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FROM DATA TO DISCOVERY – COMMUNICATING THE IMPORTANCE OF MATHEMATICS AND STATISTICS IN LIFE SCIENCES

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INTERNSHIP REPORT

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For Tiago.

May everyone have one like you.

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FROM DATA TO DISCOVERY – COMMUNICATING THE IMPORTANCE OF MATHEMATICS AND STATISTICS IN LIFE SCIENCES

MARIA ZACARIAS

ABSTRACT

Academic institutions, such as universities and research units, have become central to strengthening the relationship between science and society and over the past 20 years we have seen a rise in activities related to the public communication of science within these organisations. Despite this growing activity, science communication endeavours at these types of institutions are still restrained by a series of limiting factors. This report is the result of a four-month internship at the Centre for Research into Ecological and Environmental Modelling at the University of St Andrews (CREEM) whose focus is to develop and apply statistical methods to answer ecological research questions. Here, we describe and discuss the work involved in the improvement and development of the public engagement activities of the centre that aim to communicate the importance of Mathematics and Statistics in Life Sciences. This report further discusses our results when doing these same activities among our target audiences. Even though institutions like CREEM are still very limited by the short availability of resources for science communication, its researchers recognise the importance of communicating their work to wider publics and show keen interest in improving their institution's science communication practices. Finally, we explore how drawing from the expertise of other disciplines related to science communication, such as informal science education, can help scientists develop and improve their public engagement activities and practices.

Keywords: public engagement, research institutions, scientists and science communication, communicating statistics, informal science education.

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INTRODUCTION

This report is a result of the work developed during a 4-month internship at the Centre for Research into Ecological and Environmental Modelling at the University of St Andrews (CREEM), carried out as part of the non-curricular component of my MSc in Science Communication at the NOVA University of Lisbon, a joint course of at the Faculty of Social Sciences and Humanities (NOVA FCSH) and the Instituto de Tecnologia Química e Biológica (ITQB NOVA).

CREEM is a research centre in Statistical Ecology and their work focuses on developing and applying statistical methods to answer biological questions. Throughout the years, their public engagement activities have focused on deconstructing the idea that Mathematics and Statistics are dull subjects without real life applications. In consequence, the main objective of the internship was to improve and develop public engagement materials that focused on illustrating the central role of Mathematics and Statistics in understanding the natural world.

During the internship, three distinct outreach opportunities arose that allowed us to bring these activities to their intended target audiences. This gave way for unforeseen reflections and insights on the broader topic of science communication within research institutions. Taking the examples observed at CREEM, we felt it necessary to discuss the internship experiences from a wider perspective. Therefore, in addition to the public engagement materials developed during the internship, this report also describes these outreach opportunities – an open science day at a science centre, a primary school visit and a science-themed activity at a local cub scouts group – and discusses the results obtained from these experiences.

The report is divided into four different parts. Part I starts by establishing current definitions of science communication, recognising their diversity and contextual determinants. This section then dives into the specificity of science communication in research institutions, identifying different levels of action. It also explores scientists' many reasons to communicate their work to non-scientists, identifying their main motivations and challenges of publicly communicating science.

Part II introduces CREEM, describing the institution's internal structure and research goals, going into further detail on their current public engagement practices.

Part III describes and discusses the work developed during the internship. It begins by reporting the results obtained from four interviews to CREEM researchers carried out with the goal of better characterising science communication practices at the centre and is followed by a description of the work involved in developing the public engagement activities. This includes both the educational materials and the outreach events we attended.

Finally, in Part IV we discuss the lessons learnt throughout the internship. Recognising that not all research institutions have dedicated science communication offices, we try to suggest how scientists from institutions like CREEM can make use of the available evidence to better communicate their research. Gathering elements from every other part of the report and building on the experience of other scientists who have sought to bridge the gap between science and society through informal science education, we hope to help scientists in other research areas to plan and carry out outreach activities.

PART I – SCIENCE COMMUNICATION AND ACADEMIC INSTITUTIONS

I.1. Science Communication

I.1.1 Defining science communication

The beginnings of the public communication of science and technology as we know it today dates back to the 1960's (Schiele et al., 2012). Around this time, governments began recognising the heavy influence of science in politics and economy, which triggered a lot of research on the relationship between science and society by various fields, such as media studies, journalism and sociology (Gascoigne et al., 2010). Since then, and especially over the past two decades, the study of the science-society relationship has gained a lot of traction and grown into its own academic discipline (Bucchi & Trench, 2016), which we nowadays commonly refer to as science communication.

Because of the recent emergence of science communication as its own research field, its definition is not set in stone and, over the years, experts have taken turns at defining it – something we can see spread across the literature. According to Akin (2017), for instance, science communication is an area of study that strives "to systematically evaluate how scientists and others convey scientific information, how the public receives and interprets it, and the social and political aspects of these dynamics". This definition not only illustrates how science communication has become its own standing academic field, but also how, despite this, it remains true to its roots by still drawing and benefiting from the knowledge of social, economic and cultural disciplines.

Mulder et al. (2008) discuss science communication in a similar light, emphasising the importance that fields such as the natural sciences, the (science) education sciences, the social sciences, and the communication sciences have had (and still have) in the study of science communication (**Figure 1**). Observing how Mulder et al. have outlined these interactions, one is bound to reflect about how the overlapping and complementary aspects of these different fields can help us improve science communication practices – something we will explore later in this report.

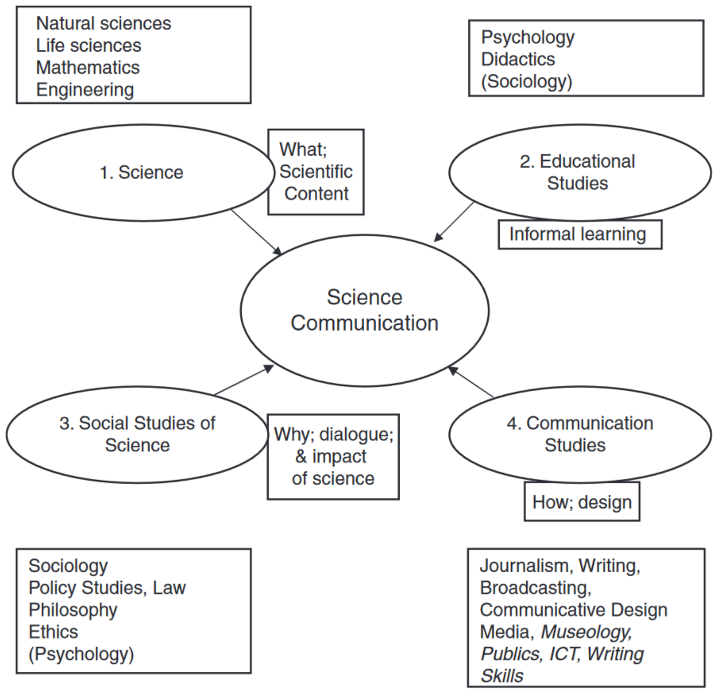


Figure 1 – Four areas of study that support the discipline of science communication. Source: Mulder, Longnecker & David (2008).

The definition given by Akin (2017) has a strong emphasis on the academic side of science communication. This field, however, has another important facet – its practice. In their work "Science communication – A Contemporary Definition", Burns et al. (2003) defines science communication from a more practical perspective as "the use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science: awareness, including familiarity with new aspects of science; enjoyment, such as appreciating science as entertainment or art; interest, evidenced by voluntary involvement with science or its communication; opinions, the forming, reforming, or confirming of science-related attitudes; and understanding of science, its content, processes, and social factors". Furthermore, they conclude by noting how the practice of science communication is one that involves many different actors, from individual scientists, research institutions and science communicators, to governments and the general public.

With so many moving parts, science communication is best understood when these complex interactions are all accounted for. One other (and more recent) definition that seems to emphasise this complexity is one by Dam et al. (2020). In their book “Science Communication: An Introduction”, they define science communication as “the many ways in which the process, outcomes, and implications of the sciences (…) can be shared or discussed with audiences”, stating that “science communication involves interaction, with the goal of interpreting scientific or technical developments or discussing issues with a scientific or technical dimension”. Furthermore, they also refer to it as a process that is “dynamic, constantly changing, and driven by a variety of interpretations, views of science, and communication goals”.

I.1.2 Models of communication

Given these various takes on science communication, how does one go about publicly communicating science and technology? In their work “Analytical Framework of Science Communication Models”, Trench (2008) characterised science communication as fitting into three categories of communication models – the deficit model, the dialogue model and the participation model. According to Trench (2008), the deficit model is when “science is transmitted by experts to audiences perceived to be deficient in awareness and understanding” and as having low scientific literacy. The dialogue model is where science “is communicated between scientists and their representatives and other groups, sometimes to find out how science could be more effectively disseminated, sometimes for consultation on specific applications”; and the participation model, is where “communication about science takes place between diverse groups on the basis that all can contribute, and that all have a stake in the outcome of the deliberations and discussions”.

In the last 20 years, and despite having been recognised as foundational theoretical concepts in science communication, these models have been continuously discussed, criticised and compared to one another, in order to understand which one is best (Bucchi & Trench, 2016). This has led, for instance, to heavy criticisms to the deficit model, which has been labelled “old and discredited”, in comparison to the dialogue model, often seen as “new and appropriate”. These criticisms, however, are not unanimous among experts. In fact, another side of research on communication models has been trying to understand how, why and in what contexts these different models are used and how they can coexist (Miller, 2001; Sturgis & Allum, 2004). Brossard and Lewenstein (2010), for instance, looked at how the models of communication were actually reflected in practice. They found that science communication projects tended to incorporate elements of every communication model and use them according to context and audiences. This also aligns with discoveries by Metcalfe (2019), whose research shows that science communication activities don't usually follow just one of the three communication models. They tend to, instead, coexist and overlap.

Stocklmayer (2013), for instance, shares a similar view of the models of communication. Without creating any apparent hierarchy of importance and emphasising the roles of each mode of communication in successfully communicating science, they discuss these models (referring to them as modes of communication instead) as the communication of science *to* the public, *with* the public and *among* the public. Furthermore, these modes of communication encompass "three different kinds of intended outcomes that essentially form a continuum".

The first mode, communicating *to* the public, refers to one-way communication often found in the media and science lectures, where the main goal is to inform the audience. Even though this doesn't allow for (immediate) feedback or comment from the audience, it still holds potential to generate behavioural or attitude change. The second mode, communicating *with* the public, is a two-way communication where dialogue is prioritised with the aim of understanding the public's perspectives and opinions on scientific issues, although it doesn't necessarily involve the incorporation of these perspectives in the scientific process. Lastly, the third mode of communication, also referred to as "knowledge building", not only prioritises the public's views and knowledge, but also seeks to incorporate them into the scientific process. Even when stemming from other disciplines such as the arts or the social sciences, the public's input is considered and used in the process of constructing knowledge, with citizen science being a great example of this.

These various approaches paint a picture of science communication, in research and in practice, as layered and highly dependent on communication goals and intended outcomes.

Moreover, they do so in a way that highlights how much science communication draws from multiple other fields of research and knowledge areas and is greatly influenced by the social, economic, political and cultural factors in which it takes place. It is under this overarching picture of science communication that we discuss the activities carried out over the course of the internship.

The practice of science communication is very diverse and occurs in many different spaces, such as science centres, academic institutions and the media, and is carried out by various actors, such as science communicators and scientists. Before diving into the specifics of the internship itself, it’s important to understand its context to, later on, better understand and discuss the activities conducted under it. This internship took place at a research institution within a university, whose particular characteristics will be discussed in detail in Part II. For now, we’ll set a wider scene and talk about what is known about science communication across the globe at three different levels: the university, the research institution and the scientist.

I.2. Communicating research at different levels - the university, the research institution and the scientist

According to Entradas (2021), “academic institutions and research universities are at the heart of the science-society relationship”, because they “provide the resources for public communication, define and reflect research priorities and set agendas for how relationships with stakeholders, the mass media and wider publics are established”. Furthermore, "public communication has become increasingly important for research institutions that are publicly funded, and there are now requirements set in place for institutions to tackle society’s economic and social problems”.

Factors such as academic research assessments, which have set in place requirements for research projects to facilitate pathways to impact on society, have applied increasing pressure on institutions to disseminate their results and create strategies to engage with the general public (Entradas, 2021). This has resulted in a rising trend within academic institutions to reach broader audiences and build relationships with non-scientists, which include a wide range of groups – from industry and policymakers to journalists, students and NGO's (Entradas & Bauer, 2017). Moreover, the strategies to achieve this vary across the different levels of academic organisations, which Entradas et al. (2020) have categorised into the central level, the meso-level and the micro level.

I.2.1 The central level – the university

The central level refers to communication by universities and larger scale research institutions, where central communication offices are becoming increasingly common and carry out functions related to public relations, marketing and science communication. Additionally, they are also responsible for activities such as branding, advertisement, maintaining contact with the media (such as journalists), producing press releases and organising institutional events. Studies characterising science communication activities at the central level have pointed to an increasing professionalisation of staff, with institutions hiring "science communicators" and "public engagement officers" to engage various target audiences with research (Koivumäki & Wilkinson, 2020; Watermeyer & Lewis, 2018). Despite this, a lot of universities still rely on non-specialist staff to carry out these various activities (Peters et al., 2008), who face challenges related to lack of resources, training and skills (Watermeyer & Lewis, 2018).

I.2.2 The meso level – the research institution

The meso level refers to the research units, centres or institutions inserted within larger academic institutions. Even though research points to a growth in science communication activity, this level is still considered to be under researched and not as intensely studied or characterised at the meso-level when compared to the central level (Entradas & Bauer 2017). Because of this, some researchers have jumped to fill this gap.

Over recent years, researcher Marta Entradas and colleagues have been trying to understand and get the full picture of how science communication is carried out at research institutions. A lot of their work aims at gaining insights on how science communication is carried out at research institutions in countries all over the globe, such as Germany, the United Kingdom, the Netherlands, Portugal, Italy, the United States, Brazil and Japan (Entradas et al. 2020; Entradas, 2021; Entradas & Bauer, 2022). With their research, Entradas et al. have found trends of growth in communication activity among research institutions, indicating that "public communication of science increased in most institutes (61%)" and that "expectations are for continuous growth with about half expecting to dedicate more resources to the activity in the coming years, and 90% expecting their researchers to engage in it".

Not only that, but they have also been able to identify the variety of activities among research institutions and their patterns of activity. They found a greater focus on activities such as public lectures and open science days whilst, on the other hand, activities such as attending science festivals, public exhibitions and science policy events appeared to be less prominent. This points to a predominance of face-to-face events, which, according to the researchers, may indicate that research units, centres and institutions "are more in control of their public science communication and less dependent from the traditional gatekeepers in the news media, which may be more in evidence at the central communications level". Furthermore, they have also found that research institutes gravitate more towards traditional news media formats, such as press releases, newspaper and newsletters, as opposed to social media channels, which appear to play a very small part in their science communication practices.

Furthermore, whilst at the central level one of the focuses of communication offices' is building relationships with media and journalists, at the meso level, and despite some attention also being given to interacting with the media, research results point to the majority of efforts being allocated into reaching the general public and "delivering the unit's activities rather than into establishing media relations".

Overall, there seems to be similarities in types of activities across the countries surveyed, but also contrasting intensities of activity, as well as resource allocation, with "the professionalisation of this communication effort only beginning in most contexts".

