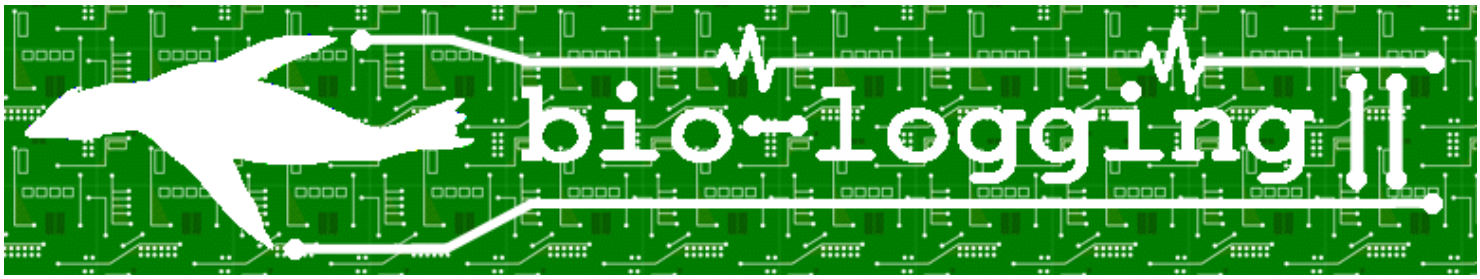
Book of Abstracts



Bio-logging techniques to explore the intersection of behaviour, physiology and ecology

2nd International Bio-logging Science Symposium

June 13 – 16, 2005

Sea Mammal Research Unit
University of St Andrews, Scotland

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Programme and Abstracts

Organizing Committee:
Drs. Martin Biuw, Sascha Hooker, Bernie McConnell, Patrick Miller, Carol Sparling

Secretariat:
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INFORMATION

Welcome to the Biologging II Symposium and to St Andrews! We hope that you will find the Symposium stimulating and fun – and that you will have a chance to explore the beautiful University Town of St Andrews.

Accomodation and Meals

For those who have registered for these, accommodation and meals are provided in New Hall (see map opposite). Mealtimes are 7:30 – 8:30am for breakfast, 12:30 – 1:15pm for lunch, and 6:30 – 7:15pm for dinner. Your name badge will indicate which meals you have paid for. Optional meal costs must be paid for in advance at the registration desk.

Symposium Venue

The Symposium itself is just five minutes walk away at the Chemistry Building (see map opposite). Oral sessions will be held in lecture theatre A. Posters will be displayed in the coffee room. Coffee and Tea will be served (in the coffee room) between 10:20 – 10:50am and between 3:20 – 3:50pm. Vendor materials will be on display in both the coffee room and the main foyer.

Oral Presentations

Would those giving an oral presentation please provide an Organiser with a copy of their presentation the day before. If you are talking on Monday, please provide your presentation at Registration on the Sunday. There will be a number of PCs available in the Chemistry Building for previewing presentations. Presentations will be strictly limited to 15 minutes, with 5 minutes for questions.

Poster Presentations and Vendor Stalls

The Chemistry Building will be open from 4:30 to 6:30 pm and between 7:30 and 9:30 pm on Sunday for setting up poster displays and vendor stalls.

Icebreaker

The Icebreaker will be held at 7pm on Monday 13th June at the St Andrews Aquarium. You will need to present your ticket in order to gain admittance to this event. There will be a cash bar.

Banquet

The Banquet will be held at 7pm on Thursday 16th June at Lower College Hall. This is a short walk (10-15 mins) from the symposium venue. You will need to present your ticket in order to gain admittance to this event. There will be a cash bar.

Ceilidh

The Ceilidh (Scottish traditional dance) will be held from 9:00 – 11:00 pm at Upper College Hall. This is immediately above the location for the symposium banquet (a short 10-15 min walk from the symposium venue). There will be a cash bar at this event. All attendees and guests are welcome (free).

