S24: Drivers for patchiness and marine vertebrate dynamics

Conveners

- Dr Peter Miller, Plymouth Marine Laboratory (PML) - *ocean fronts; remote sensing;*
- Dr Beth Scott, University of Aberdeen - *biophysical oceanography; predator hotspots;*
- Dr Lars Boehme, Sea Mammal Research Unit (SMRU), University of St Andrews - *biologging; geospatial statistics;*
- Dr Jeroen van der Kooij, Centre for Environment, Fisheries and Aquaculture Science (CEFAS) - *fisheries ecology;*
- Dr Clare Embling, University of Plymouth - *marine vertebrates & oceanography;*
- Dr Jacqueline Tweddle, University of Aberdeen - *biophysical oceanography.*

Session	Student or Early	Presenter and title
Oral Tue 1415-1515	S	**Samantha Gordine**: Long-term importance of specific frontal systems for the improvement of body condition in southern elephant seals
		Ben Wilson: Porpoises in tidal streams: Combining Eulerian and Lagrangian perspectives gives insights into behaviour
Chair: Peter Miller	S	**Olivia Hamilton**: Drivers of distribution for large marine predators in a dynamic ocean system
	S	**Nadya Ramirez-Martinez**: Modelling fin whale, short-beaked common dolphin and harbour porpoise habitat use in European Atlantic waters
Oral Tue 1545-1700		**Jeroen van der Kooij**: Ecological drivers of small pelagic fish in the Celtic Sea
	S	**Brittany Visona**: Sandeels and top predators: Effects of bio-physical coupling on predator-prey aggregations in the Firth of Forth, Scotland
Chair: Beth Scott		**Erik van Sebille**: Mapping large-scale patchiness of ocean plastic pollution and its impact on seabirds
	S	**Duncan Jones**: Influence of tidally driven processes on harbour porpoise distribution
	E	**James Waggitt**: Quantifying top-predators' use of hydrodynamic features in coastal regions; applied and ecological consequences.
Poster Tue 1700-1900	E	**Nicholas Higgs**: Going deeper: Marine vertebrate hotspots enhance carbon flux to deep-sea scavengers
	E	**Doreen McVeigh**: Behaviour matters: A coupled bio-physical model to assess the dispersal and potential population connectivity patterns of deep-sea methane seep larvae
	S	**Daniel Moore**: Effect of environmental boundaries on the population structure of marine predators

Patchiness session 1: Tue 14:15-15:15

Long-term importance of specific frontal systems for the improvement of body condition in southern elephant seals

Gordine, Samantha A. (Sea Mammal Research Unit, University of St Andrews, United Kingdom), Fedak, Michael A. (Sea Mammal Research Unit, University of St Andrews, United Kingdom), Boehme, Lars (Sea Mammal Research Unit, University of St Andrews, United Kingdom)

Southern elephant seals (SES) yearly undertake two migrations (2-3 and 7-8 months) in the Southern Ocean to replenish their resources after fasting while moulting or breeding. During these, SES

frequently associate with macroscale latitudinal fronts which provide favourable foraging conditions likely because of cascading trophic interactions and/or prey aggregation.

Previous studies observed great plasticity in the importance of frontal systems for improving body condition among different SES populations. However, it is largely unknown how flexible the reliance on certain systems is within populations over the long-term. We are the first to examine the (un-)successful resource acquisition of SES during their migrations in the Atlantic sector over several years and seasons in relation to the encountered fronts and inter-frontal zones.

Movements, diving behaviour and in-situ oceanographic properties were recorded over 3 post-moult and 3 post-breeding seasons between 2005 and 2010 using satellite-relay data-loggers deployed on South Georgia seals. For 47 individuals information on both body condition and temperature up to 500m depth could be obtained and using the potential temperature of these in-situ measurements, the fronts and inter-frontal zones between the Subtropical Frontal Zone and the Southern Boundary of the ACC could be determined for >15,000 individual dive profiles.