Their research also reveals some of the motivations to publicly communicate science. Generally, "research institutes engage in public communication because they want to disseminate their research to broader audiences and to respond to the mission statements of their parent organisations", which indicates a "commitment to public engagement, in most cases, driven by goals of enlightenment and public dissemination, rather than public engagement in research, development or policy". Furthermore, they also find "a growing international phenomenon and a change in research institutes to open up their research results to unspecific publics".

Their concluding remarks are that "research institutes are taking communication responsibilities on their own and are becoming important places for civic science communication and public engagement within the university environment", with advances of communication activities and strategies heavily limited by a lack of resources. Despite this, the "tendency of many institutes is to increase their level of communication activity, take charge of it and recruit their own professional staff", becoming independent of central level communications.

Another study from 2011 conducted by Neresini and Bucchi aimed at understanding whether public engagement activities from 40 different European research institutions had become standard and routine practices within the organisation by looking at how organisations evaluated these activities, which they found, not unlike Entradas and colleagues, were mostly aimed at schools and tended to focus on producing educational materials.

According to Neresini & Bucchi (2011), evaluation of public engagement activities "can be particularly useful for an organisation to systematically and critically reflect on its own activities rather than for plainly measuring the achieved results". This means that a critical part of incorporating well rounded evaluation methods are the investments institutions make in terms of budget, time and dedication, and the degree to which this is embodied within an institution is considered to be an indicator of the relevance public engagement activities have within a research institution. “A systematic endeavour to monitor target audiences and their features, as well as the attempt to understand whether and to what extent [public engagement] objectives have been achieved, would testify in fact not only to prudent management of resources, but also to the intention to learn from experience and obtain relevant feedback”.

That being said, Neresini and Bucchi found that in research institutions where science communication initiatives are tailored for schools and focus on producing educational materials, almost all failed to monitor audiences and evaluate the activities’ impacts. Additionally, others have also pointed to the widespread of low investments in evaluation of public engagement activities (Edwards, 2004; Neresini and Pellegrini, 2008), and to the fact that, when incorporated, do not tend to meet very high standards (Gascoigne and Metcalfe, 2001; Rowe et al., 2005).

In conclusion, Neresini and Bucchi state that evaluation in research institutions still plays a marginal role in the organisations and that “a *culture of public engagement* still seems to be lacking among most research institutions in Europe – meaning an organisation culture in which [public engagement] is appropriately recognized, evaluated and rewarded as part and parcel of the organisation life, routine activities, and identity as well as a relevant element of the broader institutional landscape in which the organisation operates”.

I.2.3 The micro level – the scientist

Finally, we have the micro-level (or individual level). This type of activity takes place when scientists communicate their own work outside of their academic institutions and peer groups. Out of the three levels, this one has received the most attention in the literature. Research at this level mainly looks at the mobilisation of scientists to publicly communicate science (pointing to an increase in activity), their motivations to do it and the challenges they face along the way (Besley et al., 2018; Crettaz Von Roten, 2021).

More recently, the European funded project CONCISE looked into the incentives and the barriers that scientists face in their science communication endeavours. The overarching goal of the project is to "generate a European-wide debate on science communication, involving a wide array of stakeholders, from media outlets to policy makers, from scientists to business companies, from science communicators to civil society organisations", and one of their objectives is to understand what incentives can be used to promote science communication among scientists. In the end, they were able to identify three main incentives and five main barriers for scientists to engage in science communication, which can be summarised in the following points.

As for scientists' incentives to engage in science communication, the main points were:

- **Social commitment** (as payment to citizens who fund science through taxes, to improve democracy, promote science, to inform society, increase scientific culture and promote scientific vocations).
- **Strategy to get personal or professional benefits** (attract funding, attract scientific collaborations, reach a broader audience, enjoy themselves).
- **Part of a researchers' job** (included as mandatory issue in research projects, promoted by research institutions, criterion by funding bodies).

As for the barriers to engage in science communication, the main points were:

- **Lack of rewards or recognition** (not included in formal evaluation of scientific careers, not included in institutions or project objectives, not sufficiently promoted by research institutions or funding bodies).
- **Lack of time** (bureaucratic burden to get funds and projects, competitiveness in science).
- **Lack of training** (no formal training in science communication).
- **Fear of being discredited by peers** (fear to be considered less scientific, have been considered less important).
- **Fear of being misunderstood** (fear the public or journalists misunderstood their messages).

These relatively recent findings have come to confirm some older research on this same matter. Brownell et al. (2013) found that a big majority of researchers from various scientific fields have never received formal training in science communication. This has been raised as an issue among the scientific community, and experts have come forward to express the necessity of promoting formal training in science communication among scientists (Mulder, Longnecker, and Davis 2008). Other barriers for scientists to engage in science communication found by the project CONCISE such as lack of time and recognition have also been found and discussed by others (Sanz Merino & Tarhuni Navarro, 2019; Besley et al. 2018).

In this section, we have set the scene for science communication across academic institutions at three levels of action – the university, the research units and the individual scientists. We have addressed the most common practices among these organisations, scientists' motivations to engage with science communication, as well as the barriers that stand in their way to do so. Having a clearer picture of these various aspects from a general perspective will help us better understand the science communication practices of the institution in which the internship took place, which we characterise in the next section.

PART II – THE CENTRE FOR RESEARCH INTO ECOLOGICAL AND ENVIRONMENTAL MODELLING

II.1. An Introduction to CREEM

The Centre for Research into Ecological and Environmental Modelling at the University of St Andrews (CREEM) is a world-leading interdisciplinary research centre in Statistical Ecology – a research field that focuses on the development and use of statistical methods to analyse ecological data, in order to gain insights in areas such as Ecology and Conservation. CREEM is divided into several research units, linking researchers from multiple Schools at the University (Mathematics and Statistics, Biology, Computer Science, Geography and Sustainable Development), with its core staff located at The Observatory in St Andrews, Scotland.

The centre focuses on wildlife population assessment, environmental impact assessment, biodiversity monitoring and the development and application of statistical methods to address pressing ecological issues. Overall, there are four primary ecological research questions CREEM tries to answer: *how many animals are there?*, which relates to estimating population sizes; *where are the animals?*, which relates to understanding animal habitat preferences and movement patterns; *what is happening to the animals?*, which relates to monitoring populations and individuals; and, finally, *what if?*, which relates to risk assessment and conservation planning, focusing on how anthropogenic disturbances affect the behaviour, health and survival of animals.

CREEM has worked on every continent and major ecosystem on the planet – from the arctic, working with polar bears, to the deserts, working with desert tortoises, among many others. The centre publishes in top statistical and environmental journals, having become a reference point in Statistical Ecology for scientists all around the world. Furthermore, knowledge transfer is also another top priority of the centre. Through the development of free software, (such as *Distance*, having been downloaded by over 50,000 users in over 110 countries), international training workshops, and the publication of textbooks in Statistical Ecology, CREEM strives to share knowledge with the scientific community, as well as acquire new perspectives from researchers at other institutions.

All of these activities have resulted in very high impacts not only within the scientific community, with more than 1000 paper and text citations per year, but also among policy makers. By having a dedicated contract research unit for this purpose, the Research Unit for Wildlife Population Assessment, CREEM works towards applying the knowledge produced within the institution in real life. This unit's work has helped shape government policy in areas such as biodiversity monitoring, impact of underwater sound, environmental impact assessment for marine renewables and wildlife crime.

II.2. Public Engagement at CREEM - Communicating the importance of Mathematics and Statistics in Life Sciences

CREEM has been engaging with the public for many years. Without a professionalised communications department or hired staff, outreach activities are carried out by a group of around 10 researchers, who collaborate in the planning and preparation of these activities, carried out either as a group or individually. Activities focus on face-to-face interactions between scientists and non-scientists, and usually take place at science festivals and open days (typically attended by a group), as well as public lectures, local youth groups and schools (typically attended individually by researchers) (**Figure 2**). CREEM also engages with other audiences, such as governments and policymakers, the scientific community (other academic institutions and individual researchers in the fields of Ecology, Statistics or other relevant scientific fields), prospective students and university staff. This report focuses on outreach activities directed at children and families.

Figure 2 – From left to right, Science Discovery Day, University of St Andrews (2018); Royal Society of Edinburgh start-up science masterclass, at the University of St Andrews (2018); European Researcher's Night (2018); St Andrews Science Discovery Day (2017); Strathkinness Cubs Science Night, helping cubs obtain their Scientist Badge.

II.2.1 Communicating the importance of Mathematics and Statistics in Life Sciences

CREEM's public engagement activities over the years have focused on communicating the various research topics and projects of the centre, which has translated into a focus in communicating the role of Mathematics and Statistics in making discoveries about the environment. Consequently, showcasing the importance of quantitative skills within biological and environmental sciences has become central in CREEM's science communication endeavours, resulting in a lot of activities about methods to monitor wildlife populations.

Consequently, CREEM's outreach activities (**Figure 3**) highlight how scientists count the number of animals through different methods. These methods include: 1) distance sampling – where the information used for inference are the recorded distances to the animals; 2) plot sampling – where plots are chosen and surveyed within a given area; 3) mark-recapture – where individual animals are physically captured in traps, released back into the wild, and then recaptured; 4) photo ID – which involves capturing and marking animals by taking pictures of their natural markings); and 5) passive acoustic monitoring density estimation – where animals are counted through recordings of the sounds they make.

Figure 3 – From left to right: plot sampling activity, photo ID activity; mark-recapture activity at "Meet the Expert" event during British Science week at Dundee Science Centre (2018); distance sampling activity; photo ID activities at the "Explorathon" event at the University of St Andrews (2018).

To illustrate the distance sampling method, researchers developed an activity whereby participants are shown a picture of squirrels spread throughout a forest (**Figure 3**) (some scaled larger than others in order to represent closer and further distances) and are then given a time frame of 30 seconds to count them. This time frame, however, is too short to be able to count all squirrels. This is done intentionally and with the aim of demonstrating 1) how difficult it can be to count animals in the wild by sighting them and 2) how the further away an animal is the harder it is to spot.

The plot sampling activity aims to show how to count animals in the wild using a plot sampling method. Supported by a poster of a 10x10 grid with images of rhinos spread throughout

(**Figure 3**), in this activity participants are asked to generate 10 random sets of (x,y) coordinates and then count the number of rhinos in the plots (squares) given by those same coordinates. In the end, participants reach an estimate of the number of rhinos in the poster.

The activities about methods 3), 4) and 5) will be described in more detail in Part III, as they were the main focus of our work during the internship.

PART III – THE INTERNSHIP

III.1 Internship objectives

Science communication and outreach activities at CREEM focus on deconstructing the idea that Mathematics and Statistics are dull subjects without real-life applications. Through its activities, CREEM has been showing how these subjects are important in answering research questions in areas of the Biological Sciences. At the same time, they unveil Mathematics' many intriguing facets, demonstrating how fun it can be. During the internship, our main objective was to develop and improve educational materials that would help broaden this message.

III.2 Interviewing the researchers

Before arriving at CREEM, I conducted semi-structured interviews via Microsoft Teams with four different researchers, with the purpose of obtaining a better understanding of how science communication was carried out at CREEM and what the researchers' views on science communication were, specifically in what concerns their scientific area. The four researchers belong to the group who regularly partake in public engagement activities and express keen interest on the topic. All of them are statistical ecologists with research focuses and projects under the general umbrella of developing and applying methods for the quantitative assessment of wildlife populations.

The interviews consisted of 8 open ended questions, divided into three parts:

Part I – The researcher's views on science communication	1) Do you take part in any science communication activities – either as an independent researcher with your own personal communication channels or representing CREEM?
	2) What are your biggest challenges when communicating science?
	3) Who are CREEM's target audiences?

Part II – Science communication at CREEM	4) What do you consider to be CREEM's best science communication activities?
	5) What is one that wasn't so successful?
Part III - Science communication in the field of Statistical Ecology	6) What topic do you find most difficult to communicate?
	7) What topic do you think is most important people know about?
	8) What topic do you find gets people's attention?

All interviews were recorded (with the interviewees consent), transcribed and analysed to characterise the science communication landscape at CREEM. The following table summarises the main points gathered in these interviews.

1)	All of the interviewed researchers had taken part in science communication activities in a variety of settings. The most common activities among the four were open days at the University of St Andrews and science centres, and public talks for school children and the general public. Apart from the latter, which usually focuses on the researcher's individual research projects, all of them are carried out by a group of researchers representing CREEM. They agree, however, that even in the context of public talks they are always representing the institution.
2)	The main challenges faced in science communication endeavours mentioned by researchers can be summarised in the following points: • **Difficulty in engaging the public**. This was described as a difficulty to engage with specific publics, especially children and teenagers in the school context. They find there is a certain challenge in creating activities that will capture everyone's attention, as there is such a mixture of interests among students. In order to overcome this, they try to incorporate topics and questions relating to real world situations in the hopes of giving students something they can relate to. Since their research focus is applying statistical methods to solve ecological issues, the topics

they usually venture in are animal abundance estimation (i.e., counting animals in the wild) and the effects of human activity on wildlife.

- **Lack of recognition by the institution**. It was mentioned how they don't feel these activities are particularly valued by the institution, and, even when it is said they are, they feel it is not fully explicit to what extent.
- **Time constraints**. Even though they all show a keen interest in science communication activities, one researcher pointed out that their professional demands (which are predominantly related to academia, such as writing and submitting research papers and grants, student supervision and teaching, among others) take up all of their work hours. This means that finding time to do extra activities related to science communication is a big challenge, especially when considering the above-mentioned point of lack of recognition by the university. One researcher mentioned they already tend to work over hours, and finding the time to do more than that is difficult.
- **Lack of opportunities**. They find there are limited opportunities for science communication and connect this challenge to the point mentioned above. With little free space in their schedules and the additional factor of ensuring that the opportunity is adequate given their set of expertise, it is difficult for them to find opportunities they can say yes to.
- **Lack of skill and knowledge in science communication**. It was mentioned that the lack of training in effectively communicating their work to audiences of non-scientists is also an obstacle. Their limited knowledge, which is usually obtained out of personal interest instead of formal training, doesn't give them the confidence they feel is necessary to feel comfortable navigating certain science communication activities and topics.
- **Fear of being misinterpreted.** One researcher mentioned how they sometimes felt apprehensive to accept invitations to be interviewed or engage with traditional media, mentioning some fear of their words being taken out of context, or being asked questions outside their level of expertise.

3)	As mentioned, public engagement at CREEM is mainly done as opportunities arise (usually by invitation). Because of this, and considering the challenges above, most activities are developed to be flexible and easily adaptable to different target audiences. Therefore, most of their activities are fit, to different degrees, for adults and children who attend the events.
4)	Researchers had trouble recalling examples of successful science communication activities, as they weren't sure what were the measurements of success. Despite not being able to point out specific activities, they mentioned certain aspects that made them feel that they had been successful in their public engagement endeavours. Some examples given were the number of attendees at a public talk (one had up to 50 and was seen as a success) and meaningful interactions with participants. Researchers recalled times when participants asked a lot of questions during and after talks, and that later came up to them to have conversations about the topics of the talk. To the researchers, this revealed curiosity and interest. Moreover, they mentioned that these feelings were what they usually took away from the activities, with anything beyond this being difficult to quantify.
5)	Researchers couldn't recall any unsuccessful activity.
6)	Researchers don't find that there is one particularly difficult topic to communicate. It was mentioned, however, that with the increasing complexity of the statistical topics comes an increasing difficulty to explain them in an accessible manner. For example, explaining statistical methods individually is rather easy, but moving up to how these methods are intertwined in research is trickier. It was also mentioned that communicating these methods in a way that doesn't scare the audience away from Mathematics and Statistics is also a challenge.
7)	Instead of mentioning one specific topic within Statistical Ecology of particular importance to communicate to the public, all researchers emphasised the importance of communicating **why** Mathematics and Statistics are important and showcasing the central role of these subjects not only in our everyday lives, but more specifically in the Life Sciences.