Proceedings

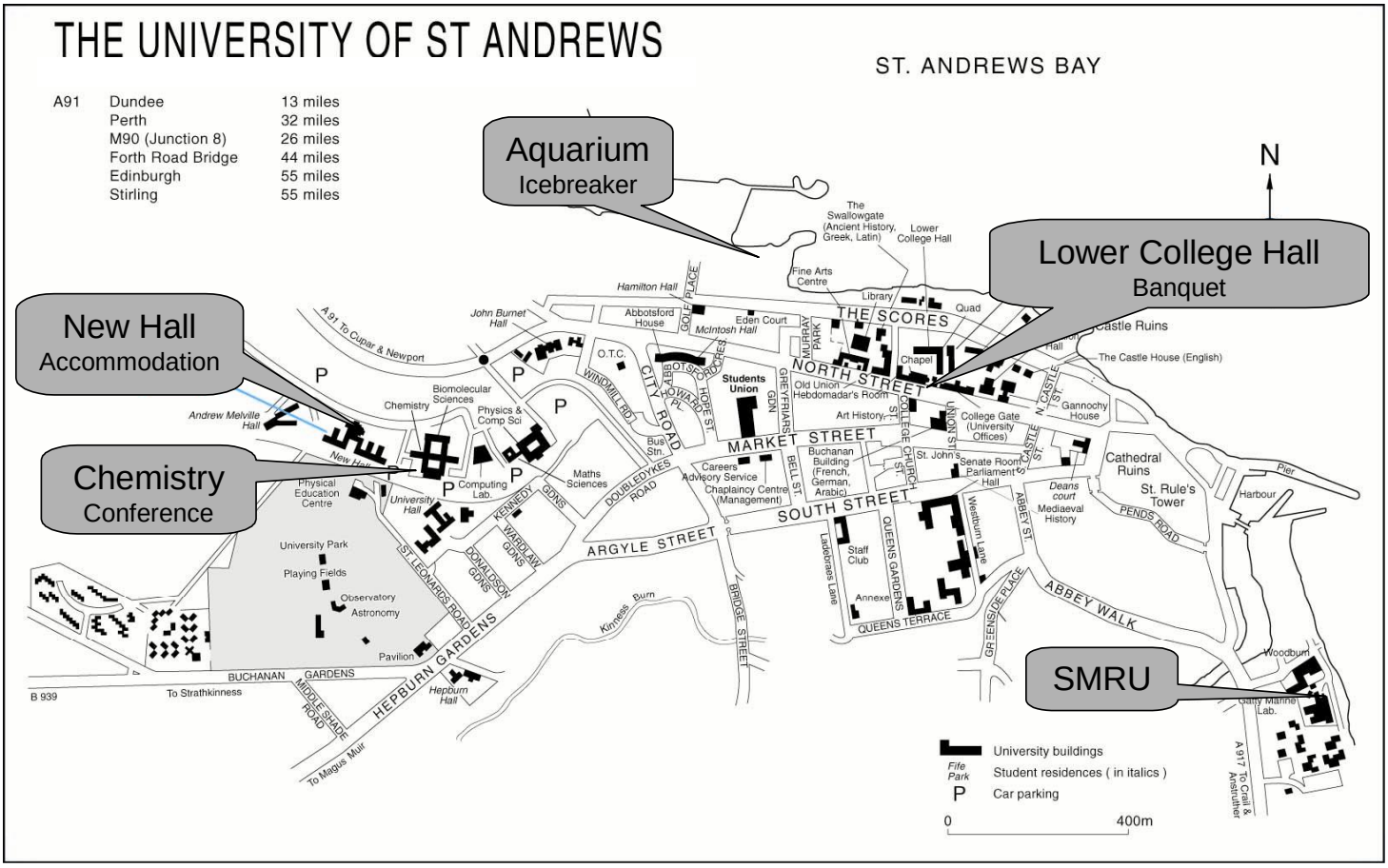
Proceedings of the 2nd International Symposium on Biologging Science will be published in *Deep-Sea Research II*. Submitted papers will follow a peer-review process. Deadline for submission of papers will be August 31 2005. Please check the website for instructions to contributors.

If you have any problems during the symposium, please feel free to contact any of the Organisers or Student Helpers who should always be available at the symposium desk.