Improvement of body condition depended on the frontal system a seal was located in; however which frontal systems were overall favourable varied strongly according to year, season and month. Variability in body condition improvements was higher in some frontal systems than in others. Yet particularly noteworthy was the unusual worsening of the seals' body condition when in the Southern Boundary in 2005 post-breeding and when in the Polar Front and Polar Frontal Zone in 2008 post-moult.

These initial results illustrate how shifts in the latitudinal positions and/or productivity within frontal systems due to global warming could affect SES movement and foraging success.

Porpoises in tidal streams: Combining Eulerian and Lagrangian perspectives gives insights into behaviour

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Benjamins, S. (Scottish Association for Marine Science, Oban, Argyll PA37 1QA, UK)
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Tidal-stream habitats present periodically fast-flowing, turbulent conditions that appear to benefit predatory marine mammals such as harbour porpoises *Phocoena phocoena*, presumably through improved foraging opportunities. Studying tidal-stream ecology requires awareness of the distinction between stationary (Eulerian) and moving (Lagrangian) observational frames of reference. Both perspectives offer insights into habitat use by marine mammals in relation to moving water vs. immobile bathymetry; however, many standard monitoring methods (e.g. stationary moorings) only provide an Eulerian perspective, potentially leading to an incomplete picture. The present study combined both perspectives to explore small-scale spatiotemporal variability in harbour porpoise distribution in relation to tidal currents within the Great Race of the Gulf of Corryvreckan (western Scotland, UK), a jetting tidal system where high-energy conditions persist across a broad range of tidal phases.

The distribution of harbour porpoises was studied using passive acoustic porpoise detectors(C-PODs) deployed on static moorings (~35 d) and on Lagrangian drifters moving freely with the current (repeated deployments up to ~48 h). This dual approach provided complementary perspectives on porpoise presence. C-PODs moored in the path of the Great Race registered a significant increase in detections during the passing of the energetic tidal jet. Comparison of encounter durations between the two recording modes revealed longer encounters on the drifters, suggesting that porpoises tended to move downstream with the flow rather than remaining stationary relative to the seabed or moving upstream. The energetic, turbulent conditions of the Great Race jet are clearly attractive to porpoises who appear to track its movement with time. This study has demonstrated the importance of considering the frame of reference (relative to bottom or relative to water mass) when studying animals in tidal streams.

Drivers of distribution for large marine predators in a dynamic ocean system

Olivia Hamilton (Institute of Marine Science, University of Auckland, Auckland, New Zealand)
Dr Rochelle Constantine (School of Biological Sciences, University of Auckland, New Zealand)
Dr Matt Pinkerton (National Institute of Water and Atmosphere, Wellington, New Zealand)
Lily Kozmian-Ledward (Institute of Marine Science, University of Auckland, New Zealand)
Dr Leigh Torres (Marine Mammal Institute, Oregon State University, Newport, Oregon, USA)

The oceanographic features of an area directly influence the distribution of prey populations, which in turn drive the distribution of large marine predators. As prey distribution data are difficult to collect, environmental variables, such as sea surface temperature and slope, are commonly used as proxies in predictive models. For systems that are highly dynamic, environmental variables do not always capture the variability of predator distribution at the chosen spatial and temporal scale of the study. Here, we investigated whether including prey distribution data improved the predictive capacity of habitat models for mega-fauna in the Hauraki Gulf, New Zealand. The Hauraki Gulf is a highly productive ecosystem, which is reflected by the number of large marine predators that frequent the area. We conducted 22 systematic aerial surveys from November 2013-October 2014 during which we recorded all sightings of mega-fauna and of potential prey patches (plankton and small fish aggregations). We used Boosted Regression Trees to model species distribution and identify which environmental and biological variables were important in explaining habitat use for two species of dolphin, one species of whale, four species of shark, and eleven species of seabirds. We found that prey data improved the predictive capacity of models for all taxa, however, this varied depending on the type of predator. For example, adding plankton and fish distribution data improved the AUC from 0.7373 to 0.8305 for Bryde's whales, with the two predictors contributing 48% to the model when included. In contrast, prey data improved the AUC to a lesser degree for bronze whaler sharks (AUC=0.8719 to 0.9146), and contributed only 26% to the final model when included. These results suggest that predators may respond to the distribution of their prey to varying degrees, which has important implications for management for predators within the Hauraki Gulf.