8)	Researchers pointed out how the mention of animals – CREEM's primary study subjects – and the use of real-life scenarios related to wildlife have great potential to capture people's attention in public engagement activities. Among the topics that trigger more interest from audiences were also interesting and fun facts about the natural world, explaining how nature works and how using Statistics helps us better understand it.

Furthermore, and also in the early stages of the internship, my advisor Dr Catriona Harris and I organised a session about public engagement, open to all researchers of the centre, with the goal of sharing what science communication activities were available at CREEM and further explaining what projects we would be working on during the internship. We held this session in a seminar room, laying out all of the activities across several tables in order to explain and demonstrate them.

Due to timetable incompatibilities, the attendance level by researchers wasn't as high as expected. Nevertheless, I was still able to gain insights on science communication practices at CREEM. One of those insights was how researchers attending the session were unfamiliar with some of CREEM's outreach activities. The session thus turned out to be a good opportunity to share what outreach activities had been developed up to that point and what resources were at their disposal – something the attending researchers were very excited to learn about. The only researcher that was familiar with all of CREEM's activities was my advisor.

The take-away points from this session and from the interviews helped me get a clearer picture of science communication at CREEM, and, interestingly, also turned out to be very aligned with the findings of science communication scholars regarding general science communication practices at research institutions across the globe (discussed in Part I.2.2).

At CREEM, there is no professional communications staff or department, and science communication is carried out by its researchers without training in the field. And despite the University of St Andrews having a Public Engagement Department, there seems to be no formal connection between the two. Public engagement activities are typically motivated by opportunity and not necessarily by a strategic plan, with the majority of activities carried out in contexts such as open science days and school visits (which focus on face-to-face interactions). Finally, structured evaluation methods are also not set in place, revealed by the difficulty in reporting on the success (or lack thereof) of public engagement activities.

It seems that, although researchers at CREEM see the importance of public engagement and are keen to get involved, they do not yet have science communication practice as a fundamental activity of the centre. This scenario, as we saw in Part I, tends to be common among research institutions and is mainly caused by a lack of resources of the institution and challenges in the way of researchers.

III.3 Developing the activities

As previously mentioned, the work developed during the internship focused on the improvement of CREEM's existing public engagement activities. During this process, our primary aim was to make these activities more effective in reaching their intended goals by making them more attractive and interactive. In practice, this translated into physically redesigning the activities, as well as changing some aspects related to how they were conducted.

While working on these developments, we kept one other intention in mind - making these activities less wasteful. This stemmed from our awareness of the University's vision and mission regarding sustainability. The University of St Andrews wishes to become a carbon net zero institution by 2035, having put in place several measures to achieve this such as adopting a circular waste economy. This means, as per the university's website statements, "reducing what we buy, reusing what we have, and recycling what we can no longer use". During the internship, we tried to follow these recommendations as much as possible.

We focused on a total of three different activities – two of them based on animal sampling methods and one based on a biological phenomenon. This part of the report discusses what our work entailed. This description is divided into three sections, one for each activity, and the structure of each section is essentially the same. They begin with a brief explanation of the research methods the activities are based on, followed by what the activity looked like prior to our intervention and what aspects we wished to improve (and why). It then moves on to how we achieved those improvements and what our final results were.

Throughout the years, CREEM has developed activities that focus on face-to-face interaction and hands-on activities, paying less attention to the development of online materials. Since one of our initial objectives for the internship was to create educational materials that helped broaden the reach of the message that Mathematics and Statistics are crucial in answering questions in the realm of Biological Sciences, we decided that making online resources was a good way to achieve this. One common thought when redesigning these activities was thus how to make them available as online resources for teachers and other researchers who may wish to conduct outreach activities in classrooms or community groups.

These efforts resulted in dedicated files with instructions on how to run the activities, which also included additional resources with more in-depth explanations about the research methods the activities aim to illustrate. While these resources haven't yet been made available on CREEM's website (at the moment of writing this report, the website is being redone), they can be found in the attachments section of this report. For the same reason we still have no data about the reach of these materials, which would allow us to assess the success of our strategy.

Throughout the internship, CREEM received invitations from organisations outside of the university to partake in public engagement events. This gave us the opportunity to conduct the activities we worked on and bring them to their target audiences. Furthermore, it also gave me a chance to experience real life scenarios side by side with the researchers and evaluate first-hand what worked best and what didn't. These moments of the internship are described and discussed in Part III.4.

III.3.1 Mark-recapture activity

The mark-recapture sampling method

Mark-recapture is a sampling method used to study animal populations through the capture, marking, release and recapture of individual animals. In other words, individual animals are physically captured in traps, marked by the application of tags, released back into the wild, and then recaptured or resighted. By using this method, scientists can study movement patterns, population size and structure, as well as survival and recruitment rates (P. Hammond et al., 1990). The mark-recapture method is widely used in the fields of ecology, conservation, and management.

According to Hammond (2009), to estimate abundance through mark-recapture "a sample of individuals is captured, marked and released (n_1) and on subsequent occasion, a second sample of individuals is captured (n_2) of which a number are already marked (m_2). If a number of assumptions are met, the proportion of marked individuals in the second sample should equal the proportion of marked animals in the population at large (N), which allows population size to be estimated as

$$\widehat{N} = \frac{n_1 n_2}{m_2}$$ "

The mark-recapture public engagement activity

Tailored for primary school children, the goal of this activity is to illustrate how scientists estimate the number of animals in a population through the mark-recapture sampling method. Whilst embedding statistical concepts such as estimation, sample, and population, this activity shows how Mathematics and Statistics are pivotal for counting animals in the wild. Usually conducted by a researcher, this activity can be done either one-on-one (researcher and participant) or with bigger groups.

When we began working on this activity, the first step was assessing what aspects needed our attention the most. But before discussing our conclusions, let's first go through what we were working with in the beginning. This activity required participants to follow a series of steps, which guided them through the process of collecting the necessary data to estimate the size of a population. The activity required the following physical materials: a worksheet with activity steps and brief explanations of the various concepts at play, an A3 sized numbered grid, an opaque bag with 50 rubber ducks and small stickers (**Figure 4**).

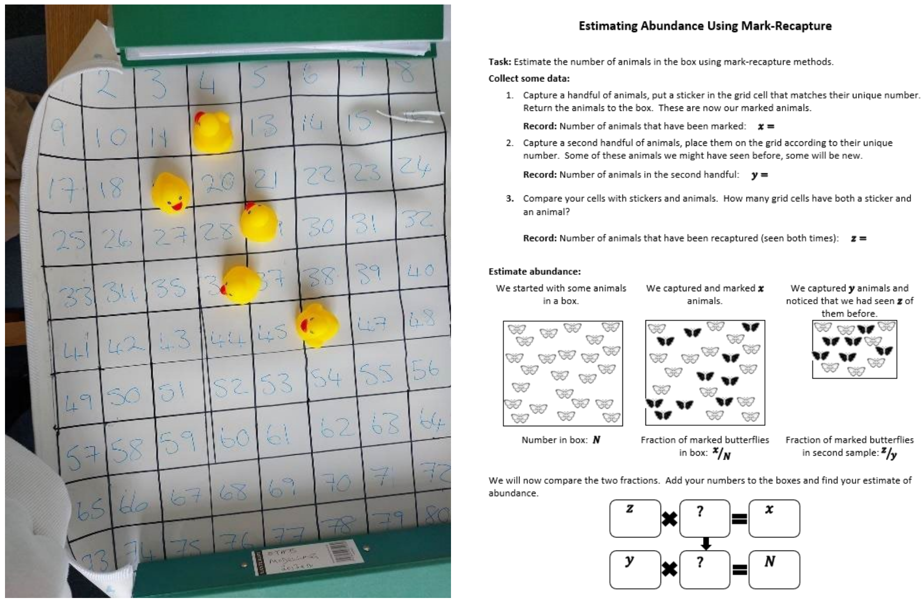
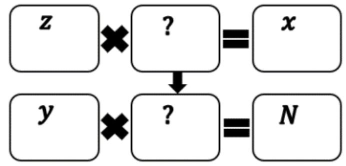


Figure 4 – From left to right: A3 numbered grid and rubber ducks, activity worksheet.

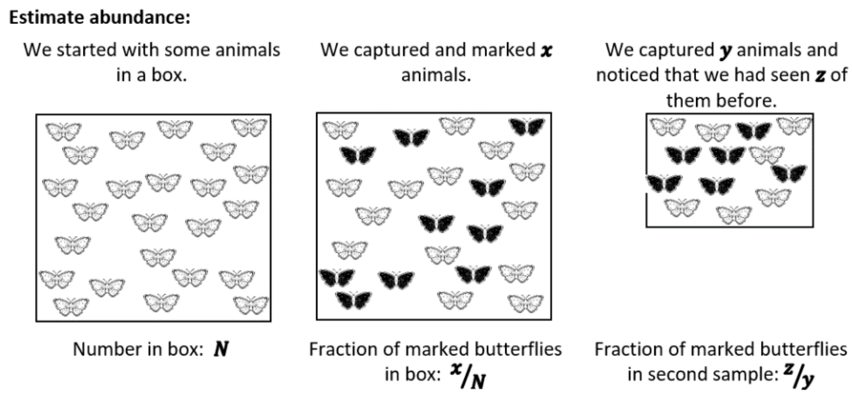
The steps for the activity and the explanation of the mark-recapture method, as per the worksheet in **Figure 4**, were as follows.

Steps

1) Capture a handful of animals, put a sticker in the grid cell that matches their unique number. Return the animals to the box. These are now our marked animals. Record the number of animals that have been marked (x = [...])
2) Capture a second handful of animals, place them on the grid according to their unique number. Some of these animals we might have seen before, some will be new. Record the number of animals in the second handful (y = [...])
3) Compare your cells with stickers and animals. How many grid cells have both a sticker and an animal? **Record** the number of animals that have been recaptured (seen both times). (z = [...])
4) We will now compare the two fractions. Add your numbers to the boxes and find your estimate of abundance. (N = [...])



Explanation



Deciding what aspects to tackle in this activity involved several discussions with the researchers where we talked about what we thought were the elements that needed more attention. In the end, we decided to maintain the sequence of steps that guide the participant through the activity, as no issues had been found regarding this aspect, and chose to change the overall design of the activity. We agreed that some features seemed somewhat outdated and needed to be made clearer and more attractive.

Our first remark was how much the activity worksheet resembled those typical of classroom settings. Agreeing that we wanted to steer away from this appearance, we aimed at redesigning this worksheet in a way that allowed participants to engage in a deeper way and not feel as though they were completing classroom work. To achieve this, we split the initial worksheet into three separate ones, A4 sized and laminated (**Figure 5**) – one with the formula needed to calculate the estimate of rubber ducks in the bag, one schematically explaining how the mark-recapture method works and one with flashcards for participants to record the information they gathered throughout the activity. Additionally, we also redesigned the numbered grid, this time in size A3.

We removed most written instructions present in the initial version. Since participants are meant to be guided through the activity by a researcher, we found no need for the written instructions. As for the look and feel of these new activity sheets, we wanted them to match the living environment of the activity's study subject – the ducks. For this, we tried recreating the feel of a pond/ water, by designing the new background in different shades of blue.

We decided to use flashcards to make the activity more engaging. We figured that by recording the information in separate places and being able to move it around throughout the course of the activity could make it more interactive. Also, physically placing each piece of information on the formula sheet could make it easier to explain (and understand).

The decision of laminating the activity worksheets was important to fulfil the goal of creating less waste. In the initial version, the numbered grid was made out of regular paper and the markings were made with small stickers that couldn't be reused (and were, therefore, thrown away), and had to be sticked on and removed for every new round. Not only did this create a lot of waste, but it also made the activity somewhat time consuming. Laminating the sheets allowed for the markings to be done with white board markers instead, which could be easily erased with a cloth.

Figure 5 – New mark recapture activity designs.

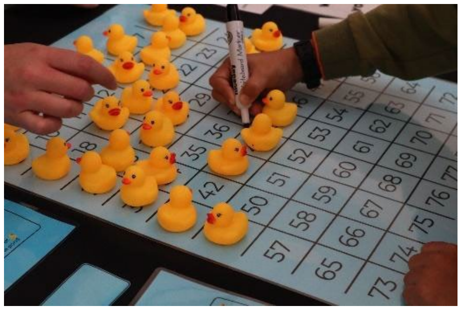
Once these design changes were finished, we moved on to creating the PDF for the website. This included rewriting the steps for the activity, adding the additional resources, adding links for the download of the newly designed activity sheets and listing the new materials required to conduct the activity (which are now the printed and laminated activity sheets, a set of 50 to 60 identical and numbered rubber ducks (or any other set of identical and numbered objects), an opaque bag to place the rubber ducks, a white board marker and a cloth). Furthermore, because this file was created after one of the outreach events, we were able to include pictures of this activity being done in real time. Screenshots of the PDF file can be found in the attachments sections and below are the rewritten steps for the activity.

To run the activity, some context is given on the mark recapture method, with accompanying explanations as to why and how scientists use it. Once this is established, the steps are as follows.

1) Take 2 big handfuls of ducks from the bag.

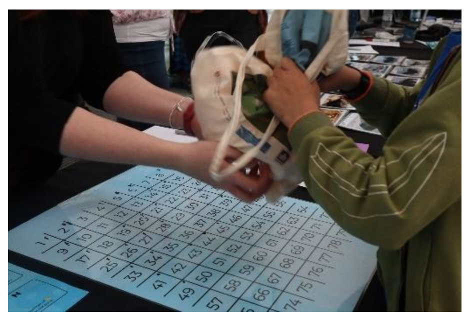

2) Place the ducks on the grid according to their number.


3) With the white board pen, mark every square that has a duck.




4) Count how many ducks were captured – *this will be your x (number of ducks that have been marked)* – and write it down on the x flashcard.


5) Place the ducks back in the bag and mix them around.

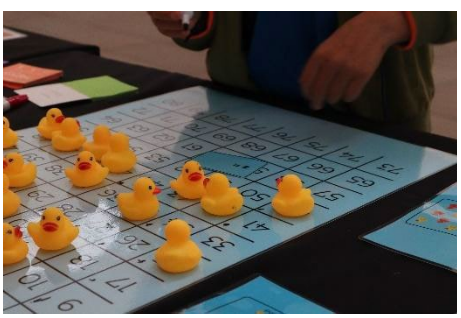



6) Take another 2 big handfuls of ducks.


7) Once again, place the ducks on the grid according to their number.


8) Count how many ducks were taken out of the bag – *this will be your y (number of ducks in the second sample)* – and write it down on the y flashcard.


9) Count how many ducks have been recaptured (ducks in the marked squares) – *this will be your z (number of ducks that were seen twice)* – and write it down on the z flashcard.




10) Place each flashcard on the formula sheet and solve the equation to calculate N – estimated number of ducks.


