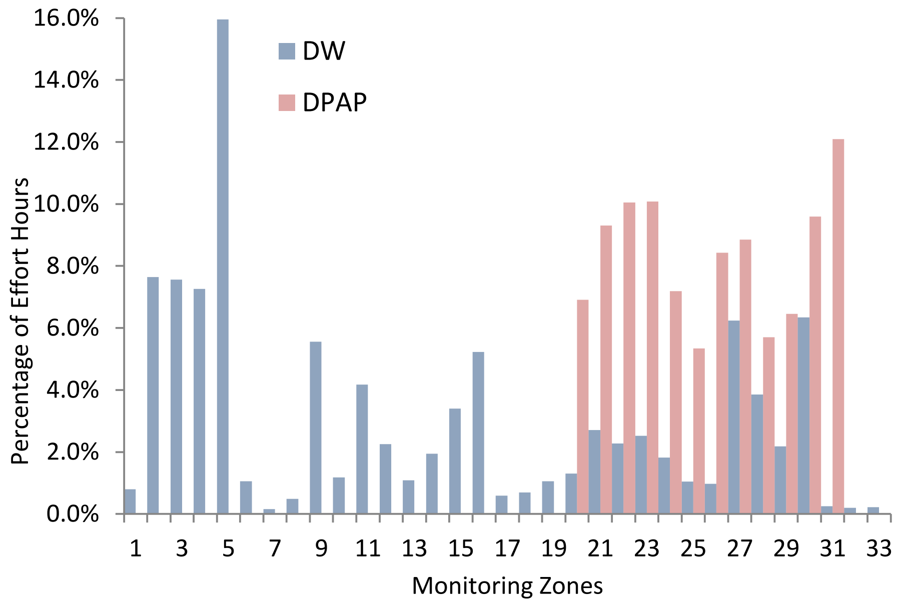


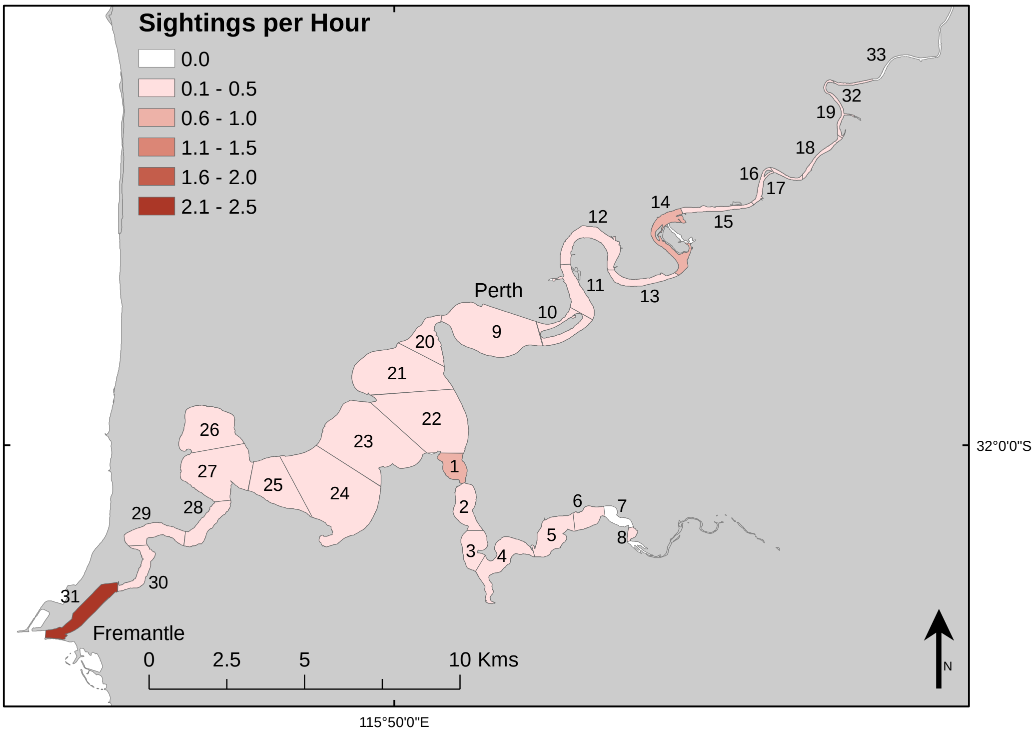
Figure 4.3 Spatial distributions of the effort hours (percentage of total) in each of the projects.