Modelling fin whale, short-beaked common dolphin and harbour porpoise habitat use in European Atlantic waters

Nadya C. Ramirez-Martinez & Philip S. Hammond (Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, St Andrews, Fife KY16 8LB, Scotland, UK)

In European Atlantic waters fin whale (*Balaenoptera physalus*), short-beaked common dolphin (*Delphinus delphis*) and harbour porpoise (*Phocoena phocoena*), represent extremes of the cetacean fauna. Their general distributions are well established but the environmental conditions that influence their distribution are not well understood. To investigate the relationship between abundance and oceanographic variables, we used cetacean data from large-scale surveys conducted in July 2005 and 2007. Environmental data included depth and related relief variables, and satellite-derived data processed by NEODASS included sea surface temperature, chlorophyll *a*, primary productivity and ocean front derived covariates.

The relationships between abundance estimated along transects (taking detection probability into account) and the oceanographic covariates were explored using Generalized Additive Models (GAMs).

The covariates that best explained fin whale distribution were June sea surface temperature and depth. For short-beaked common dolphin, distribution was best explained by March sea surface temperature and primary productivity, April and June ocean front strength, July distance to the major fronts, depth and distance to the 200 m contour. Harbour porpoise distribution was best explained by April sea surface temperature, May chlorophyll *a* concentration, June distance to the major fronts and depth. For dolphins and porpoises the oceanographic covariates retained in the models showed a similar pattern of temporal lagged relationships suggesting mechanisms of oceanographic processes. The temperature variables were more lagged than the biological variables

and the ocean fronts variables were least lagged. Models for all species showed a lagged pattern, however each species' covariates and their lags were different. Variation among species seems to reflect the relationship with their prey (krill for fin whale and different fish species for dolphin and porpoise) that is described indirectly by habitat variables. Further research should explore these relationships more fully to understand better the mechanisms that link the physical oceanography to the biological responses.

Patchiness session 2: Tue 15:45-17:00

Ecological drivers of small pelagic fish in the Celtic Sea

Jeroen van der Kooij *(Cefas, UK), Peter Miller (PML, UK), Serena Wright (Cefas) and Elisa Capuzzo (Cefas)*

Small pelagic fish (SPF) play a key role in shelf-sea foodwebs, channelling energy from primary producers to top predators. Most SPF are short-lived and have lots of offspring. Ecological drivers are therefore thought to have a relatively direct effect on SPF, and changes in the physical oceanography may manifest itself in abrupt changes in abundance and distribution. The waters of the eastern Celtic Sea and western English Channel are home to a rich diversity of SPF, including sprat, sardine, mackerel and herring, and in recent years, other species have emerged, such as anchovy. This diversity can in part be attributed to the fact that the area represents a transition from the warmer Lusitanian waters in the south to the cooler boreal waters to the north, and distribution of species associated with both regimes overlap here. In this study we combine data collected during an integrated pelagic survey series with remote sensing products, to examine the different environmental drivers of these SPF. Part of the focus is on meso-scale features such as frontal zones. Frontal zones are generally perceived to be ecologically important for large mobile marine vertebrates. In the study area, several piscivorous predators have been associated with these features, and this has generally been attributed to foraging and migration behaviour. However, there have been very few studies linking their prey, the SPF, to frontal systems. The results of this study contribute to a better understanding of some of the processes and interactions of the marine ecosystem in the southwest of the United Kingdom.