11) Compare the N that you calculated with the real number of ducks in the bag.

Ideally, the last step is to discuss the results, i.e., the obtained estimate of rubber ducks inside the bag. In the instructions PDF for this activity, we have suggested some questions to prompt this discussion, such as *Do you think your estimate matches the true number of animals in the box?*, *If you ran this experiment again, would you get exactly the same answer?*, *How does your estimate compare to the estimates made by other groups?*, and *How could you combine the estimates from the different groups into a single number?*.

III.3.2 Passive acoustics monitoring density estimation activity

The passive acoustic monitoring density estimation method

Passive acoustics monitoring density estimation (PAM DE) is a method whereby scientists record and count the sounds animals produce to estimate their abundance. This method is well explained by Thomas & Marques (2012), who use this method to estimate whale abundance. By randomly deploying acoustic recorders in the region of interest, i.e., where they want to estimate animal density, an area a is surveyed. From the recordings obtained, detection algorithms produce a count, n, (which can be, for example, the number of a particular type of call) that is then converted into estimated density, through the following equation,

$$\widehat{D} = \frac{n}{a} \times \widehat{m}$$

where m represents two other elements – false detections and the cue rate (i.e., the number of sounds produced per animal per unit of time) – that allow the conversion of $\frac{n}{a}$ into animal density.

For the purpose of the outreach activity, this equation has been simplified,

$$number\ of\ animals = \frac{number\ of\ calls\ heard}{recording\ time \times average\ cue\ rate \times detected\ proportion}$$

where *number of calls heard* refers to the count produced, *recording time* refers to the length of the recording, *average cue rate* refers to, as mentioned above, the average number of sounds produced per animal per unit of time, and *detected proportion* refers to the ability to detect sounds produced.

The passive acoustic monitoring density estimation activity

Aimed at primary school children, the main goal of this activity is to illustrate how scientists estimate the number of animals in a population through PAM DE. Just like the mark-recapture activity, the PAM DE activity also embeds statistical concepts such as estimation and population, and shows how Mathematics and Statistics help scientists count animals in the wild (this time, through the sounds they make). Usually conducted by a researcher, this activity can be done either one-on-one (researcher and participant) or with bigger groups.

During the internship, we worked on this activity twice. The first time we worked on it was to prepare it for an outreach event where we were going to collaborate with another research institute from the university, the Sea Mammal Research Unit (SMRU), and the second time was to improve some aspects we found to not work so well during that event (which we later took to another event). But before diving into those details, let us see what we were working with from the beginning.

This activity led participants through a series of steps to collect the necessary data to calculate an estimate of the number of fin whales in a given area, and the materials required were a worksheet with those same steps (**Figure 6**) as well as a sound recording of fin whale calls. The steps on that worksheet can be read in **Figure 6**.

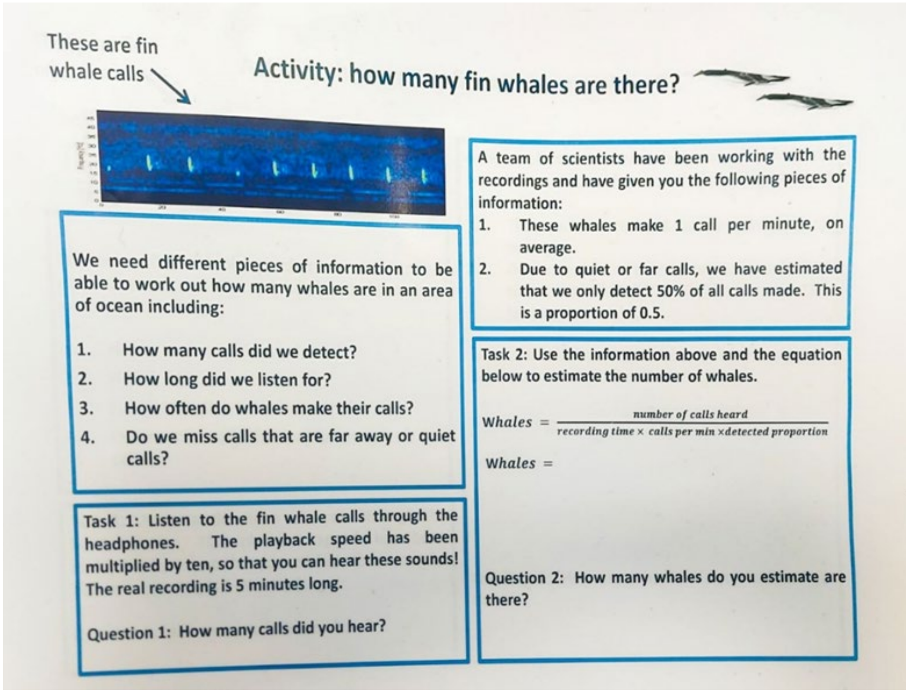


Figure 6 – Initial PAM DE activity design.

As mentioned, the first round of work on the PAM DE was the result of a collaboration between CREEM and SMRU. As we will see in Part III.4.1 in more detail, we partnered up with SMRU to attend a Marine Showcase at Dynamic Earth in Edinburgh – a visitor attraction about the history of Planet Earth. In preparation for the event, we held several meetings to discuss what activities we wanted to take, and whether there were activities from both centres that had the potential of complementing each other. These discussions were between me, my advisor, a CREEM researcher, a SMRU PhD student, and a SMRU researcher. We discovered that SMRU had an activity related to studying acoustics of marine mammals that we found could very well complement CREEM's PAM DE activity.

SMRU's activity had been created by a PhD student whose research focus was the development of a model to classify species based on their vocalisations. In other words, they studied the uniqueness of sounds produced by whales and how this can be used to identify different species. Following this research interest, they created an outreach activity with the purpose of showcasing the singularity of whale calls, while illustrating how us, humans, also share that uniqueness.

For this activity, they used the following equipment: a computer, a monitor, a microphone, a sound recording system and headphones. In the monitor, a spectrogram of a marine mammal is presented accompanied by sound recordings of their calls, and below a blank spectrogram is presented. In this blank spectrogram, signals can be created by the participant by speaking into the microphone. Participants were asked to speak their own name into the microphone, which resulted in a unique spectrogram, different from the spectrograms of other participants. This, therefore, created a great parallel between marine mammals, whose sounds, just like humans', are all different.

Given this SMRU activity and CREEM's PAM DE activity, for the purpose of the outreach event we decided to join them into one. After some discussion, we agreed this meant adding another key learning point to SMRU's activity – how we can count animals from their calls – and another key element to CREEM's activity – how animal calls are unique across species and individual animals.

In terms of the structure of the joint activity, during the introductory stage, the researcher introduces the subject of the uniqueness of these sounds, invites participants to create their own spectrogram and, by the end, asks them to listen closely to the animal calls and count them not by looking at the spectrogram, but by listening to the recording. After obtaining the count, participants followed the steps of CREEM's activity, seen in **Figure 6**.

Regarding the physical materials for this activity, we created individual A4 activity sheets for each step of the CREEM activity, adding an extra one with information on average cue rates of four different marine mammals to choose from – killer whale, humpback whale, fin whale and bottlenose dolphin. These sheets can be seen in **Figure 7**, along with the final set up of the activity. Like in the mark-recapture activity, all sheets were laminated and allowed participants to write directly on them as they went, which meant avoiding extra waste as well.

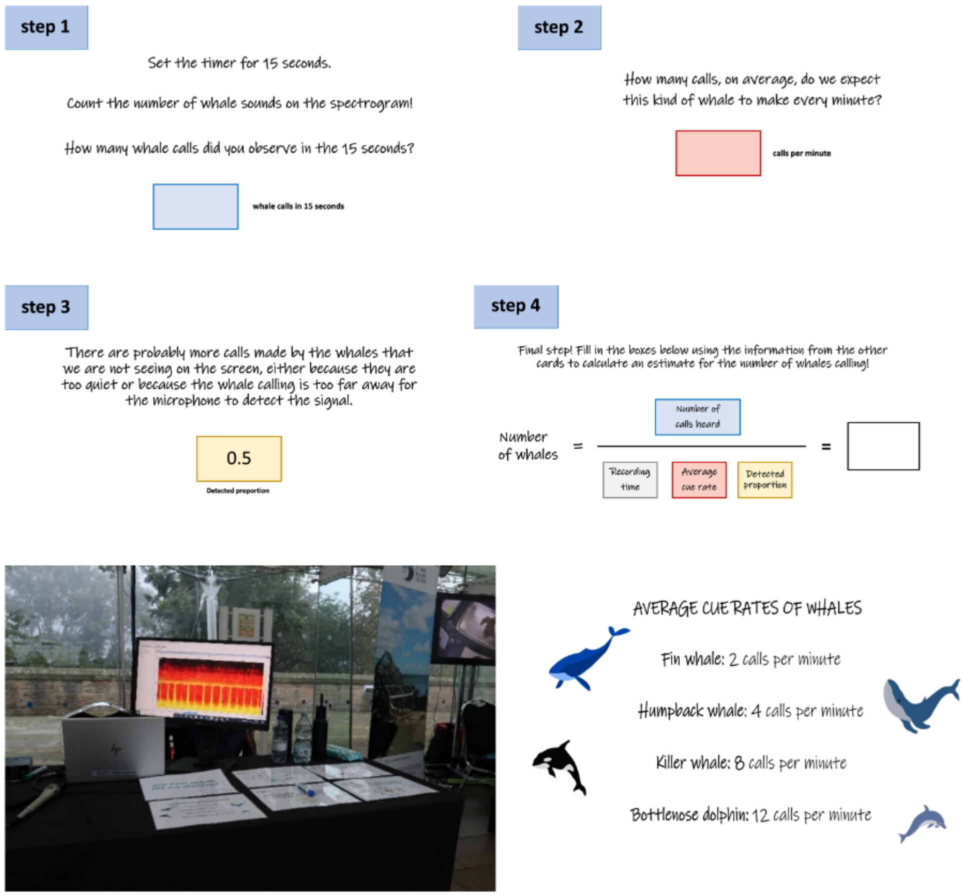


Figure 7 – Activity sheets and set up at the Marine Showcase at Dynamic Earth in Edinburgh.

The second time in which we worked on this activity was after the Marine Showcase in order to improve some aspects we found to not work as well as we expected. One of those things was the step where participants count the calls by listening to the recording. During the Marine Showcase, we realised some participants found this step particularly tricky. The problem is that recordings of marine mammal calls are not completely isolated from other surrounding sounds, making the individual calls hard to identify to the untrained ear. Whilst wanting to keep the element of listening to marine mammals' calls, we wished to make counting them easier.

To achieve this, we made this step less central to the activity, framing it as an "extra". The recordings would instead be utilised to show participants what the animals sounded like instead of being used to count calls. This meant we needed to create three new activity sheets – each one with a spectrogram of each animal. Furthermore, we removed the step where participants spoke into the microphone, as it required a lot of equipment. Since we wanted to make this activity available online, we wished to structure it in the simplest manner we could, making it as easy as possible to follow and recreate in other scenarios (in classrooms, for instance).

Lastly, we had to change the cue rate values on the cue rate sheet. Initially, we thought it would work well if we added random numbers for the cue rates, i.e., not the real cue rates of those animals. It did not, however, work as expected, resulting in estimates that didn't make sense (such as 0,8 animals). Because of this, we discussed this detail with a CREEM researcher whose focus is on PAM DE in order to understand where the issue was and figure out what values would work best. Discussing this aspect with a researcher was not only essential to understand what we had gone wrong, but also showed how important it is for scientists and science communicators to collaborate with each other to create engaging and scientifically accurate activities.

Later in the internship we took this final version to a Cub Scouts Science Night (discussed in Part III.4.3) and found that these changes had greatly improved the activity – it became quicker to set up, participants found it easier to count the number of animal calls and the final estimates of the number of whales were much more accurate. Setting up the activity turned out to be much quicker, as it didn't require sound systems – only a laptop and headphones. As for the final estimates obtained, these ended up being much more appropriate given the new cue rates and counting method. In the end, the materials required for the final version were a set of newly designed printed and laminated activity sheets (**Figure 8**), animals call videos and a white board marker.

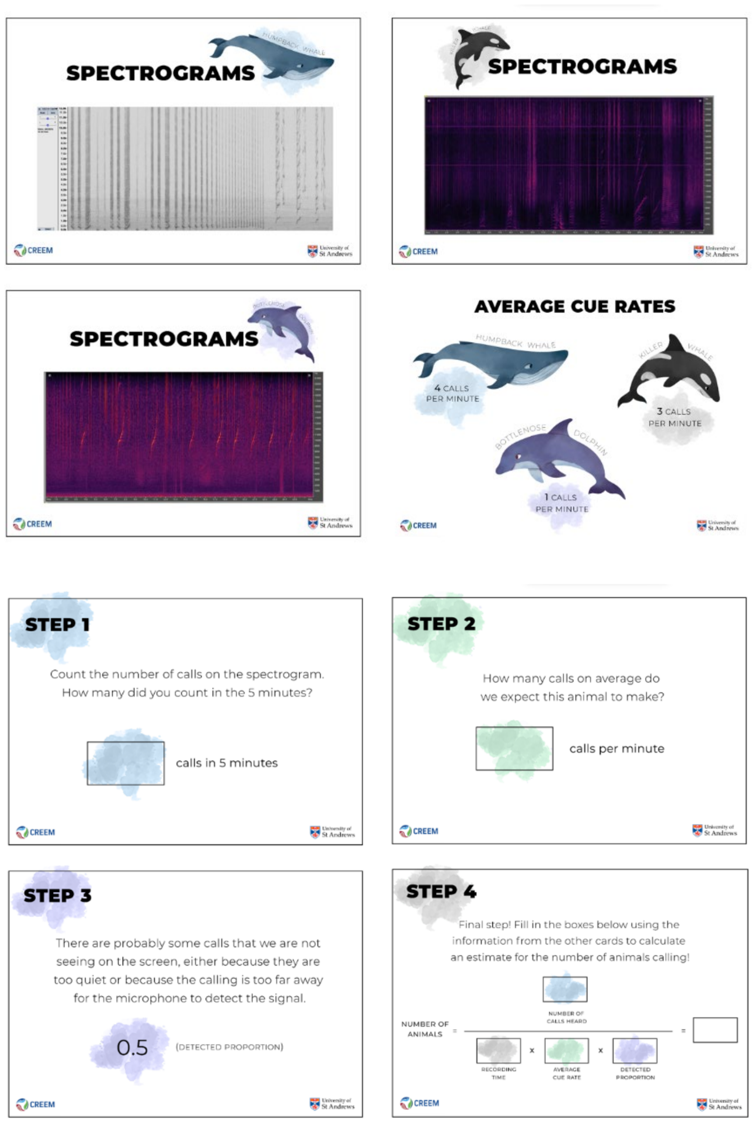


Figure 8 – New PAM DE activity design.

Screenshots of the PDF instruction files can be found in the attachments sections of this report. Below are the rewritten steps for the activity.

1) Give some context on the PAM DE method, explaining to participants why and how scientists use it, and that we will try to recreate it through this activity by estimating the animals in the recording.