Best wishes

Biologging II Organising Committee

Martin Biuw, Sascha Hooker, Bernie McConnell, Patrick Miller, Carol Sparling
Sea Mammal Research Unit, University of St Andrews



TIMETABLE

	Monday 13 June	Tuesday 14 June	Wednesday 15 June	Thursday 16 June
8.45	Introduction	Plenary 2	Plenary 3	Plenary 4
9.05	Plenary 1			
9.20-9.40		Oral session	Oral session	Oral session
9.40-10.00	Oral session			
10.00-10.20				
10.20-10.50	**BREAK**			
11.00-11.20	Oral session	Oral session	Oral session	Oral session
11.20-11.40				
11.40-12.00				
12.00-12.20				
12.30-1.15	**LUNCH**			
2.20-2.40	Oral session	Oral session	Oral session	Oral session
2.40-3.00				
3.00-3.20				
3.20-3.50	**BREAK**			
3.50-4.10	Oral session	Oral session	Oral session	Plenary 5
4.10-4.30				
4.30-4.50		POSTER SESSION	POSTER SESSION	Discussion
4.50-5.10				
5.10-5.30				Closing remarks
5.30–6.00				
6.30-7.15		**DINNER**	**DINNER**	
7.00	**ICEBREAKER**			**BANQUET**
8.00		Evening session: Argos	Evening session: Best Practice	
9.00				**CEILIDH**
10.00				

PROGRAMME

MONDAY 13 June

Chair: Martin Biuw

08:45 Opening Remarks by Prof. I. L. Boyd, Director of the Sea Mammal Research Unit
09:05 **M. A. Fedak - Plenary talk: "Ecologging": using biologgers to link behaviour from mobile marine animals to their dynamic environment**
09:40 **C. R. McMahon et al. -** Getting it right: how accurate temperatures from animal borne sensors can contribute to global climate monitoring
10:00 **A. Takahashi et al. -** Thermocline shapes diving behaviour of thick-billed murres

10:20 COFFEE BREAK

Chair: Henri Weimerskirsch

11:00 **D. Costa et al. -** Tagging of Pacific Pelagics: using electronic tags to discover hotspots in the pelagic realm
11:20 **D. Pinaud et al. -** Using first-passage time analysis to assess the search scales of satellite-tracked seabirds
11:40 **F. Bailleul et al. -** Foraging in southern ocean by southern elephant seals: importance of Antarctic sea ice
12:00 **B. D. Best et al. -** Analysis of telemetry data within a dynamic oceanographic context

12:30 LUNCH

Chair: Dan Costa

14:20 **S. Garthe et al.** - Foraging habitat selection by northern gannets preying on cold-water fish in the Low Arctic
14:40 **B. J. Godley et al. -** Contrasting migration and over-wintering strategies in sympatric marine turtle species in the Mediterranean
15:00 **E. Hunter et al. -** Linking natural and electronic data records to determine the lifetime movements of fish

15:20 TEA BREAK

Chair: Yan Ropert-Coudert

15:50 **M. T. Tinker et al. -** Individual dietary specialization and dive behaviour in the California sea otter: using archival time-depth data to detect alternative foraging strategies
16:10 **A. Lescroel et al. -** Microgeographic variation in the foraging behaviour of two coastal seabirds
16:30 **F. Daunt et al. -** Wintering foraging strategies of European shags from long-term logger deployments: impacts on survival and future breeding
16:50 **C. E. Kuhn et al. -** Examination of the foraging behaviour of the California sea lion: population differences and individual foraging strategies
17:10 **I. Staniland et al. -** Telemetry reveals the pre-breeding foraging of male Antarctic fur seals

19:00 ICEBREAKER (St Andrews Aquarium)

TUESDAY 14 June

Chair: Sascha Hooker

08:45 **M. P. Johnson - Plenary talk: 'Make me one with everything' Appropriate technology for holographic biologging**
09:20 **R. D. Hill et al. -** The life history transmitter: a new concept for long-term monitoring of oceanic vertebrates
09:40 **K. Holland et al. -** Towards development of "ecology tags" for large pelagic fishes
10:00 **M. Horning et al. -** Autonomic computing in bio-logging