Spatial distribution of dolphin sightings

Both Dolphin Watch and the Dolphin Population Assessment Project recorded elevated sighting frequencies in zone 31 (Figure 4.4). Dolphin Watch recorded 2.35 dolphin sightings/ hour, whereas the Dolphin Population Assessment Project recorded 1.03 dolphin sightings/ hour. Dolphin Watch did not record any other dolphin sighting hotspots in the Lower Swan River. However, the Dolphin Population Assessment Project recorded another high frequency sighting location in zone 29 (Figure 4.4). For the Dolphin Population Assessment Project, there was moderate sighting frequency in zone 21 and 25-28 (average = 0.67 dolphin groups/ hour; SE ± 0.06).

Dolphin Watch indicated two other zones (zone 1 and 14) with elevated dolphin sighting frequency (Figure 4.4). Both these zones are outside of the Dolphin Population Assessment Project study area. Zone 1 is the first zone within the Canning River and is adjoined to zone 22, which is surveyed in the Dolphin Population Assessment Project (Figure 4.4). Zone 14 is 10.8km upstream and five zones from the closest point to where the Dolphin Population Assessment Project reaches in the Swan River (Figure 4.4).

A) Dolphin Watch Project



B) Dolphin Population Assessment Project

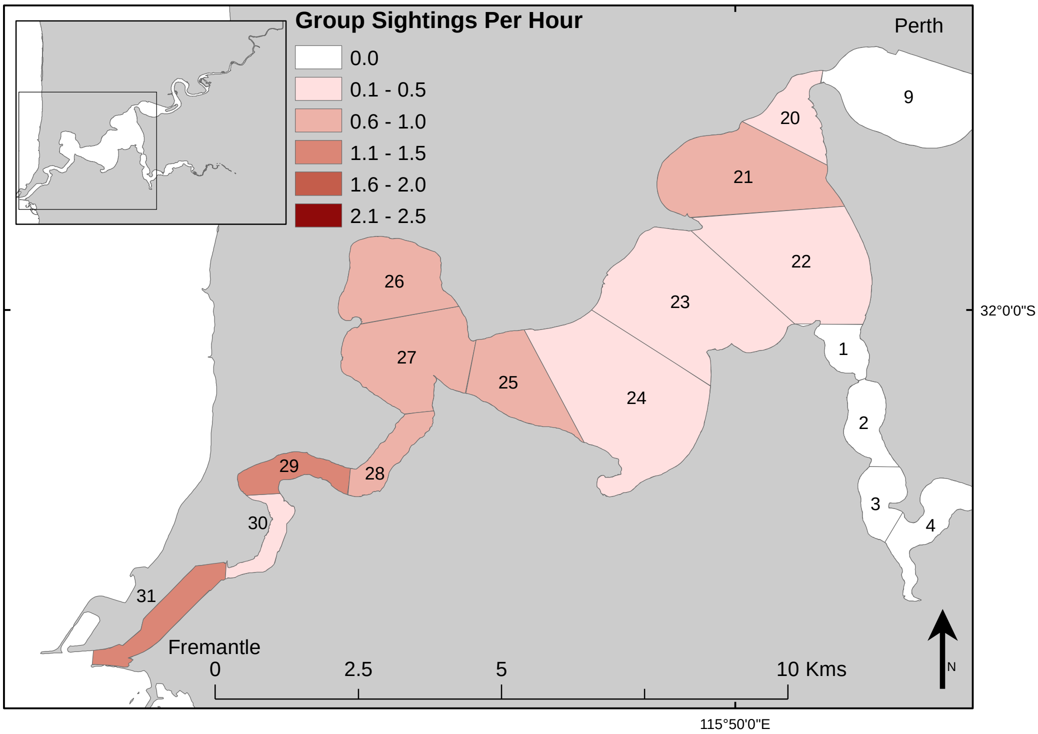


Figure 4.4 Distribution of Sighting Frequencies for both the Dolphin Watch Project and the Dolphin Population Assessment Project in their respective study areas.

4.4.3 Frequency of Dolphin Sightings

Frequency of Dolphin Sightings

When comparing the common zones the average frequency of dolphin sightings was higher in the Dolphin Population Assessment Project. The frequency of dolphin sightings for the Dolphin Population Assessment Project was 0.639 dolphin sightings per hour; whereas the frequency for Dolphin Watch was 0.005 dolphin sightings per hour.

With the exception of zone 31 and 20, the Dolphin Population Assessment Project reported higher sighting frequencies in all common zones (Figure 4.5). Zone 31 is located in the Fremantle Inner Harbour and is the closest zone to the mouth of the river. Zone 20 is the zone that is furthest from the mouth of the river and adjoins the zone associated with Perth CBD.

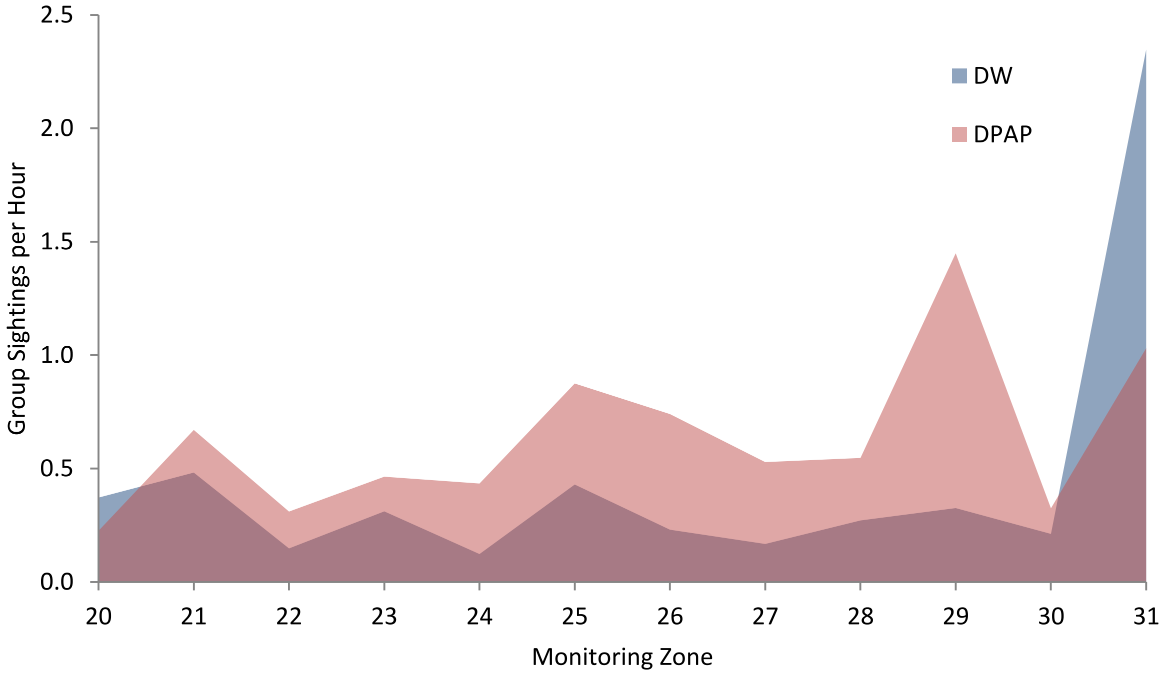


Figure 4.5 Dolphin sightings across zones where both Dolphin Watch and the Dolphin Population Assessment Project conducted surveys.