2) Ask participants what animal they would like to work with from the Average Cue Rate sheet.
3) Pick up the spectrogram of the selected animal.
4) Count the number of calls on the chosen spectrogram.
    - To show what the animal sounds like and make the activity more immersive, videos of the spectrogram can be played along as participants count the calls. Here is how to identify the calls in each spectrogram (marked by green lines in **Figure 9**):

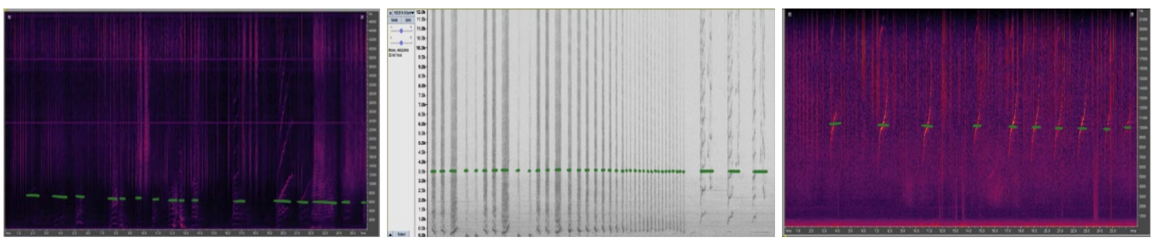


Figure 9 – From left to right, killer whale (total number of calls = 16), humpback whale (total number of calls = 40), bottlenose dolphin (total number of calls = 10).

5) On the STEP 1 sheet, write down the number of calls counted on the spectrogram (note that the spectrograms represent 5-minute-long recordings).
6) Fill in the STEP 2 sheet with the information given by the Average Cue Rate sheet.
7) Read STEP 3 sheet.
8) Fill in the STEP 4 sheet with the information from the previous cards (each STEP sheet is colour coded to make this step easier).
9) You will now have an estimate of the number of animals.

Ideally, the last step of this activity is to prompt discussion about the results obtained. In the instructions PDF for this activity, we have suggested some questions to prompt this discussion, such as *How can the movement of the animal affect our estimate?*, *How can our estimate change if the animals spend a bit more time silent than what we expected?*, *How will our estimate be affected if the sounds are associated with seasonal activity?*.

III.3.3 Masking activities

The outreach activities presented in this section differ from the previous two in the sense that they don't focus on the mathematical or statistical methods of research. Instead, they focus on the biological concepts those methods aim to understand, which, at CREEM, are always related to animals. One of the goals of this approach – placing Biology (and animals) at the centre of the activity – is to engage with audiences in a different manner, making them curious about the work of a biologist through their study subjects, as opposed to the methods used. Later, this would hopefully lead them to one of the central parts of a biologist's work at CREEM – Mathematics and Statistics.

The masking phenomenon

Masking is a phenomenon that occurs when increasing background noise, which can take the form of natural ocean sounds (such as waves, wind and animals going about) or human generated sounds (such as shipping, sonar and oil exploration), affects an animal's ability to perceive sound. For many marine species, sound is the preferred medium to communicate with each other, find prey and escape predators (as opposed to sight, for instance). This means that being able to detect and hear particular sounds is critical for their survival, making the study of the impacts of anthropogenic underwater noise on marine mammals extremely important.

At CREEM, the effects of human generated underwater noise is an important research branch, particularly on whale and dolphin species. In collaboration with biologists and acousticians, CREEM has developed methods to determine some of the behavioural responses of animals to these sounds and assess the chronic effects of multiple small disturbances at the population level. This is achieved, for example, through the development of methods to model marine mammals' distribution across space for risk mitigation purposes.

The masking activities

CREEM’s outreach activities about masking seek to inform audiences about the phenomenon of masking, while highlighting some of the concerns scientists have regarding the effects of sound pollution on marine life, as well as some of the strategies used to mitigate these effects. Previous to the internship, CREEM had two activities related to sound and masking tailored for primary school children – a masking game and a forks and string experiment.

The forks and string experiment is a hands-on activity that aims to illustrate how sound travels in waves. The experiment itself is quite simple. Requiring only a fork and a piece of yarn tied together, participants put the string to their ear and, with another piece of silverware, tap the tied-up fork. As the resulting sound waves travel up the yarn, participants can make bell-like sounds, which the researcher then explains is because of their wave-like nature.

The masking game aims to illustrate first-hand how increasing background noise levels can affect an animal’s ability to communicate, i.e., how the phenomenon of masking works. To set up the activity, two participants stand on opposite sides of the room and the remainder of the group sit between the standing two. After everyone is in their positions, the researcher asks one of the standing participants to ask the other a question, while the group in between remains silent. Importantly, these can't be a yes/ no question, as the answer can be easily communicated by a shake or nod of the head.

The goal with this first step is to show how easily the standing participants can hear each other if there is no background noise. Then, the researcher asks the standing participants to ask each other another question. This time, however, the participants in the middle begin speaking at a low volume. With every new question, they are asked to read louder to the point where the participants standing opposite in the classroom are unable to hear each other. By this point, the group will have experienced first-hand how loud background noise can affect communication, which is one of the ways masking affects marine mammals. To solidify this new knowledge, there is a follow-up discussion covering questions such as *Why did the message get harder to send and receive?*, *What animals might be affected by this and in what ways?* and *What are possible noise sources in different environments?*.

The masking video

Instead of focusing on the improvement of the above-mentioned activities, we decided to create a new resource – an outreach video. At CREEM, some researchers focus on the impacts of anthropogenic noise on marine mammals. One example of this is the work of my advisor, who does so through, for example the development of methods to model marine mammals' distribution across space for risk mitigation purposes and the analysis of behavioural responses to sound. For this video, we focused on one of the biological phenomena her work tries to understand – masking.

This video aimed at broadening the reach of the message that Mathematics is crucial to answering questions in the realm of Biological Sciences by focusing on the biological aspects of research. For the video specifically, this approach was taken with the intent of attracting more audiences, complementing CREEM's classroom activities on the subject of masking, and communicating the effects of increasing background noise in the ocean on marine animals' ability to communicate and navigate their environment.

Since one of the main goals of this video was to complement the already established classroom activities about masking, we decided it would make most sense for the target audience to be the same as those activities – primary school students and teachers. To reach the intended audience, the video was made available in a way where 1) by being uploaded to CREEM's website on the University of St Andrews channel, it could reach its target audience online, while, simultaneously, allowing for audiences that may not have been initially considered to be reached; 2) be used as extra educational material in classrooms by teachers; and 3) be used as a new resource to be integrated in CREEM's outreach activities. Following this, we decided to produce the video in a way that would be understood by children of the age of 8 and forwards, while also being able to capture the attention of other audiences interested in the topic.

As for the message of the video, it aims to communicate the harmful effects of excessive background noise on marine mammals, with special focus on anthropogenic sources, through colourful animated drawings. Throughout the video, it is explained what masking is, how and why it happens, and what is the importance of studying this topic. With this in mind, we hoped to capture viewers' curiosity about the work of biologists who study masking, and what it is that they do to better understand its effects in marine life.

Regarding the format, we established the video would be around 3 minutes long, consisting solely of animated drawings and a voice over, keeping it concise and straight to the point. Besides these aspects, we also wanted to create the video in the most compelling way possible. For this, we decided to add characters and write the script in a way that told a story, without, however, making either of these elements too specific.

After establishing these points, the production of the video was divided into researching the topic, writing the script, creating a storyboard, recording the voice over, drawing characters and settings and, finally, editing the video.

1) Researching the topic.

This first step was essential to creating the video. As I wasn't too familiar with the concept of masking, the first day we started working on the script was dedicated to researching the topic and getting familiarised with it. Having a background in Biology myself, this process was rather fast and I quickly grasped the topic well enough to allow me to begin writing a script.

2) Writing the script.

Once research was done, it was time to begin writing the script, which I did hand in hand with my advisor. We knew from the start that we wanted to keep the video under the 3-minute mark, and thanks to previous experience in creating science videos, we knew our aim would have to be a maximum of 400 words if we wanted to keep to our time frame.

As for the structure of the video, we divided it into an introduction to the importance of sound to marine animals, followed by an explanation of where these sounds come from, what happens when animals can't detect these sounds (i.e., when masking occurs), an example of what this can look like for whales, and finally, what scientists can do to help mitigate this problem. We tried to keep it as clear, simple and jargon-free as we could.

3) Creating a storyboard.

The next step was to create a storyboard that helped get an overview of how we wanted the ideas in the script to be translated onto the screen (and, therefore, the different drawings and scenes we wanted to include). For this, we added numbers throughout the script that represented the different scenes. These numbers were then used on the storyboard (**Figure 10**) and allowed us to easily connect what was being said to what we would eventually see on the screen at each moment. This storyboard was meant to serve as a simple outline without much detail so as to not make this step too time consuming.

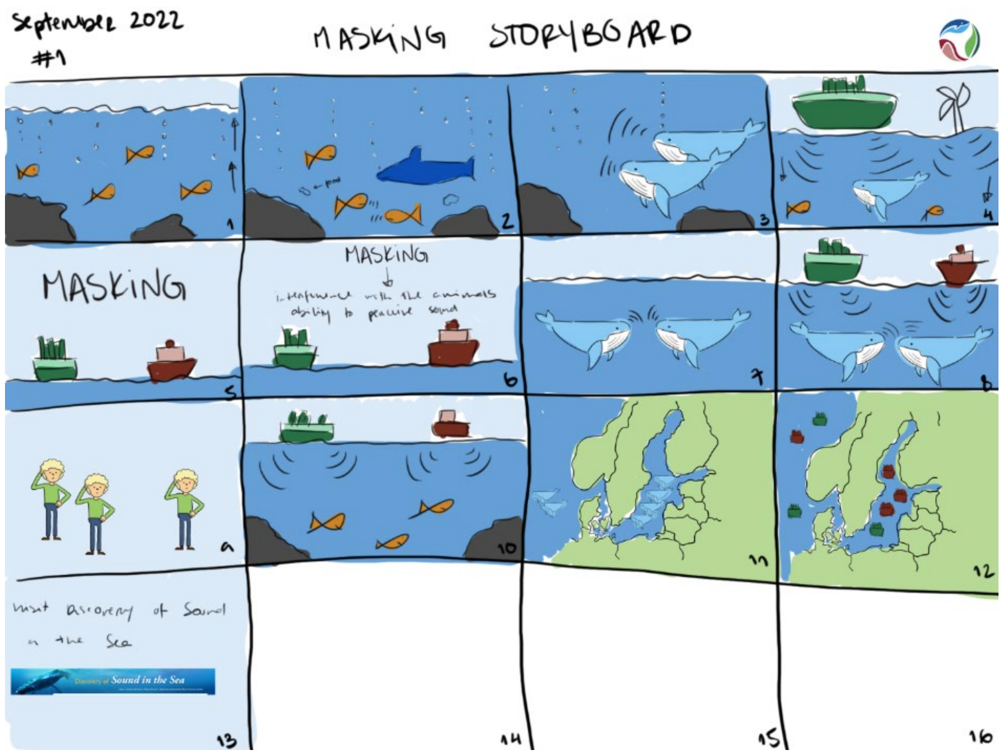


Figure 10 – Video storyboard.

4) Recording the script

The voice over for the video was done by me. Having had some experience creating science videos in the past, I felt comfortable recording the script myself. For this we used an external microphone connected to a laptop and, for editing the audio files, used Adobe Audition.

5) Drawing the characters and settings

For drawing and animating the video characters, we used Adobe Premiere Pro and Adobe Photoshop. I was familiar with both programs, but wasn't too familiar with animation. We experimented with some methods and decided to draw the different characters and settings (**Figures 11** and **12**) in Adobe Photoshop and create GIFs out of these drawings so that they could have movement to them. Once imported into Adobe Premiere Pro, they could be made to move through the screen using keyframes.

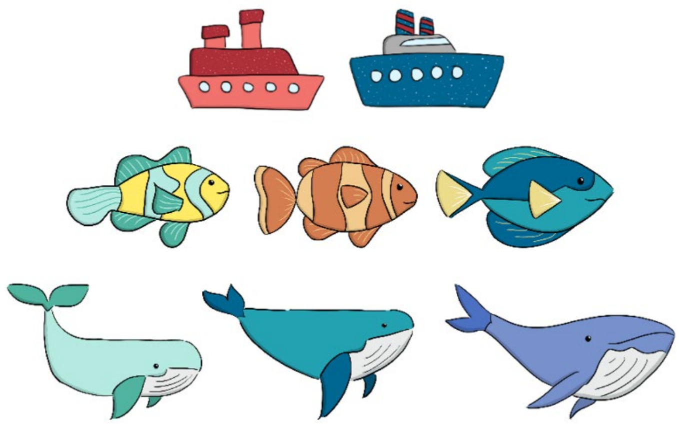


Figure 11 – "Masking in Marine Mammals" video characters.

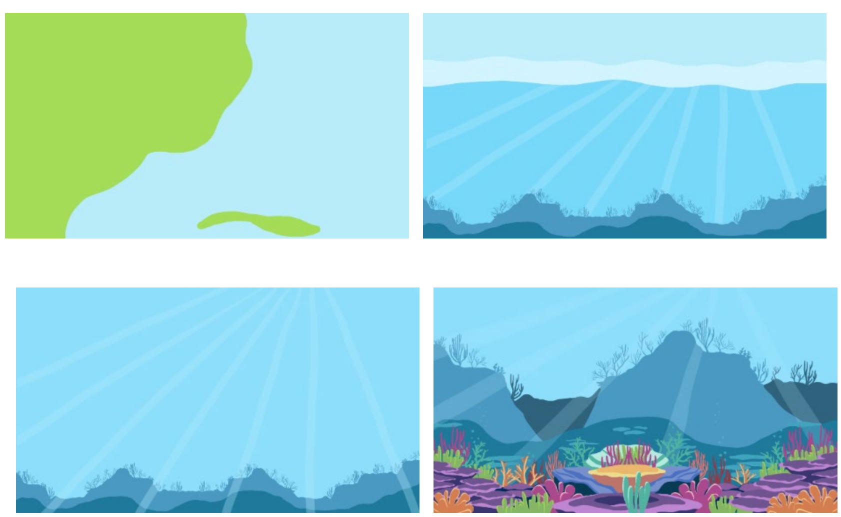


Figure 12 – "Masking in Marine Mammals" video backgrounds.

6) Editing the video

In this final phase, we put together the audio and the different drawings in Adobe Premiere Pro. We added additional elements, such as visual and sound effects. Lastly, and for accessibility purposes, we added the subtitles.

Figure 13 – "Masking in Marine Mammals" video screenshots (https://www.youtube.com/watch?v=WT4QtD4q4KI&ab_channel=UniversityofStAndrews).

While writing this section, I've been able to reflect on the particular direction we took with this video regarding its content and our end goal with its conception. I now see that, if our goal for this video is to communicate that Mathematics is crucial to answering biological questions, some things might need improvement to increase the chances of meeting our initial goal.

After some reflection, I believe that making a second part could be a great way to do so. For this second part, we could, for example, explain in more detail the ways through which scientists try to understand this issue using Mathematics and Statistics. The original video could be used as a starting point for establishing a common ground with viewers about what masking is and the problems it creates, and in a follow up video we could discuss what ways scientists try to work towards understanding and creating solutions for said problems. Furthermore, the mention about how scientists still don't fully understand the effects of masking could be used as an anchor for this second video, where we explain some of the ways scientists have been trying to understand this issue and mention the different statistical methods at play.