10:20 COFFEE BREAK

Chair: Mike Fedak

11:00 **B. Mate et al. -** The evolution of an implantable ARGOS satellite-monitored radio tag for the year-round monitoring of large whale movements and dive habits
11:20 **T. Mattern et al. -** How to get the most (or anything) out of GPS loggers: a case study with Snares penguins
11:40 **J. D. Metcalfe et al. -** All washed up: a "pop-up and drift" approach to data recovery from archival tags on basking sharks using GSM mobile phone technology
12:00 **R. Virtue et al. -** Energy efficient protocols for subcutaneous RF identification tags in marine mammals at remote sites

12:30 LUNCH

Chair: Bernie McConnell

14:20 **T. Patterson et al. -** Analysis of marine telemetry data using hidden Markov models
14:40 **J. Matthiopoulos et al. -** Estimating animal space use and environmental preference from telemetry data
15:00 **S. Brasseur et al. -** Clustering for more insight in summary data from satellite tags

15:20 TEA BREAK

Chair: Bernie McConnell

15:50 **P. Gaspar et al. -** Coupling satellite oceanography and satellite tracking to analyze navigation skills of leatherback turtles
16:10 **P. W. Robinson et al. -** Comparison of indirect measures of foraging location and extent via remote tracking

16:30 POSTER SESSION: Ecology, Technology and Analysis, and Physiology

18:30 DINNER

20:00 **Evening Session: Argos – Understanding Error**
(Organiser: Bernie McConnell)

WEDNESDAY 15 June

Chair: Patrick Miller

08:45 **H. Weimerskirsch - Plenary talk: Foraging behaviour and environmental conditions in seabirds**
09:20 **M. S. Coyne et al. -** Building capacity to manage, analyse and publicly share marine vertebrate tracking data and integrate movements with oceanographic data
09:40 **G. Müller et al. -** From form to function - determination of diving behaviour on the scale of individual dives
10:00 **R. P. Wilson et al. -** All at sea with animal tracks and dead-reckoning solutions for the resolution of movement

10:20 COFFEE BREAK

Chair: Katsufumi Sato

11:00 **R. W. Davis et al. -** Diving behaviour of Weddell seals based on three-dimensional movements paired with video recorded observations
11:20 **L. A. Fuiman et al. -** Hunting behaviour of Weddell seals (*Leptonychotes weddellii*) diving from an isolated hole in McMurdo Sound, Antarctica
11:40 **C. A. Bost et al. -** Feeding behaviour of penguins detected by oesophageal temperature: a three dimensional approach
12:00 **N. Liebsch et al. -** Mouthing off about fish capture: jaw movements in pinnipeds reveal the real secrets of ingestion

12:30 LUNCH

Chair: Mark Johnson

14:20 **Y. Mitani et al. -** Stroking pattern and body angle in diving elephant seals
14:40 **K. Sato et al. -** Optimal stroke cycle frequency according to the body size of swimming animals
15:00 **Y. Hirose et al. -** Activities during foraging trip of streaked shearwaters: insights yielded by using acceleration data loggers

15:20 TEA BREAK

Chair: Mark Johnson

15:50 **Y. Watanabe et al. -** Blubber and buoyancy in Baikal seals *Phoca sibrica*, a marine mammal in freshwater
16:10 **T. Akamatsu et al.** - Swimming porpoises acoustically inspect areas that lie ahead in advance

16:30 POSTER SESSION: Behaviour

18:30 DINNER

20:00 **Evening Session: Search for consensus on best practice in biologging science. (Organiser: Patrick Miller; Chair: Rory Wilson)**

THURSDAY 16 June

Chair: Carol Sparling

08:45 **P. J. Ponganis - Plenary talk: Biologging of physiological parameters in higher marine vertebrates**
09:20 **A. Schmidt et al. -** Alternative thermoregulatory strategies in king penguins at sea: physiological adjustments and energetics in relation with sustained diving activity versus interbout resting
09:40 **Y. Handrich et al. -** Thermoregulation in the diving king penguin. A complex feature: what is known and what is unexplained.
10:00 **J. A. Green et al. -** Year-round behaviour and energetics of Macaroni penguins