4.4.4 Group Dynamics

Number of Dolphins per Sightings/ Dolphin Group Sizes

The average recorded dolphins per sighting for Dolphin Watch was 2.6 (SE ± 0.04). Most of records submitted through Dolphin Watch recorded below three dolphins per sighting (473 records; 78.8%) (Figure 4.6). A total of 37.5% (223 sightings) of DW sightings recorded two individuals, a further 21.8% (132 sightings) recorded one dolphin and 19.5% (118 individuals) recorded three dolphins.

The group size for the Dolphin Population Assessment Project was 5.7 (SE ± 0.65). No individual group size category exceeded 15% of the number of sightings (Figure 4.6).

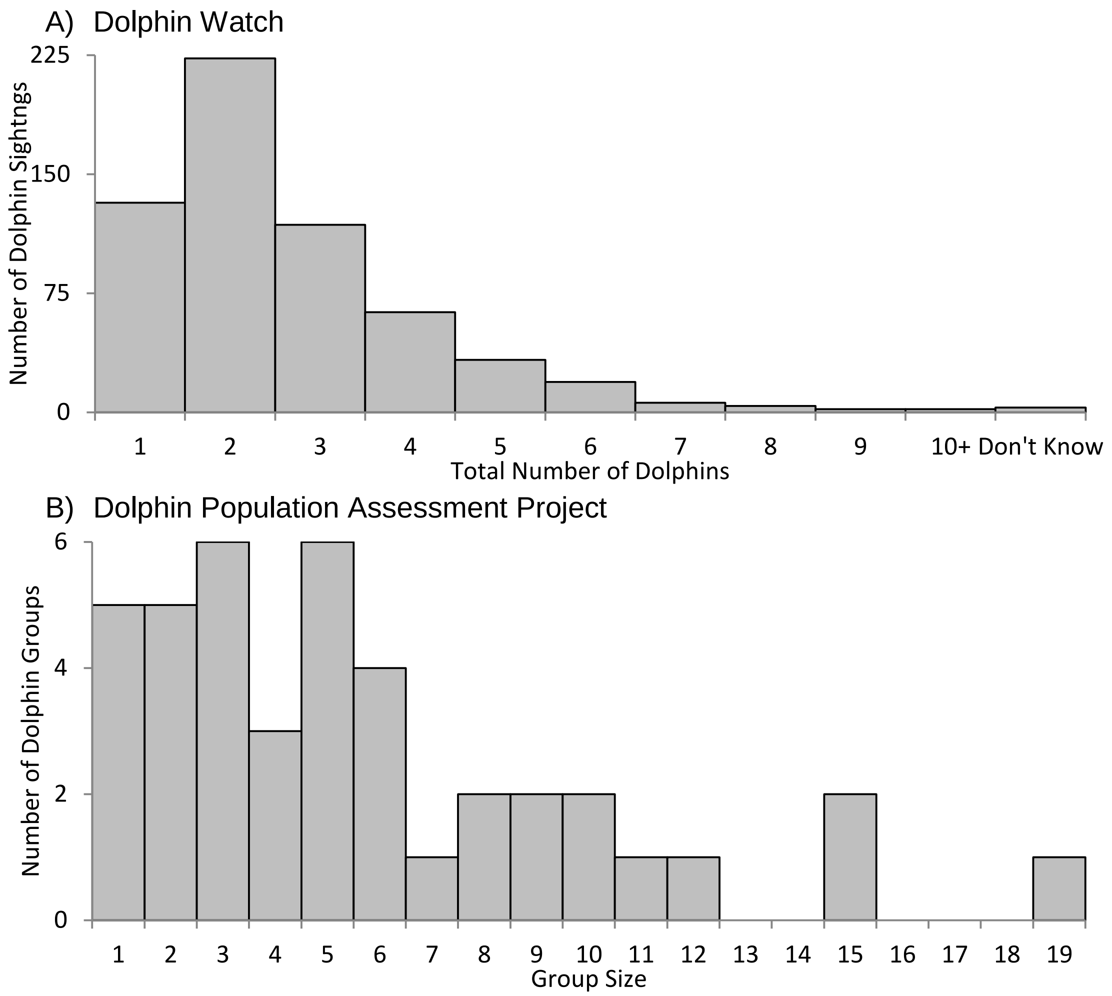


Figure 4.6 Frequency of dolphin sightings among a) total number of dolphins, and b) group size recorded by the Dolphin Watch and Dolphin Population Assessment Project respectively.

4.5 Discussion

4.5.1 Quantity of Sampling Effort

A larger quantity of data was collected through Dolphin Watch within the common monitoring zones (zones 20-31; located in the Lower Swan River). Collecting more data through Dolphin Watch was expected. This expectation was based on the two characteristics of the citizen science project: (1) the project had been successfully operating for over four years at the commencement of this study (SwanRiverTrust 2014) and (2) a number of volunteers were already motivated and contributing surveys (Chapter 2). Citizen science projects are known to have the potential to collect large quantities of data, often in a time frame that would make it impossible to collect that quantity through professional science methods (e.g. Sullivan *et al.* 2009, Ries & Oberhauser 2015). Where, Sullivan *et al.* (2009) describes the eBird project that collected data on multiple bird species predominantly in North America and Ries and Oberhauser (2015) investigated the migratory pattern of monarch butterflies.

The quantity of data collected through citizen science has the ability to focus on different research objectives. Research objectives can focus on understanding large scale patterns, processes and environmental changes, which would otherwise be impossible to study in the rigorous methods of professional science (Huntington *et al.* 2004).