III.4 Outreach Events and Opportunities

III.4.1 Marine Showcase at Dynamic Earth

During the month of August 2022, CREEM was invited to participate in a Marine Showcase to take place on October 22nd 2022, at Dynamic Earth – a five-star visitor attraction in Edinburgh that tells the story of Planet Earth. During the course of two weekends, visitors were invited to meet experts from various research institutions, such as Heriot Watt University, Whalewise, St. Abbs Marine Station, MASTS, to discover the diversity of research projects and careers within the field of marine science through engaging outreach activities. This presented itself as an excellent opportunity to not only showcase CREEM's work to the public, but also put into practice what we had worked on during the previous month.

On the day of the event, the stands for each institution were located at the end of the journey by which the visitors are led during the attraction, ending in a cafeteria zone open to everyone, non-visitors (people who didn't pay to visit the main attraction) included. This meant that, in order to attend the Marine Showcase, visitors did not have to pay any entrance fee and, therefore, could come straight to us from outside the building. Regardless of this, we found that the people we engaged with mainly came from having finished a visit.

In preparation for this event, as mentioned in Part III.3.2, CREEM partnered up with SMRU. For the event, we took the PAM DE activity, the mark-recapture activity (both described in Part III.3) and a matching pairs game developed by SMRU (**Figure 14**). The latter is based on the most commonly used technique of capturing and marking cetaceans and consists of taking pictures of the natural markings of individual animals (P. Hammond et al., 1990) over a given period in time. Utilising sets of pictures collected over years of research of different marine mammals, such as cetaceans and pinnipeds, researchers from SMRU developed a matching pairs game to demonstrate how researchers use the photo ID method to identify and count animals.

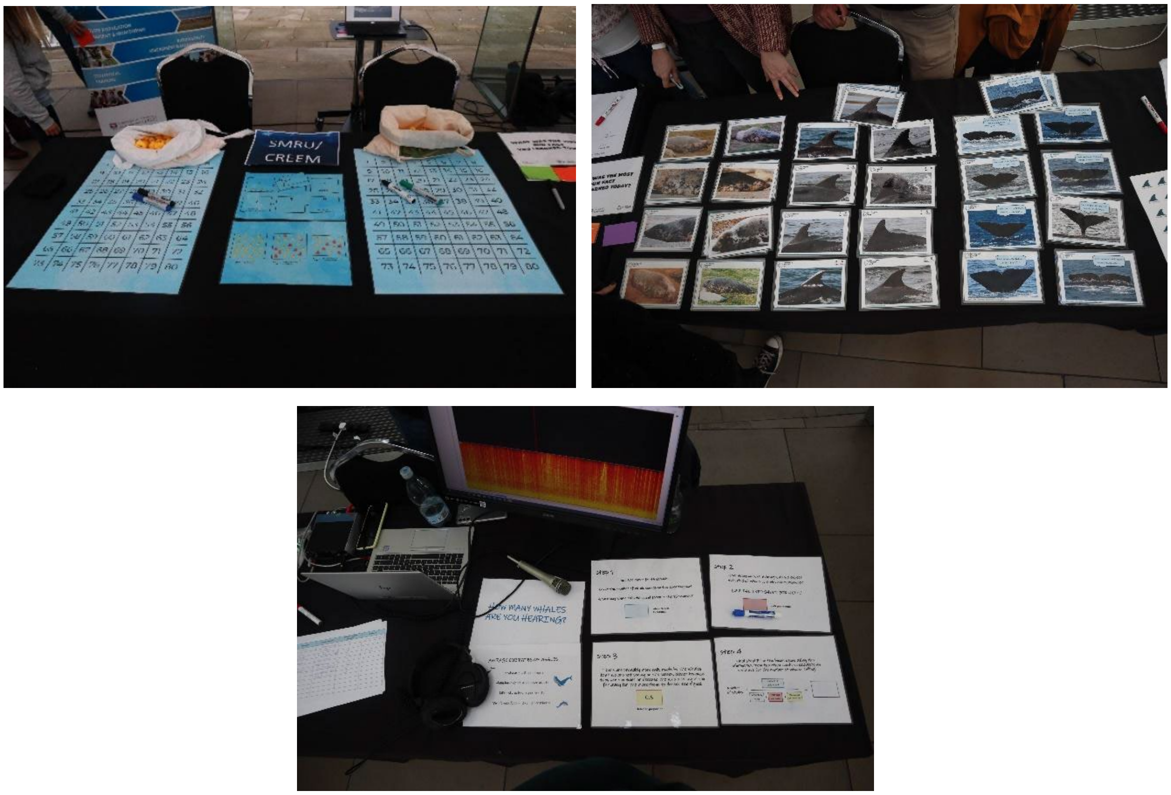


Figure 14 – From left to right, mark-recapture activity, Photo ID game and PAM DE activity.

Over the weeks of preparation for the event, our focus was mainly on the development of the activities. One aspect that we ended up leaving behind was how we were going to evaluate these activities, which hadn't been much of a concern up until about two weeks prior to the day of the event. Because of this, we did not have much time to carefully think and plan how we would evaluate our activities during the day of the event.

Because neither myself or the researchers I was working with were familiarised with evaluation methods for events such as this one, we met with the Head of the Public Engagement Department at the University of St Andrews to discuss this topic and understand what options we had given our resource limitations, specifically in terms of time and skill. Furthermore, one of the requests of Dynamic Earth on their invitation had been to make the activities fun and engaging for families. Because of this, we wished to avoid a method that made it explicit we were evaluating our activities.

Given these circumstances, we decided to focus on a post evaluation method, where we focused on what people had learned with our activities. For this, we used what we referred to as a "post-it wall". We prepared a sheet with the question "What was the most fun fact you learned today?" with pen and paper around it for people to answer (**Figure 15**). Our goal with this method was to assess participants' biggest takeaways from our different activities.

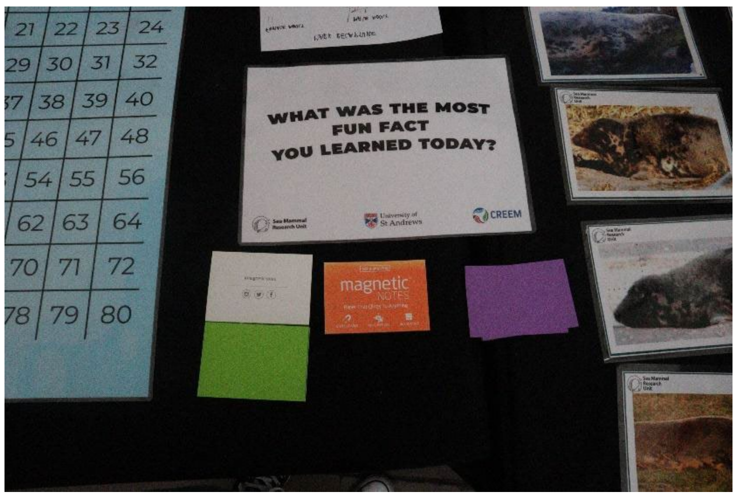


Figure 15 – "post-it wall" evaluation method.

This, however, turned out to be quite unsuccessful. By the end of the event, we had not gathered any written answers from participants. During the event, we found it difficult to ask visitors to do this after having participated in all three activities, on top of the hour-long visit to the main attraction of Dynamic Earth. By the end of the activities, we found that visitors' disposition to keep engaging had significantly lowered, and they were usually ready to move to the next thing. Because of this, it felt unnatural and difficult for us to stop them and ask them to write down a fun fact they had learnt.

After some discussion trying to understand what went wrong, we reached a few conclusions. Throughout the event, we were mostly approached by families, but the ones who were doing the activities were the children, with parents standing over their shoulders, watching and providing additional guidance. Our activities required some attention, especially the PAM DE and mark-recapture activities, as they involved visitors solving mathematical problems. As mentioned above, participants came to us directly after finishing a visit, which meant that they had already been doing several other activities during the attraction.

Maybe a combination of this very intense focused time across the three different activities and having already spent an hour visiting the whole attraction caused some saturation among participants, especially the children. Despite recognising the importance of evaluation in understanding our activities' success, we found it difficult to follow through with our chosen method.

Bearing all these aspects in mind, we didn't find the event nor the activities themselves to be unsuccessful. The qualitative observations we made during the day, such as visitors' behaviours, willingness to engage with our stand and whether or not they were having fun, gave us a feeling of success (which as we saw in Part III.2 is usually the measure used by CREEM researchers to grasp an activities' success). We found people, especially children within the range of 7- to 9-year-olds, to be very engaged with our activities.

We also found the photo ID game to be the best activity to get visitors' attention, revealing a great starting point for the other two activities. With the images of marine mammals inspiring curiosity in children, that was the activity they gravitated towards the most. It was quite a simple game, not involving too much critical thinking. Once we'd played the game, it was easy to redirect them to one of the other two activities, which, on the other hand, had a different impact on participants' attention and ability to do more than that one activity.

If a participant approached our stand and played the mark-recapture game first, it was unlikely that they would then do the PAM DE activity in full. They would usually go to the photo ID game, and once they'd reached the PAM DE activity, we found their attention to not be very sharp. This made us decide to only do the first part of this activity with participants, where they listened and talked to the microphone producing their own spectrogram. Removing the Mathematics part of this activity didn't allow us to fulfil its full potential, but still allowed us to interact with the audience. A similar observation could be made the other way around. If participants began by doing the PAM DE activity, followed by the photo ID, very rarely would they do the mark-recapture activity. Without an attractive element equivalent to listening to whale calls (like in PAM DE), it was difficult to bring them to that part of the stand and do the activity.

Furthermore, some participants would only do one of the activities. Younger children only had the ability to do the photo ID game, while older children could do all three. Doing either the PAM DE activity or the mark-recapture activity usually depended on whether they were old enough to do the calculations that were required.

Figure 16 – Moments from the Marine Showcase.

III.4.2 Primary School Visit

On November 9th 2022, we visited a year 3 (8 years old) classroom at a primary school in Strathkinness (**Figure 17**), a town about 7 km from St Andrews, as a result of an invitation to Dr Catriona Harris to give a talk and do some activities in the context of their current study module about pollution. Since my advisor's research focus is the effects of noise pollution on marine mammals, this was a great outreach opportunity.

Figure 17 – Strathkinness Primary School

For this, we prepared a presentation about marine pollution (**Figure 18**) with emphasis on sound pollution that guides the class through different aspects of this subject. The presentation is divided into 8 parts: 1) What is marine pollution?; 2) Examples of marine pollution; 3) What is noise?; 4) What is sound? (where we played the forks and string game); 5) Sound in the ocean; 6) Effects of noise in marine mammals (where we played the masking game); 7) Masking (where we played the masking video); 8) How scientists study noise in the ocean.

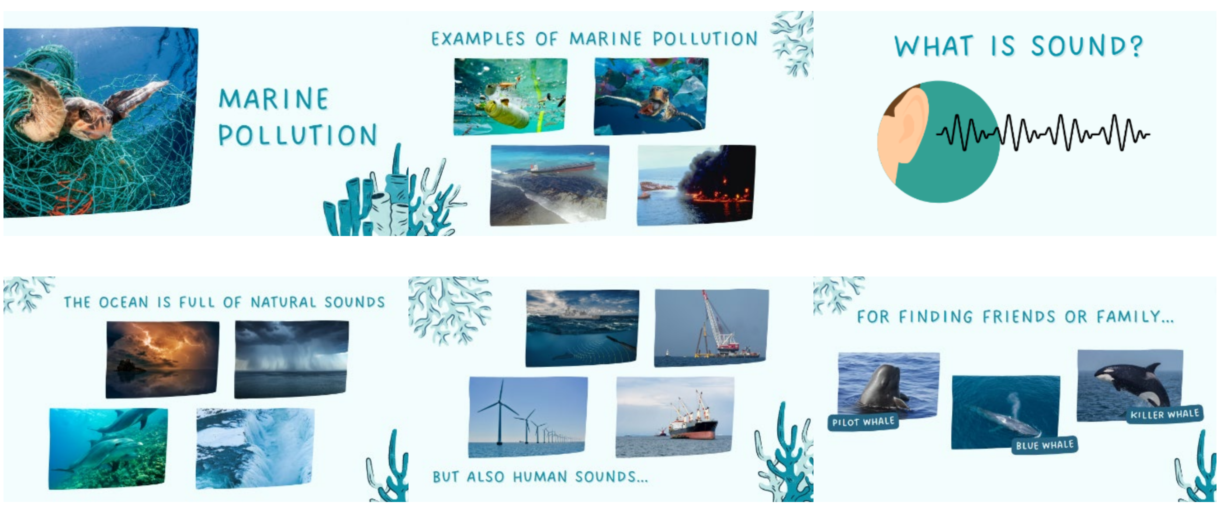


Figure 18 – Example slides of the Marine Pollution presentation.

Throughout the talk and activities, the classroom was engaged, felt comfortable in asking questions, and knew how to answer our questions quite promptly. We felt like we had their attention and all of the activities went smoothly. We found their excitement and attention rise when we initiated any of the practical activities, such as the forks games and the masking talking activity.

At the end, we applied a similar method of evaluation we chose for the Marine Showcase. By the end of the presentation, we asked the children the question “what is making?” and had them write it down. This turned out to work much better than at Dynamic Earth, as we found ourselves in a much more controlled environment, with constant support of the class teacher. Below are the children’s answers. From every response, it is clear to see that the concept got through, as in just one sentence the children were able to describe what masking is.

Child 1	*“Masking is when a noise that’s too loud covers something that is talking.”*
Child 2	*“Masking is when two whales call each other but it is too noisy.”*
Child 3	*“It means blocking off sounds so marine mammals cannot interpret what was ‘said.’”*
Child 4	*“Masking is when a form of loud noise disturbs animals calling to each other and can confuse it for a predator.”*
Child 5	*“I think masking is that noise like boats, wind turbines and submarines.”*
Child 6	*“Masking is when two animals try to talk but it is too loud.”*
Child 7	*“A sound overlapping a sound.”*
Child 8	*“I think masking is where two underwater animals are talking, but they can’t because there’s too much noise.”*
Child 9	*“Masking is when there is too much noise in the sea, so animals can’t hear each other.”*
Child 10	*“I loved the video. Great drawings. Masking is when two animals are talking and there is a lot of noise and [they] can’t hear each other.”*
Child 11	*“Masking is when all of the noises in the ocean block out the sound of animals trying to communicate.”*

Child 12 *"Masking is when animals try to communicate but can't because of loud noises of other animals, boats, etc."*

III.4.3 Cub Scouts Science Night

On November 15th 2022, we hosted "Science Night" for the Cub Scouts community group in Strathkinness (**Figure 19**), consisting of 16 children from the ages of 7 and 9. During "Science Night", Cub Scouts do a series of science related activities in order to earn their scientist badge. My advisor is one of the leaders of this community group, so she thought it would be a good idea to bring to "Science Night" some of the activities we had been working on throughout the internship.

Figure 19 – Science Night with Cub Scout from Strathkinness.

We introduced the session with a conversation about marine mammals and talked about how many species of them there are in the world. To aid with this introductory stage, we also took with us a poster representing all different species, as well as a mock killer whale skull (**Figure 20**). The goal of bringing this mock killer whale skull was to trigger some curiosity in them. When presented with the object, the scouts were asked what animal they thought that skull belonged to, with most of them excitedly answering dinosaur, with one child answering correctly (although I later found out that they had already seen and discussed the skull before in previous activities).

Figure 20 – Mock killer whale skull.