10:20 COFFEE BREAK

Chair: Dave Thompson

11:00 **J. U. Meir et al. -** Emperor penguin heart rate profiles during dives, surface intervals and rest periods: the value of digital ECG records
11:20 **T. K. Stockard et al. -** Use of an indwelling oxygen electrode probe to measure air sac Po_2 in diving emperor penguins
11:40 **S. L. H. Teo et al. -** Movement patterns, diving behaviour and thermal biology of Atlantic bluefin tuna on their spawning grounds
12:00 **D. J. McCafferty et al. -** Using infra red thermometry to examine surface effects of instrument attachment on grey seals (*Halichoerus grypus*)

12:30 LUNCH

Chair: Rory Wilson

14:20 **J. Hennicke et al. -** Foraging ecology of the endangered Abbott's booby - first data for an effective protection
14:40 **R. A. Phillips et al. -** Wintering distribution and activity patterns of white-chinned petrels from South Georgia: individual strategies and implications for conservation
15:00 **C. McClellan et al. -** Using telemetry to reduce the by-catch of long-lived marine vertebrates

15:20 TEA BREAK

Chair: Bernie McConnell

15:50 **P. J. Butler - Plenary talk: Future directions and challenges for biologging sciences**
16:30 Discussion
17:10 Closing Remarks

19:00 BANQUET (Lower College Hall)
21:00 CEILIDH (Upper College Hall)

POSTER PRESENTATIONS

13-16 June: All posters will be displayed throughout the symposium

Ecology – poster session Tuesday 14 June 16:30 – 18:00

P-01 **J.-B. Charrassin et al.** - Elephant seal-borne miniaturized CTDs provide an unprecedented number of temperature and salinity profiles for the poorly known Southern Indian Ocean.
P-02 **S. E. Simmons et al.** - Time and space, the final frontiers? Foraging behaviour of northern elephant seals (*Mirounga angustirostris*) related to oceanographic features at different spatial and temporal scales
P-03 **S. L. Robinson et al.** - The post-breeding distribution of adult and juvenile Antarctic fur seals (*A. gazella*) from South Georgia
P-04 **J. van den Hoff et al.** - Diving behaviour of male and female southern elephant seals

Technology and Analysis – poster session Tuesday 14 June 16:30 – 18:00

P-05 **A. Chiaradia et al.** - The effect of logger size and position on the diving performance of the smallest penguin (*Eudyptula minor*)
P-06 **P. Ekstrom** - Error measures for template-fit geolocation based on light
P-07 **S. Elwen** - Investigating the use of GSM mobile phone and GPS to track a coastal odontocete, Heaviside's dolphin, a preliminary report
P-08 **S. Frydman** - Animal tracking spatial environment analyser (AT SEA)
P-09 **J. Y. Georges et al.** - Assessing actual movements of ARGOS tracked marine animals: a novel approach
P-10 **A. Myers et al.** - Relaying dive profiles for marine animals via the ARGOS system
P-11 **T. Norris** - MANTA: The marine animal tracking apparatus
P-12 **V. V. Pavlov et al.** - A new approach to tag design in dolphins telemetry
P-13 **M. J. Rehberg et al.** - Objective classification of dive shapes from satellite relay data recorders
P-14 **K. M. Schaefer et al.** - Comparative performance of current generation geolocating archival tags

Physiology – poster session Tuesday 14 June 16:30 – 18:00

P-15 **P. B. Frappell et al.** - Factors influencing the prediction of field-metabolic rate in a reptile
P-16 **C. Gilbert et al**. - Energy savings and parental effort in breeding Adelie penguins
P-17 **T. Kitagawa et al.** - Physiological thermoregulation assisted by thermal inertia in gigantic ectothermic fish
P-18 **T. Kojima et al.** - Spectral characteristics in heart rate variability as an index of physiological condition of fish attached micro data logger

Behaviour – poster session Wednesday 15 June 16:30 – 18:00

P-19 **K. Aoki et al.** - Differences in diving behavior of sperm whales between two areas, off Kii Peninsula and off Bonin Islands, Japan
P-20 **A. Bunce** - Individual foraging strategies in Australasian gannets (*Morus serrator*)
P-21 **K. A. Call et al.** - Attendance patterns of juvenile Steller sea lions (*Eumetopias jubatus*) derived from satellite dive recorders (SDR's): a comparison between declining and increasing populations
P-22 **N. Ebihara et al.** - Seasonal migration and diving behaviour of Caspian seals, *Phoca caspica*
P-23 **Y. Goimier et al.** - Fine-scale analysis of acceleration and flipper strokes to assess locomotor work on different scales of the foraging trip. Case of the king penguin.