Sandeels and top predators: Effects of bio-physical coupling on predator-prey aggregations in the Firth of Forth, Scotland

Visona, Brittany[a]; *Scott, Beth E.*[a]; *Tweddle, Jacqueline*[ab]; *Lawrence, Joshua M.*[a]; *Armstrong, Eric*[b]; *& Boulcott, Philip*[b]

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Biological patchiness in marine ecosystems can be attributed to climatic and oceanographic variables driving productivity in space and time, forming predator-prey hotspots during optimal physical conditions. Understanding the main bio-physical drivers that create biological aggregations is required for improved management of marine systems. Sandeels (*Ammodytes* spp.) act as a mid-trophic prey species for a variety of top predators in the North Sea. Studies of seabirds and sandeel distributions have been performed, but little has been done in terms of examining the relationship with marine mammals. Because of their life history characteristics, sandeel distributions are highly affected by bio-physical processes which effect conditions for foraging, their degree of aggregation (school morphology), and depth they inhabit in the water column. The primary objective of this study is to determine the biological and physical factors that control variability in annual sandeel horizontal and vertical distributions, abundance, and schooling behaviour, and how these factors may influence foraging distributions of harbour seals, grey seals, and harbour porpoise.

Sandeel schools are detected using a Simrad EK60 multi-frequency echosounder, from acoustic surveys conducted annually in summer (June) in the Firth of Forth, Scotland by Marine Scotland

Science. CTD casts are taken at the time of survey, however, to provide information on the bio-physical conditions that occurred up to several months before the surveys, 1-D bio-physical models are run at areas of contrasting depths and tidal forcing, providing insight into the oceanographic variables driving annual sandeel size, abundance, and distributions. In order to assess the potential effect of the range of sandeel distributions on the three marine mammal species, Generalised Additive Modelling techniques have been employed. The study will also show how determining the bio-physical drivers controlling variability within predator-prey aggregations can aid in stock management, along with marine spatial planning of Marine Protected Areas and marine renewables.

Mapping large-scale patchiness of ocean plastic pollution and its impact on seabirds

Erik van Sebille (Imperial College London), Chris Wilcox, Kara Lavender Law and Denise Hardesty

Microplastic debris floating at the ocean surface can harm marine life. Understanding the severity of this harm requires knowledge of plastic abundance and distributions. Dozens of expeditions measuring microplastics have been carried out since the 1970s, but they have primarily focused on the North Pacific and North Atlantic accumulation zones, with much sparser coverage elsewhere.

Here, I will show how we use the largest dataset of microplastic measurements collated to date to assess the confidence we can have in global estimates of microplastic abundance and mass. We use a rigorous statistical framework to standardise a global dataset of plastic marine debris measured using surface-trawling plankton nets and coupled this with three different ocean circulation models to spatially interpolate the observations.

In particular, I will focus on patchiness in the distribution of floating plastic. we have related that distribution to foraging areas of seabirds and turtles, to investigate where these animals are most at risk. I will show how we found that the areas where marine biota are most at risk from plastic do not necessarily coincide with the areas of highest plastic abundance.

Influence of tidally driven processes on harbour porpoise distribution

Duncan Jones (Marine Discovery Penzance, Falmouth Marine School and Lund University), Dr. Marjke de Boer (Seven Seas Marine), Dr. Claire Embling (Plymouth University)

Due to its Annex II European Habitats Directive status the Joint Nature Conservation Committee (JNCC) have recently proposed four Special Areas of Conservation (SACs) for the harbour porpoise. Due to poor dedicated survey coverage for most UK waters a number of these proposed areas are based on habitat models that use information from the well surveyed Southern North Sea to predict key habitat around the rest of the coast. Our lack of understanding of how topographic and temporal variables influence their distribution at a fine scale suggests there is potential for inaccuracies in this modelling.