We also covered topics such as marine mammal's different habitats and morphologies, and ended with covering the topic of how scientists count them in the wild. To demonstrate the latter, we did four abundance estimation activities with the cubs – the PAM DE activity, the photo ID activity, the mark-recapture activity and the plot sampling activity. To set up for the activities, we split the group into four smaller groups, and set up four different stations around the pavilion (**Figure 19**) – one for each activity, each led by one adult. There were four adults in total – me, my advisor, one CREEM researcher, and one leader of the Cub Scouts of Strathkinness – and we used a system whereby the groups rotated all stations and did all four activities.

I was responsible for leading the PAM DE activity in one of the stations, where we used the final version of the activity described in Part III.3.2. This was the first time I led one of our activities by myself and it ended up working very well. I found the group of children we were engaging with to be very curious about the topic we brought them, and they also knew more than I had initially expected. Some were already familiar with the term "estimate" and were able to explain it back to me. They were very keen to choose which animal they wished to count and, regardless of being given three different options, all four groups chose to count killer whales.

After doing the PAM DE activity, they were all very excited to hear the recorded clips of their calls. Passing the headphones around, they were all surprised by what they sounded like, and some even found it funny. Whilst we waited for other groups to finish their activities, I showed them the other two recordings of humpback whales and bottlenose dolphins, which they really liked as well.

After about one hour, all groups had done every activity, and we gathered around in a circle to discuss what we had done over the past hour. We prompted the discussion with the question “have you done science today?” and the answers were mixed – some children saying yes and others saying no. When inquiring the children that had responded no as to why they thought they hadn’t done science, one child responded that “they had only done Maths”. My advisor carried on explaining that, in fact, Mathematics is a central part of studying marine mammals. This activity helped us understand that the definition of science was not very clear for all children.

PART IV – LEARNING FROM INFORMAL SCIENCE EDUCATION

Throughout the report, we have seen how CREEM fits into the category of research institutions that don't have professional communications staff, with public engagement activities (usually motivated by arising opportunities such as invitations) being carried out by researchers without training in science communication. Furthermore, we have also seen that these circumstances are not unique to CREEM, as this reality appears to be spread across research institutions around the globe. Researchers seem to be forced to take matters into their own hands and create their own outreach materials, regardless of how limited their resources may be. This scenario has led me to question what are some possible actions that researchers can take to improve the public communication of science at their institutions given all of their limitations.

In 2018, April Killikelly, at the time a researcher from the Vaccine Research Centre at National Institute of Allergy and Infectious Disease, asked the following question: "how can researchers strengthen the connection between science and society?". This led her to write an article entitled "Using the tools of informal science education to connect science and the public", where she discusses how there seems to be a growing need for scientists to use educational tools to engage with the public, and how their unfamiliarity with these tools may be the reason why they don't seek more outreach opportunities. Given this scenario, Killikelly goes on to suggest how, from a science communication standpoint, researchers may have something to gain from looking at the knowledge and practices of fields like informal science education.

We've seen in Part I that science communication is a field that benefits from the knowledge of other areas, informal science education being one of them. This has led experts to research what characteristics of both fields might overlap and complement each other. A survey conducted by the Centre for Advancement of Informal Science Education – whose aim is to support the continued professionalisation in the fields of informal science education and science communication – sought a clearer picture about how the two fields diverge and converge, both in practice and in research. Whilst finding clear differences, they also found areas of beneficial overlap.

Among their findings were 1) how "informal science education's experience and expertise in broadening participation of underrepresented audiences can inform issues of growing interest in science communication, such as the desire to engage with new, diverse publics" and 2) that "science communication's growing knowledge about decision-making can inform informal science education efforts to design for changing behaviour". At the end, they point out that this may "suggest that there is unrealised potential for mutual learning, knowledge-building, and advancement" in both fields (Bevan et al. 2019).

Other explorations of these overlaps have also been done by Ellenbogen (2013), who points to the benefits of exploring the ways in which the two fields might be strengthened by taking more notice of each other, given that both are working toward a common outcome – increasing the public's interest and awareness of science. Furthermore, Stocklmayer & Rennie (2017) sought to identify the main characteristics of both fields and combine them to provide a framework where skills and knowledge required for successful science communication are drawn out in an attempt to guide informal science educators in becoming more effective communicators of science.

Furthermore, and going back to Killikelly's exploration, she mentions how informal science education spaces, such as science museums and science centres "provide the opportunity for researchers to directly connect with the public". Given their foundational theories, "informal science education institutions have the potential of providing tools and give scientists the opportunity to directly interact with the public". This also leads to benefits across all parties involved: the public, "who have the opportunity to learn more about the science of their daily lives, scientists"; the scientists, "who have the opportunity to directly control the scientific message, and the informal science education institutions, "who, in providing the location of this exchange, confirm their cultural and societal importance to both the scientific community and the broader public" (Killikelly, 2018).

To explore these ideas in practice, Killikelly (2018) collaborated with educators at the Smithsonian National Museum of Natural History. In the end, and through the combination of her own expertise in virology and the educators' background in engagement, she learned three specific tools derived from informal science education theories and frameworks that can be used by scientists and researchers to bridge gaps between science and society and enhance engagement with audiences: 1) 3D objects, 2) games and 3) storytelling.

Object-based experiences are known to encourage learning given how informationally dense they can be (Paris & Hapgood, 2002) and their ability to promote "learning at a glance" (Hooper-Greenhill, 2007). These features have been shown to make object-based learning very satisfying for visitors (Allen, 2004). Games, on the other hand, can promote an environment for learning through social interaction (social learning), generate longer term retention of science related content (Su et al., 2014) and shed light on problem solving techniques used in real life scenarios (Smithsonian Institution, Office of Policy and Analysis, 2004). Games can also generate "wins" for participants which, in turn, increases engagement (Smithsonian Institution, Office of Policy and Analysis, 2004). Finally, storytelling can also increase engagement given its reliance on narratives. Narratives have been shown to increase recall, both of the storyline (Hong & Lin-Siegler, 2012) and of the scientific content linked to it (Töpper et al., 2014), and to appeal to publics given how they increase comprehension, sustain interest (Dahlstrom, 2014).

One common aspect among these three tools is how it is possible to incorporate them in outreach activities, even with limited resources. They can give scientists ideas to create new outreach activities or improve/ tweak certain elements of their established activities. To exemplify this, we propose looking at the activities we worked on during the internship to see how we could make further use of these tools to increase engagement, without making radical changes.

Both the mark-recapture and the PAM DE activities could be slightly tweaked to resemble games. The mark-recapture activity, for instance, could be done with two competing teams. During redesign, we prepared two separate numbered grids, which would allow for a game between two teams, where the team who gets closer to the true number of ducks in the bag wins. With the PAM DE activity, something very similar could be applied – two teams trying to reach an estimate of the number of whales heard and the team who gets closer to the true value wins. Additionally, both games could be accompanied by scoreboards. For open science day events, for example, these scoreboards could keep a tally of all the teams who play the games throughout the day, ordering the teams by total final scores (final estimates of ducks), which could in turn motivate participants to want to play the game to beat other teams. This would also allow for the activity to be conducted as a game even if only one person (or group) is at the stand, as it would keep the element of competition.

Elements of storytelling could also be added to these two games by adding a narrative. For the PAM DE activity, an example could be to tell children in the beginning of the activity that they now are biologists trying to discover how many whales there are in the ocean. If in a larger group, they could also be told that among their team of biologists there are also statisticians. When proceeding to the actual activity, children could be given tasks according to what type of scientist they are – biologists could listen to the recordings and count the number of calls (data collection), and then pass on the data to the statisticians, who would then do the calculation for the final estimates (data analysis). With the mark-recapture activity, the biologists could be the ones to take the ducks out of the bag and register the data in the flashcards (data collection), and then the statisticians would gather the flashcards and solve the equation (data analysis). Incorporating a storyline of this kind could not only help increase engagement among children as they take on the identity of a scientist, but also help them see how science is a collaborative process between experts from multiple disciplines.

As for objects, these are already spread through some of CREEM's activities – some as integral elements, such as the rubber ducks in the mark-recapture activity, and others simply standing on their own, such as the mock killer whale skull. In both situations, these objects proved to be great ways to spark curiosity among participants. That being said, adding new elements seems only beneficial for engagement levels with audiences. One idea to achieve this in the PAM DE activity, for example, could be to materialise the study subjects, just like with the ducks in the mark-recapture activity. This could translate to including small sized representations of each of the marine mammals (whales and dolphins) and have participants be able to hold and look at the animal while they listen to its sounds. This could help participants make stronger connections between the different marine animals and the sounds they make.

When thinking about improving science communication practices, it is crucial to consider all the limitations institutions have and make reasonable recommendations within those same limitations. At CREEM, for instance, suggestions like hiring professional communications staff or implementing strategic evaluation plans, while valuable, are still somewhat far away from becoming achievable changes. And whilst they should still be goals for the institution to have, other more feasible actions should also be taken in the meantime. Here I have presented some that I believe fit into that category.

CONCLUSION

The increasing activity of science communication activities in academic institutions points to a growing recognition of the importance to publicly communicate science. By increasing their own engagement with science communication, research institutes and scientists have been reaching wider audiences with the aim of informing and enlightening the public, promoting science and increasing scientific literacy and culture.

Nevertheless, and despite this growing activity, the widespread lack of resources for science communication still imposes a lot of limitations for the advancement of science communication among these organisations. This has created many obstacles in effectively incorporating formal science communication strategies, as the transition from ad hoc unstructured activities to routine practices requires resources that are not yet readily available to most organisations.

CREEM was a good example of this and a great place for me to witness first-hand how scientists and organisations face these challenges. In spite of the struggles imposed by lack of time and training, there is still a lot of motivation to get involved and to raise awareness on the importance of Mathematics and Statistics in Life Sciences. Moreover, I was also able to see how these difficulties do not mean that no improvements are possible even given all the mentioned limitations. In this report, we have seen how 1) relatively small improvements to activities can help increase engagement with audiences and how 2) by drawing from practices and tools of experts from other fields we can keep improving public engagement activities and strengthen the connection between science and society.

In conclusion, despite the many challenges and barriers that have been recognised many times over, the importance of science in our society seems to speak louder and (slowly) allow for the creation of the space needed for science communication to play a more central role in academic institutions. Even though there is still a lot of room for growth and improvement, there is also some evidence that we are moving in the right direction.

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LIST OF FIGURES

ATTACHMENTS

Instructions PDF

Mark-recapture activity

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MARK RECAPTURE Activity Instructions

Activity summary: This activity is meant to illustrate how to estimate the size of a population using the mark recapture method. The mark recapture method is used to estimate population sizes by capturing, marking, releasing and recapturing individual animals.

Learning outcomes:

- Understand the concepts of "**estimation**", "**sample**" and "**population**".
- Understand what the mark recapture method is, as well as when, how and why scientists use it.
- Understand how scientists estimate population size through the mark-recapture method.

Resources:

Hammond, P. S. (2009). Mark–Recapture. *Encyclopedia of Marine Mammals*, 705–709. https://doi.org/10.1016/b978-0-12-373553-9.00163-2

RoyalStatSoc. (2018, September 14). *Hands-on statistics – Capture recapture*. YouTube. https://www.youtube.com/watch?v=Gkg8Q6nYdQM

Number of participants required: minimum of 1 (can be done with groups).

Materials needed:

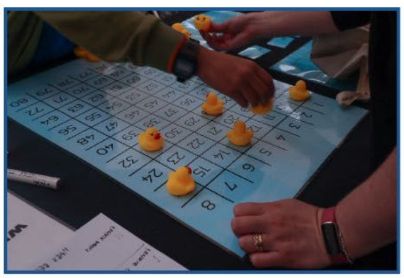
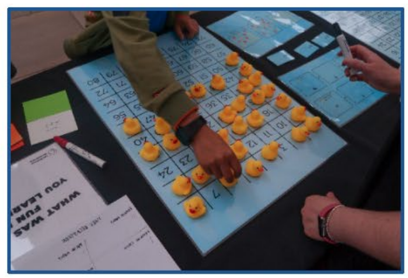
- Printed PDFs available on the "Sampling Activities & Resources" section of the website (see Attachments for guidance).
- 50 to 60 identical and numbered rubber ducks (or any other set of identical and numbered objects, such as lollipop sticks or laminated pictures of ducks or other animals).
- Opaque bag to place the ducks.
- White board pen.

How to run the activity (step-by-step):

1. Explain the main goal of the activity – estimate the number of rubber ducks in the bag – and give some context on the mark recapture method.

2. Take 2 big handfuls of ducks from the bag.


3. Place the ducks on the grid according to their number.

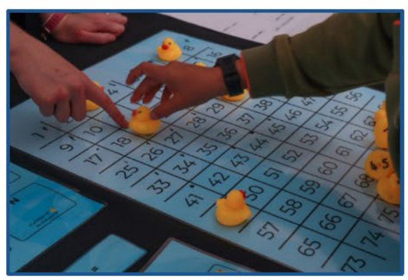
4. With the white board pen, mark every square that has a duck.


5. Count how many ducks were captured – this will be your **x** (number of ducks that have been marked) – and write it down on the x flashcard.

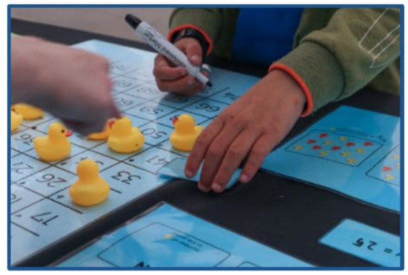

6. Place the ducks back in the bag and mix them around.


7. Take another 2 big handfuls of ducks.

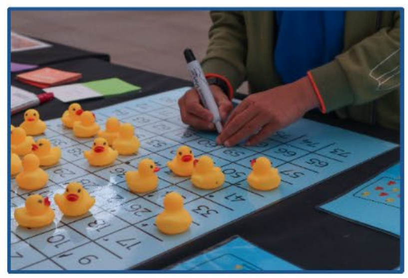
8. Once again, place the ducks on the grid according to their number.

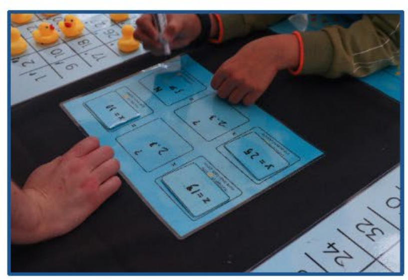
9. Count how many ducks were taken out of the bag – this will be your **y** (number of ducks in the second sample) – and write it down on the y flashcard.



10. Count how many ducks have been recaptured (ducks in the marked squares) – this will your **z** (number of ducks that were seen twice) – and write it down on the **z** flashcard.



11. Place each flashcard on the formula sheet and solve the equation to calculate **N** – estimated number of ducks.

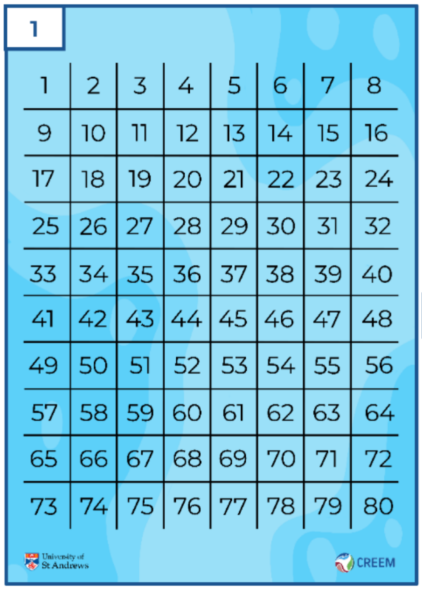


12. Compare the **N** that you calculated with the real number of ducks in the bag.

After finishing the activity, you can begin a discussion by covering questions such as:

- Do you think your estimate matches the true number of animals in the box?
- Do you think your estimate is higher or lower than the true number of animals? Why?
- If you ran this experiment again, would you get exactly the same answer?
- How does your estimate compare to the estimates made by other groups?
- How could you combine the estimates from the different groups into a single number?
- Can you suggest a way to express the variability across our estimates?