P-24 **J. Hassrick et al.** - Swimming speed and foraging strategies of northern elephant seals, *Mirounga angustirostris*
P-25 **E. Hunter et al.** - Seasonal migration of Thornback rays and implications for closure management
P-26 **A. Kato et al.** - Flipper or foot: which works best against buoyancy?
P-27 **R. Kawabe et al.** - Diel movements of the Japanese flounder, *Paralichthys olivaceus*: time or energy minimization?
P-28 **T. Kudo et al.** - Homing behaviour of chum salmon from coast to river in Otsuchi Bay area revealed by newly developed temperature/depth/acceleration/geomagnetic micro data logger
P-29 **P. J. O. Miller et al.** - Short-term effects of suction cup tagging on the deep-diving behaviour of sperm whales.
P-30 **H. Mitamura et al.** - Vertical movement of Mekong giant catfish *Pangasianodon gigas* limited by the hypoxic waters in the reservoir
P-31 **N. Miyazaki et al.** - Bio-logging science research in Ocean Research Institute, the University of Tokyo, Japan
P-32 **Y. Mori et al.** - Estimates of prey richness using diving profiles in Weddell seals: comparison with the estimates using image data
P-33 **Y. Naito et al.** - Large amount of visual image may support our understanding on underwater lives and environment
P-34 **F. C. Neat et al.** - Residency and depth movements of a coastal group of Atlantic cod (*Gadus morhua* L.)
P-35 **Y. Ropert-Coudert et al.** - Heart rate of foraging Cape gannets
P-36 **K. Suzuki et al.** - Monitoring on valve movement of the pen shell under natural condition
P-37 **K. Wang et al.** - A passive acoustical monitoring method applied to observation and abundance estimation of finless porpoises
P-38 **Y. Watanuki et al.** - Swim speed and regulation of stroke in wing-propelling divers: a comparison among alcids and a penguin
P-39 **M. J. Weise et al.** - Dispersal and diving behaviour of male California sea lion (*Zalophus californianus*)
P-40 **K. Yoda et al.** - Development of flying and plunging performance in the juvenile brown booby

EVENING SESSIONS

Tuesday 14 June.

Argos - Understanding Error

Organiser: Bernie McConnell (bm8@st-andrews.ac.uk), NERC Sea Mammal Research Unit.

Most studies that use Argos to track marine animals end up with the bulk of their fixes being "un-guaranteed" – that is location qualities 0, A or B. In addition the fixes may be infrequent and irregular in time. How do we estimate the real track from such noisy data?

First it is sensible to consider the source of error. How does Argos actually estimate location and how can estimate uncertainty be best relayed to the user? Also, is each location estimate independent of all others? To address these and other questions there will be a technical presentation by an Argos representative.

How do we then incorporate such uncertainty into movement models, and how do we test such models? Here we invite brief presentations of completed, current or future work. Each presentation is limited to 10 minutes. The objective of this workshop is to encourage both communication between Argos and the user community and collaboration in the modelling of movement data. A second objective is to finish the workshop before the local hostelries close.

Wednesday 15 June.

Search for consensus: best-practice (minimizing impact) in bio-logging science

Organiser: Patrick Miller (pm29@st-andrews.ac.uk), Sea Mammal Research Unit
Chair: Rory Wilson

Two inter-twined questions arise when we attach devices to animals. The first is a pure science concern: how might the device itself alter the behavior/phenomenon we wish to study? For example, it has been shown that attaching devices to measure speed itself influences speed. The second concern is the broader ethical consideration of how attachment of a logging device might affect animal well-being. It may be the role of a biologging society to identify basic principles that should be followed, and to provide resources and information to help others conduct biologging science following those best-practice principles.