A platform of opportunity has been used to collect effort based sightings data for harbour porpoises and other species in Mount's Bay, Cornwall over the last eight years. All sightings in sea state two and below have been analysed accounting for bias introduced by the opportunistic platform. This analysis has identified several hotspots. Presence and absence in these areas is now being analysed in relation to: depth, slope, slope aspect, tide speed, tide direction, tide percentile, water temperature gradient, sea state and time of year. Preliminary results suggest, as found in other areas (IJsseldijk et al., 2015, Embling et al., 2009 and de Boer et al, 2014), that tidal regime is a key driver for both spatial and temporal presence.

It is hypothesised that tidal the turbulence created by tidal flow along the inner shelf between 20 metres depth to 50 metres depth triggers baroclinic waves. As these waves propagate south south west from the coast the mechanical forcing in the troughs focuses zooplankton attracting clupeid species. This creates hotspots of prey availability and attracts high aggregations of harbour porpoises.

In order to test this it is proposed to survey through a complete tide cycle during spring, mid percentile and neap tides using an acoustic Doppler profiler in order to vertically profile the water column properties.

De Boer MN, Simmonds MP, Reijnders PJH, Aarts G (2014) The influence of Topographic and Dynamic Cyclic Variables on the Distribution of Small Cetaceans in a Shallow Coastal System. *PLoS ONE* 9(1): e86331. doi:10.1371/journal.pone.0086331

Quantifying top-predators' use of hydrodynamic features in coastal regions; applied and ecological consequences.

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The construction of anthropogenic structures within coastal regions, in particular those associated with marine renewable energy installations, will change these environments physically through the alteration of hydrodynamic regimes and the removal of energy. Top-predators (cetaceans and seabirds) exploiting coastal regions often exploit hydrodynamic features (e.g. eddies, divergences/convergences, shear-lines) originating from interactions between tidally-driven currents and bathymetric features for foraging opportunities. These opportunities likely concern the aggregation of exploitable prey items at very predictable and particular times and places, reducing searching and capture costs and therefore increasing foraging efficiency. An increased understanding of precisely how top-predators exploit these hydrodynamic features, including the physical quantification and comparison of the features being used by these species, could allow the impacts of anthropogenic developments to be better predicted and mitigated. Comparisons among species and seasons, and across sites, would also offer insights into the mechanisms driving inter and intraspecific variations in foraging strategies.

To improve our understanding, observational surveys have been combined with computational models to quantify relationships between foraging activity and hydrodynamic features in coastal regions characterised by strong tidal currents in northern Scotland and Anglesey. Numerous associations were found between top-predators and hydrodynamic features. These associations revealed differences among species, and within species across seasons and sites, suggesting that foraging strategies were likely determined by a combination of fundamental behaviours and spatiotemporal variations in resource availability and requirements. Further work is concentrating on understanding how hydrodynamic features could directly influence prey behaviour and abundances within coastal regions - knowledge which could help explain the associations detected within these studies. In any case, results indicate that impacts from anthropogenic developments could be species, season and site-dependent, and this knowledge should be used when conceiving mitigation measures aiming to reduce the potential for negative impacts on top-predators.

Patchiness session 3: Posters Tue 17:00-19:00

Going deeper: Marine vertebrate hotspots enhance carbon flux to deep-sea scavengers

Nicholas D Higgs (Marine Institute, Plymouth University)

Hotspots of large marine vertebrates have the potential to play an important role in the coupling of pelagic and benthic ecosystems through the enhanced transfer of surface productivity to the deep ocean in the form of dead carcasses. Pelagic areas that concentrate large marine vertebrates will have an increased flux of carbon to deep waters because larger animals have lower rates of predation than smaller ones, so a higher proportion of their biomass is exported to the deep sea rather than recycled in the pelagic food chain. This provides a bounty to food poor deep-sea benthic communities and there is evidence that these large food-falls play a significant role in structuring benthic communities. Here, I present evidence of this phenomenon in the form of an elasmobranch carcass aggregation on the deep seafloor below a region of high primary productivity on the Angola margin and discuss the importance of marine vertebrates as food for deep-sea scavengers.