4.5.2 Distribution of Effort and Dolphin Sightings

Dolphin Watch recorded surveys over a larger spatial scale both in: area (additional 13.1 km^2) and river length (approximately 38 km). The spatial range of dolphin sightings to both projects was expected considering dolphin had been sighted in all monitoring zones in previous years (SwanRiverTrust 2014). Previous studies, both citizen science and professional science indicated the presence of a dolphin community in the Swan Canning Riverpark (Chabanne *et al.* 2012, SwanRiverTrust 2014). Investigating the dolphin community at two different spatial scales with different research objectives benefits each other with the knowledge that can be shared (Walters & Holling 1990, Chaffey 2003, Huntington *et al.* 2004). By collecting data on a board spatial range, citizen science has the ability to identify knowledge and research gaps, evaluate unplanned changes in the environment, investigate large complex ecosystems and experiment in alternative data collection methods (Walters & Holling 1990). Professional science uses rigorous methods to collect detailed information that investigates narrow precise goals in a restricted spatial scale (Walters & Holling 1990). An example of professional science project that investigated at a precise goal with a small spatial scale is found in the study by Nicholson *et al.* (2012) that investigated the abundance, survival and temporary emigration of bottlenose dolphins in Shark Bay.

The distribution of volunteer's effort in Dolphin Watch was varied throughout the study area; whereas the distribution of effort was more consistent for the Dolphin Population Assessment Project. The Dolphin Population Assessment Project used a systematic sampling design; whereas Dolphin Watch surveys are more closely categorised as opportunistic. The systematic nature of sampling in a professional science context develops more confidence and certainty within results produced (Walters & Holling 1990). The variation seen between monitoring zones in the Dolphin Population Assessment Project are likely resulting for additional time spent in a zone associated with a dolphin sighting and the transect passing through some zones twice to accommodate the width of that section of the river.