As scientists we are bound by common principles of scientific method, but each individual may have different personal thresholds of what might be acceptable biologging practice. The goal of this evening session is to identify a set of best-practice principles on which we have consensus, and discuss why consensus may be more difficult with other potential principles. Our plan includes a survey before the session on nominated best-practice principles which will provide a focal point for discussions. These range from obvious to controversial principles. A few examples:
-Animal handling procedures should follow local law.
-A specific analysis of the potential effect of the biologging device on the measured parameters should be undertaken before publication.
-Techniques for device attachment should be openly shared to avoid new-comers having to "re-invent" the wheel and unnecessarily disturb research subjects.

During the symposium, but before the session, each attendee PLEASE fill out an **anonymous** survey sheet rating how acceptable you judge each potential practice principle to be for your work. Surveys will be collected and results compiled before the start of the evening session.

During the session, we will present the results of the survey, including response statistics. Potential principles will then be ranked from 'most' to 'least' acceptable, and considered in that order. Our hope is to move quickly through the acceptable principles to be able to spend the bulk of the session discussing potential principles where consensus does not exist. Please be prepared to speak up for principles that you consider important.

Following the session, we will produce a report containing the results of the survey for each potential best-practice principle, and discuss the issues involved those on which consensus was not reached. All reporting will be 100% anonymous. Finally, we will consider what role, if any, a biologging science society might have to promulgate best-practice principles.

ABSTRACTS

ORAL PRESENTATIONS

MONDAY 13 June

Mon 09:05 – 09:35

Plenary talk: "Ecologging": using biologgers to link behaviour from mobile marine animals to their dynamic environment

Fedak, Mike (maf3@st-andrews.ac.uk)
NERC Sea Mammal Research Unit, University of St Andrews

Having developed the means to effectively track the movements of larger marine creatures, we biologists understandably wanted to be able describe their behaviour in greater detail and do this in relation to both their immediate environment and in the context of the range of environmental conditions potentially available to them. We now often want to answer questions about what features of the environment are important to the animals, how they locate these places and what happens if the distribution or quality of such places change. These questions arise as we try to understand the ecology of these animals and how the environment shapes their life histories. Approaching these questions is a far more complex task than that of quantitatively describing their location, itself not a simple one. The dynamic and unpredictable quality of the marine environment combined with the often remote locations used by animals means that a whole range of new data collection, analysis and modelling tools need to be created that document the immediate environment of the animals in a broader synoptic context. These are required to demonstrate environmental associations and monitor the animal's success in exploiting their surrounding for growth and reproduction. This process of methodological development is underway in many laboratories world-wide. Progress is swift but we still have a long way to go on all fronts. It is arguable that the fastest and most dramatic progress has been made in cooperative groups where experience across the full range of disciplines involved, such as biology, engineering, oceanography and data analysis, can be combined. In this talk I will bring together some approaches and experiences that exemplify the range of instruments, measurements and analytical tools required, and suggest avenues for work that I think may prove particularly productive in the future, particularly with regard to how they can provide synergies between disciplines.

Mon 09:40 – 10:00

Getting it right: how accurate temperatures from animal borne sensors can contribute to global climate monitoring

McMahon, Clive R. (C.R.McMahon@swansea.ac.uk), Graeme C. Hays
Institute of Environmental Sustainability, School of Biological Sciences, University of Wales Swansea, Singleton Park , Swansea SA2 8PP

Sophisticated animal borne sensors allow water temperature to be monitored across a range of depths, over entire ocean basins and over long periods and so may potentially play a key role in assessing global climate change. However, for temperature information collected in this manner to be useful to climatologists the data need to be accurate. The long-term (many months after deployment) accuracy of animal-borne sensors is not known from such deployments. Here we compared the ocean temperatures collected by leatherback turtles in the Atlantic Ocean and an *in situ* network of ocean floats and could find no systematic errors that could be ascribed to sensor instability, thus satisfying the requirements set by climatologists. Moreover, these accurate temperature recordings are also important for studying the conservation biology of turtles. The temperatures recorded by the SRDLs on the turtles has allowed us to accurately describe the thermal habitat of this apex predator in the Atlantic Ocean and to assess how changing climates may affect the distribution of this endangered animal and therefore provide information that contributes to the conservation and management of these turtles.