Attachments



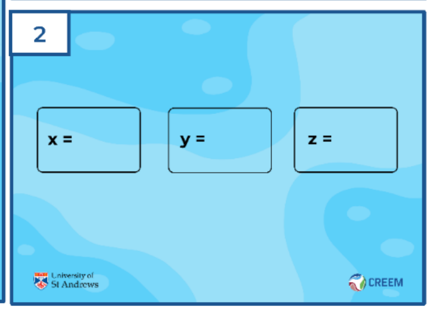
PDF FILE NAMES

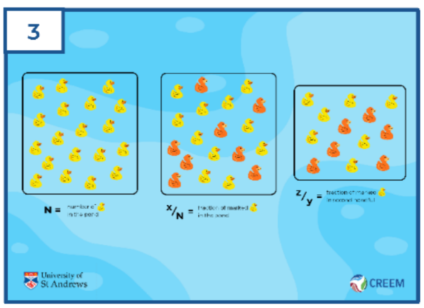
1 – **"markrecapture-grid"** (A3 and laminated)

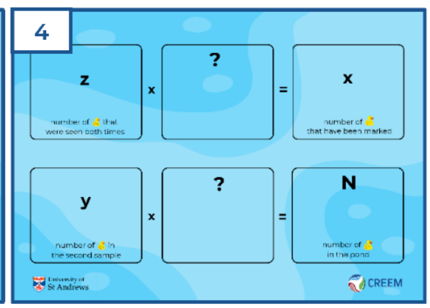
2 – **"markrecapture-flashcards"** (laminated and cut into flashcards)

3 – **"markrecapture-explained"** (A4 and laminated

4 – **"markrecapture-formula"** (A4 and laminated)







PAM DE activity

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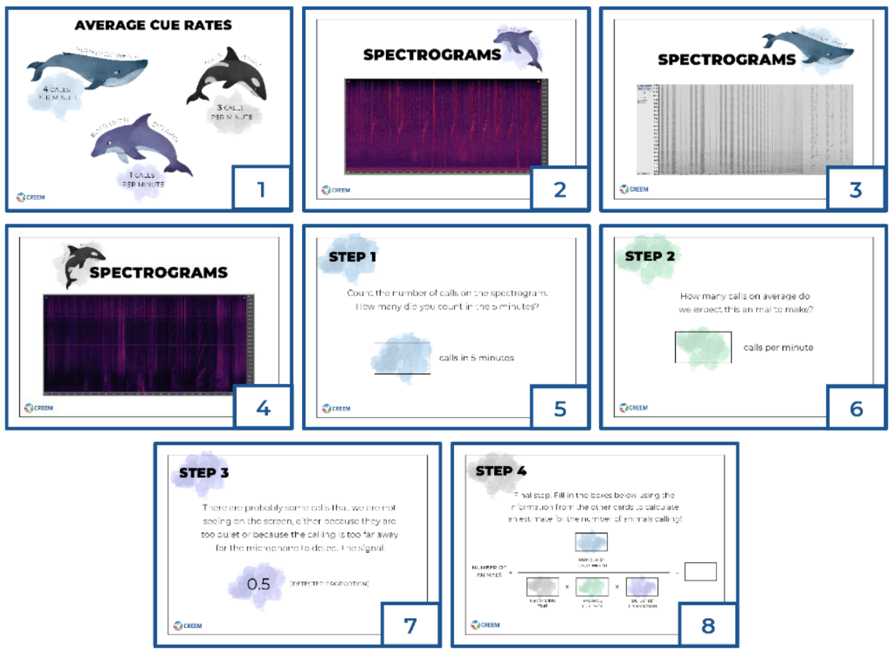
Attachments



PDF FILE NAMES

1 – **“average-cue-rates”** (A4 and laminated)

2 – **“spectrogram-dolphin”** (A4 and laminated)

3 – **“spectrogram-humpback-whale”** (A4 and laminated)

4 – **“spectrogram-killer-whale”** (A4 and laminated)

5 – **“STEP1”** (A4 and laminated)

6 – **“STEP2”** (A4 and laminated)

7 – **“STEP3”** (A4 and laminated)

8 – **“STEP4”** (A4 and laminated)

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PASSIVE ACOUSTICS MONITORING DENSITY ESTIMATION (PAM DE) – Activity Instructions

Activity summary: This activity is meant to illustrate how to estimate animal density using Passive Acoustics Monitoring Density Estimation (PAM DE). PAM DE is a method used to estimate number of animals from their sounds.

Learning outcomes:

- Understand the concept of "**animal density estimation**".
- Understand how scientists can estimate animal density by counting their sounds.

Resources:

Marques T, Dornellas L, Guerra A, Marques C, Tempero B, Zacarias M and Hart C (2022) Counting Animals by Recording Their Voices. Front. Young Minds. 10:704420. doi: 10.3389/frym.2022.704420

ACCURATE Project. (2022, February 10). Passive Acoustic Monitoring Density Estimation - counting animals from their sounds. YouTube. https://www.youtube.com/watch?v=UhyGHVe9HFI

Thomas, L., & Marques, T. (2012). Passive Acoustic Monitoring for Estimating Animal Density. *Acoustics Today*, *8*, 35. https://doi.org/10.1121/1.4753915

Sound files for the activity:

- Killer whale https://www.youtube.com/watch?v=nRYT_6vGzkI&ab_channel=MarineConservationResearch
- Humpback whale https://www.youtube.com/watch?v=boJ8PzYOhWE&ab_channel=MarineConservationResearch
- Bottle nose dolphin https://www.youtube.com/watch?v=xl0X3L8XTPc&ab_channel=MarineConservationResearch

Number of people needed for the activity: minimum of 1 (can be done with groups).

Materials needed:

- Printed PDFs available on the "Sampling Activities & Resources" section of the website (see Attachments for guidance).
- Sound files available in the "**Resources**" section of this document (optional).

How to run the activity:

1. Explain the main goal of the activity – estimating the number of animals by counting their sounds – and give some context on PAM DE.
2. Ask what animal the participants would like to work with from the **Average Cue Rate** sheet.
3. Pick up the spectrogram of the selected animal.
4. Count the number of calls on the chosen spectrogram.
   - To show what the animal sounds like and make the activity more immersive, play the sound files provided in the **Resources** section.

Here is how to identify the calls in each spectrogram (marked by green lines):

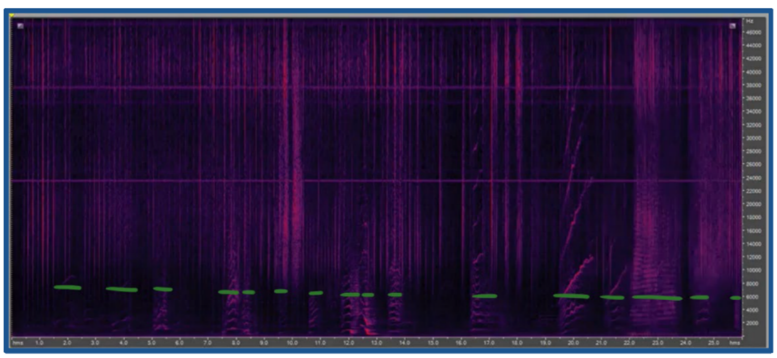

Figure 1 – Killer whale (total number of calls = 16) (**NOTE** – these calls can be difficult to idenitfy, so we recommend watching the video at the same time)

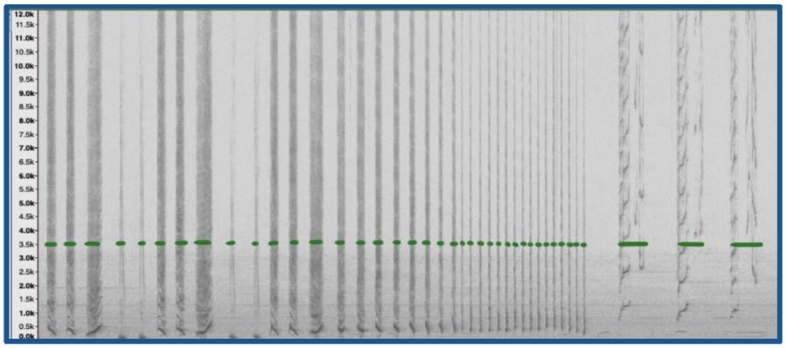

Figure 2 – Humpback whale (total number of calls = 40)

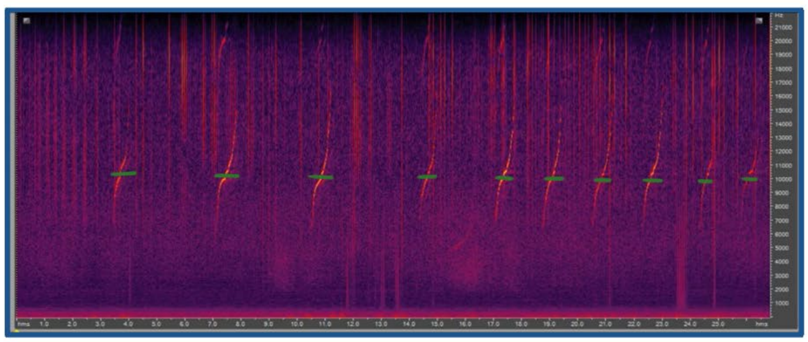

Figure 3 – Bottlenose Dolphin (total number of calls = 10)

5. On the **STEP 1 <u>sheet</u>**, write down the number of calls counted on the spectrogram (note that the spectrograms represent 5-minute-long recordings).
6. Fill in the **STEP 2 <u>sheet</u>** with the information given by the **Average Cue Rate** sheet.
7. Read **STEP 3 <u>sheet</u>**.
8. Fill in the **STEP 4 <u>sheet</u>** with the information from the previous cards (each **STEP <u>sheet</u>** is colour coded to make this step easier).
9. Solve the equation. You will now have an estimate of the number of animals.

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After finishing the activity, you can begin a discussion by covering questions such as:

- How can the movement of the animal affect our estimate?
- How can our estimate change if the animals spend more time silent than what we expected?
- How will our estimate be affected if the sounds are associated with seasonal activity?

Masking activity

MASKING Activity Instructions

Activity summary: This activity is meant to illustrate first-hand how increasing background noise levels can affect an animal's ability to communicate, i.e. masking occurs.

Learning outcomes:

- Understand the concept of masking.

Resources:

Discovery of Sound in the Sea Website – https://dosits.org/

"Masking in Marine Mammals | CREEM" video – https://youtu.be/WT4QtD4q4KI

Number of participants required: Minimum of 10.

Materials needed:

- Print outs of the nursery rhymes (see Attachments).

How to run the activity:

Before the activity begins, it's important to provide some context on the subject. This can be done by having a short conversation with the class, or by watching the 3-minute video available on CREEM's website about masking (see "**Resources**").

To set up the activity, begin by asking two young learners to stand on opposite sides of the room and have the remainder of the group sit between the standing two. After everyone is in their positions, ask one of the standing participants to ask the other a question, while the group in between remains silent. Importantly, these can't be a yes/ no question, as the answer can be easily communicated by shake or nod of the head. Examples of questions to ask could be "What is your favourite ice cream flavour?" and "What is your favourite animal?" (see Attachments for more examples). The goal with this first step is to show how easily they can hear each other if there is no background noise.

Then, have the standing participants ask each other another question. This time, however, have the participants in the middle begin reading out loud the different nursery

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rhymes at a low volume. With every new question, ask them to read louder and louder until they reach a point where the participants standing opposite in the classroom are unable to hear each other.

By doing this, you'll have shown the group first-hand how loud background noise can affect communication, which is one of the ways masking affects marine mammals. To solidify this new knowledge, you can start a discussion by covering questions such as:

- Why did the message get harder to send and receive?
- What animals might be affected by this (marine and terrestrial) and in what ways (e.g., what messages might they want to send/ receive?)?
- How light and sound travel differently in air and water. Therefore, the importance of sound to animals living in different marine and terrestrial environments can be different too.
- What are possible noise sources in different environments?

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Nursery rhymes examples

Pat a cake, Pat a cake, baker's man
Bake me a cake as fast as you can;
Pat it and prick it and mark it with a 'B',
And put it in the oven for Baby and me.

Seesaw Margery Daw
Johnny shall have a new master
He shall earn but a penny a day
Because he can't work any faster

Humpty Dumpty sat on a wall,
Humpty Dumpty had a great fall.
All the King's horses,
And all the King's men
Couldn't put Humpty together again!

Jack and Jill went up the hill to fetch a pail of water
Jack fell down and broke his crown
And Jill came tumbling after.
Up got Jack, and home did trot
As fast as he could caper
He went to bed and bound his head
With vinegar and brown paper.

One, two, three, four, five.
Once I caught a fish alive,
Six, seven, eight, nine, ten,
Then I let it go again.
Why did you let it go?
Because it bit my finger so.
Which finger did it bite?
This little finger on the right.

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One two buckle my shoe
Three, four, knock at the door
Five, six, pick up sticks
Seven, eight, lay them straight
Nine, ten, a big fat hen
Eleven, twelve, dig and delve
Thirteen, fourteen, maids a-courting
Fifteen, sixteen, maids in the kitchen
Seventeen, eighteen, maids in waiting
Nineteen, twenty, my plate's empty.

What is your favourite colour?

What is the name of your street?

What is your favourite animal?

What is your favourite ice cream flavour?

What is your favourite movie?

Masking Video Script

Life underwater is full of sound. From animals croaking, clicking and snapping, to the breaking waves and the rain, every moment there is something to be heard.

As a marine animal, being able to hear and detect particular sounds is very important for survival. It allows them not only to protect themselves from predators, but also find food and communicate with others. A good example is the importance of sound to whales who call to each other to communicate who they are, where they are and other information we don't yet understand.

But sound doesn't come only from natural sources, like waves and marine life. It can also be caused by human activity, like ship traffic and construction, and research tells us that these human-made sounds can impact marine life in a few ways. One of them is masking. Masking happens when the background noise gets loud enough that it becomes hard for animals to hear each other, hear predators or use sound to find food.

Imagine two whales are trying to communicate with one another in a usually quiet place. Without much else going on, it's rather easy for them to hear each other. But what would it be like if these whales were in an area close to a lot of ship traffic? Now surrounded by more noise, picking up on each other's sounds will be much harder. And since detecting sounds is key to their survival, this increase in background noise may cause the animals to change their behaviour, and this can mean, for example, turning up the volume of their calls or to give up and stop calling altogether.

Scientists still don't understand all of the effects masking may have on marine animals, but with the current levels of human activity in the sea it is thought to be having a large impact on their ability to communicate. As we learn more about these issues, certain measures are being put into place to help reduce the effects of noise, such as industry avoiding areas with lots of marine mammals and removing or changing sound sources that may disturb the animals.