Absence records were used to standardise the Dolphin Watch dolphin sightings, which was important with the variety of effort conducted between monitoring zones. The absence records were critical in reducing biases when investigating spatial distribution of sightings (Dickinson *et al.* 2010).

The distribution of dolphins identified by both projects supported each other with both Dolphin Watch and the Dolphin Population Assessment Project recording sightings in all common monitoring zones. The consistency of this information strengthens the results produced by each project, particularly the citizen science project (Chaffey 2003). The extended spatial area monitored by Dolphin Watch volunteers provides observations where professional science does not exist; sharing baseline ecological patterns that gives a large scale perspective on the dolphin community (Chaffey 2003).

4.5.3 Frequency of Dolphin Sightings

The Dolphin Population Assessment Project recorded a higher frequency of dolphin sightings across the common monitoring area (zones 20-31). Professional science aims to remove observer bias from sampling procedure (Huntington *et al.* 2004); the Dolphin Population Assessment Project achieved this by constantly using more than one observer during a survey. When there is only a single observer the detectability of a dolphin is influenced greatly by the probability that the observer is looking in the right place at the right time when the dolphin is observable (at the surface) (Beidatsch 2012). Using multiple observers reduces the probability that recording a false absence is caused by the observer not looking in the right direction; as a result the probability to detect the presence of dolphins was higher. A higher probability of detecting a dolphin's presence directly impacts the frequency of dolphin sightings.

Zone 31 was an exception to this trend; as Dolphin Watch recorded a very high sighting frequency. The high sighting frequency can be attributed to the very low effort hours that were recorded in this zone. This result confirms the importance of recording absence surveys to standardise dolphin sightings across the study area. The sighting frequency is likely elevated above reality due to the few absence records in this zone. Cooper *et al.* (2012) suggests that volunteers are less likely to record absence records than presence because absence records can be perceived to have a lower importance to volunteers. This concept was supported in the Dolphin Watch study with just over one out of five volunteers only recording a dolphin sighting during the study.

4.5.4 Group Dynamics

The group dynamics used to describe the number of dolphin present was recorded differently between the two projects. Dolphin Watch volunteers recorded the total number of dolphin within a sighting; whereas the Dolphin Population Assessment Project recorded the group size, which was determined through the 100-chain rule (Chabanne 2015b). A direct comparison cannot be made between this characteristic of group dynamics because the definition of a dolphin group is not communicated with volunteers from Dolphin Watch. Volunteers could not be expected to differentiate between multiple dolphin groups within the same monitoring zone. Even when using criteria, different observers can identify group sizes differently (Gerrodette *et al.* 2002). Professional scientists will aim to remove this bias as much as possible, but there is still a possibility for different scientists to apply identification criteria differently in the field. Although measuring group dynamics increased the information produced from Dolphin Watch and the Dolphin Population Assessment Project these measures cannot be compared accurately. Additionally, due to the different ways to measure the numbers of dolphins present between the projects; group dynamics would not be able to support the claims of the other project.

4.6 Complementary Studies

While Dolphin Watch and the Dolphin Population Assessment Project both investigate the spatial and temporal distribution, as well as the quantity of dolphins present, they approach these research objectives differently. In contrast to professional science projects, which tend to have a small number of highly-trained observers and consequent limitations to sampling effort and (in particular) to the amount of time and area that can be sampled; citizen science projects often involve large numbers of observers and thus can collect data over a large spatial area (e.g. Sullivan *et al.* 2009, Bonter & Cooper 2012).

This thesis examined the differences in research objectives for the Dolphin Watch and the Dolphin Population Assessment Projects as examples of citizen science and professional science projects. Both projects investigated the dolphin community in the Swan Canning Riverpark, but they did so by asking different research questions and by applying different research methodologies. A project's research objectives often influences the design and structure of the project (i.e. if the research is best conducted under a citizen science design or the structure of a professional science project) (Chelimsky 1991).