Behaviour matters: A coupled bio-physical model to assess the dispersal and potential population connectivity patterns of deep-sea methane seep larvae

Doreen M. McVeigh [Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University], David B. Eggleston [Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University], Ruoying He [Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University], Austin Todd [Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University] Craig M. Young [Oregon Institute of Marine Biology, University of Oregon]

Since their discovery, deep-sea chemosynthetic ecosystems have been novel systems within which to test the generality of paradigms developed for shallow-water species. This study explored the roles of larval behaviour, pelagic larval duration (PLD), and putative spawning locations on potential population connectivity of methane seep invertebrates. The goal was to assess the dispersal trajectories of the polycheate, *Lamellibrachia luymesi*, gastropod, *Bathynerita naticoidea*, and crustacean, *Alvinocaris muricola* among seep-sites in the Gulf of Mexico (GOM) and Western Atlantic Ocean (WAO) using a coupled bio-physical model. Larval particles were programmed with species-specific PLDs and swimming behaviours that best matched empirical data, and released into a flow field that accurately characterises climatological conditions at ~7-kilometer horizontal resolution. While there was variation in average dispersal distance, the overall trend was consistent, with the greatest dispersal observed for *A. muricola*, followed by *B. naticoidea*, and *L. luymesi*. *L. luymesi* mean particle distance travelled was significantly higher when released from western GOM (274 km ± 0.823), followed by WAO (213 km ± 0.823), and eastern GOM (171 km ± 0.823). *B. naticoidea* mean particle distance travelled was significantly higher when released from western GOM (670 km ± 1.27), followed by WAO (287 km ± 1.27), northern WAO (286 km ± 1.27), central GOM (241 km ± 0.15), and western GOM (268 km ± 1.27). *A. muricola* mean particle distance travelled was significantly higher when released from eastern GOM (854 km ± 2.53), followed by central GOM (846 km ± 1.27), western GOM (757 km ± 1.27), WAO (616 km ± 1.27), and northern WAO (612 km ± 1.27). This integrative approach of hydrodynamic modelling and simulated behaviour advances our understanding of the factors regulating dispersal throughout the ocean, and the combined effects of oceanographic conditions and larval behaviour on potential connectivity of methane seep species in the Gulf of Mexico and Atlantic Ocean.

Effect of environmental boundaries on the population structure of marine predators

Daniel M Moore (Durham University), Oscar Gaggiotti (University of St. Andrews), Per Berggren (Newcastle University), Rus Hoelzel (Durham University)

A fundamental problem in biology is to understand the drivers and mechanisms for the formation of genetic differentiation, population structure and eventual speciation.This problem is often even more challenging in the marine environment where physical barriers to movement and gene flow are often weak or non-existing, yet many marine species still exhibit complicated population structures.

The Siculo-Tunisian front, off the South coast of Italy, is an area of great marine environmental differentiation with either side displaying different underwater topology, water temperature, current direction and depth parameters. Given that previous studies have shown many marine species to exhibit genetic breaks across this boundary, the Siculo-Tunisian front presents an ideal study system for examining the environmental drivers of population structuring.

We will examine the bottlenose dolphin *Tursiops truncatus* in this region as recent genetic evidence shows clear population divides between the East and West Mediterranean basins, focused on the Siculo-Tunisian front. Given that *T. truncatus* is known to be a highly social species with strong familial bonds and prey specialization re-enforced by cultural learning we will also examine the Yellowmouth Barracuda *Sphyraena viridensis*, a non-social fish, in order to extricate the important environmental factors only.

Utilizing a blend of Next Generation Sequencing (NGS) and Stable Isotope Analysis (SIA) combined with secondary environmental data and analyzed using novel Bayesian modelling approaches this work hopes to shed light on the impact of physical and biological oceanographic processes on the population structure of marine vertebrates.