As the two different projects approach the research differently and focus on different objectives; when the project's work together they can collect supportive information and work together to investigate a wildlife population. Dolphin Watch has consistently worked with professional scientists to adapt to the research objectives and to motivate volunteers. For example, in 2010 the study area expanded (SwanRiverTrust 2011) and in 2011 the dolphin identification 'FinBook' was expanded to include information on dolphin behaviour in 2013 (SwanRiverTrust 2013).

A citizen science project has the potential to outlast a professional science project; where volunteer can continue to collect valuable information when and where other projects cannot collect (Chaffey 2003). Incorporating data from multiple years allows researchers to study temporal changes in the Swan Canning Riverpark dolphin community, such as seasonal changes in distribution or in the occurrence of particular individuals in the Riverpark. Developing citizen science projects that outlast professional science project and provide background information over an extended period of time would benefit the community (Walters & Holling 1990).

5. Conclusion

The aim of my study was to investigate two empirical research projects studying the Indo-Pacific bottlenose dolphin community in the Swan Canning Riverpark. The first project was Dolphin Watch, which was a citizen science project that continues to collect data throughout the Riverpark. The second project was the Dolphin Population Assessment Project, which was a professional science project that collected data over a total of four years.

The objectives of this research were to assess:

- the quantity of sampling effort
- spatial and temporal distribution of dolphin sightings; and
- dolphin group dynamics (group size/ sighting size).

An additional aim was to assess the motivations of volunteers and the level of volunteer contribution to the Dolphin Watch project over a one-year period in which a smart-phone application was introduced and several training events occurred.

Data was used from two sources: (1) the Dolphin Watch database, where data was collected by volunteers; and (2) data collected by a Murdoch University researcher as part of the Dolphin Population Assessment Project. Data included in this study was from March 2014 to February 2015.

A higher quantity of data was recorded through Dolphin Watch. This outcome was seen in: (1) sampling hours; (2) number of surveys; (3) number of sightings; and (4) number of dolphins sighted. Both newly trained volunteers and existing volunteer contributed to the data collected. Dolphin Watch draws new volunteers regularly with two training events held each year. Communication between volunteers and Dolphin Watch organisers was important in continuing volunteer motivations and the level of commitment to the project; this was seen in the uptake of volunteer contribution that followed a training event.

Dolphins were observed throughout the study area, with sightings from the Inner Harbour in Fremantle upstream to the upper reaches of the Swan River and in the Canning River up to Guildford and the Kent Street Weir respectively. Both projects observed dolphins in all of the common monitoring zones (zones 20-31). The frequency of sightings varied across the monitoring zones but distribution patterns could not be determined with the heterogeneity of dolphin detection.

The differences between the two research projects allowed them to complement each other and support each other's claims. Citizen science and professional science are able to focus on collecting different information about the same community or population. Additionally, the same type of data can also be collected at different spatial scales; a citizen science project can collect information about a community's geographic range whereas a professional science project focuses on assessing the spatial distribution and population's abundance. Two projects that collect the same type of data can validate each other's projects findings (Chaffey 2003). For example, both projects showed that dolphins were present year-round in the Lower Swan River (as this was where the common monitoring zones were located).

Potential Future Research

The Dolphin Watch smartphone app was integrated into the collection methods with a variable level of success. The app was used to submit over a third of all surveys; additionally, 38% of volunteers used the app during the course of this study.

The smartphone app was a new optional component in the Dolphin Watch collection method. The integration of this technology into the project created some challenges but also allowed for volunteers to contribute their surveys in new innovative ways. The smartphone app will change and adapt for the future based on its performance over its first year in operation.

As the smartphone app has the ability to change the ways volunteers record their location; currently the app automatically records this data. Potentially, the smartphone app will be able to make recording surveys in multiple zones easier by trialling different ways of tracking location data. There is potential to follow the process of how Dolphin Watch adapts to smartphone technology and how technology can better accommodate the data collection needs of the volunteer.

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