Mon 10:00 – 10:20

Thermocline shapes diving behaviour of thick-billed murres

Takahashi, A. (1) (atak@fish.hokudai.ac.jp), Matsumoto, K. (1), Hunt, G. (2), Shultz, M. (3), Kitaysky, A. (3), Sato, K. (4), Watanuki, Y. (1)
(1)Graduate School of Fisheries Sciences, Hokkaido University, Japan.
(2)Department of Ecology and Evolutionary Biology, University of California, Irvine, USA.

(3)Institute of Arctic Biology, University of Alaska Fairbanks, USA.
(4)Ocean Research Institute, The University of Tokyo, Japan.

Linking diving and foraging behaviour of small seabirds with fine-scale characteristics of water masses has been challenging largely due to technological constraints. We examined the diving behaviour of 12 chick-rearing thick-billed murres (*Uria lomvia*) at St. George Island, Eastern Bering Sea, in relation to sea surface temperature (SST) and thermocline depth that were recorded by ventrally-attached depth-temperature-acceleration data loggers (16g; Little Leonardo, Tokyo). Our initial results from summer 2004 showed that murres utilized various water masses, ranging from well-mixed water (SST 7-9 C, near the island) to well-stratified water (SST 9-12 C, relatively far from the island). Murres dived deeper (modal depth: 70-80m) in the mixed water mass, whereas dives were shallower (modal depth: 20-30m) and to just below the thermocline depth in the stratified water mass. In the stratified water mass, murres dived deeper, to below the thermocline, during the last dive bout in a foraging trip, when they were presumably foraging for a chick meal rather than foraging for themselves. We suggest that the thermocline is important in shaping depth utilization of thick-billed murres, possibly through its effect on the vertical distribution of both zooplankton and fish prey.

Mon 10:20 – 10:40
Tagging of Pacific Pelagics: using electronic tags to discover hotspots in the pelagic realm

Costa, D.P. (1) (costa@biology.ucsc.edu), Block, B.H. (2) Bograd, S. (3) Kochevar, R. (4) and the TOPP Science Team
(1)Long Marine Lab, UC Santa Cruz, CA
(2)Stanford University, Pacific Grove CA
(3)NOAA/NMFS Pacific Fisheries Environmental Laboratory, Pacific Grove, CA
(4)Monterey Bay Aquarium, Monterey CA.

In an effort to understand and locate biological hotspots in the North Pacific Ocean, the Tagging of Pacific Pelagics program is using biologging technology to simultaneously map the location of marine vertebrates including sharks, tuna, albatrosses, seals and whales. Hot spots are regions of high biological activity where linkages occur between physical forcing, primary production, secondary consumers and top pelagic predators. Although it is generally accepted that these hotspots occur and are important, surprisingly little is known about these congregating spots for marine organisms in the open ocean. Our lack of understanding of the aggregating forces in the pelagic ocean ecosystem stems largely from limitations of available technology. Prior studies have focused on single species tracking and few have attempted to examine interactions among top pelagic species. TOPP is coupling electronic tagging data with satellite remote sensing technologies to simultaneously map the movements of diverse pelagic species and link their movements to oceanographic processes. To date we have tagged and tracked mako, salmon and white sharks, elephant seals, bluefin and yellowfin tuna, black-footed and Laysan albatross, California sea lions and leatherback sea turtles. Preliminary analysis indicates that frontal features associated with the North Pacific Transition zone and the California Current comprise a region of common habitat utilization for many of these species.

Mon 11:20 – 11:40
Using first-passage time analysis to assess the search scales of satellite-tracked seabirds

Pinaud, D. (puffin@cebc.cnrs.fr), Weimerskirch, H.
CNRS-Centre d'Etudes Biologiques de Chizé, 79360 Villiers-en-bois, France

Oceans are assumed to be very variable habitats, where patchy resources are distributed over a large range of spatial scales. We expect that long-range predators like albatrosses change their foraging movement pattern according to prey density and increase their search effort in high profitability zones. Finding these foraging areas at the correct scales of interaction is an important clue to understand foraging strategies of seabirds in relation to their environment.
A new analysis described by Fauchald & Tveraa (2003, *Ecology*) allows to assess search radius and high search effort zones at the correct scale. We illustrated this technique on 121 individual satellite tracking trips of 7 species of great Procellariiforms in south Indian Ocean, in order to test if foraging strategies and scales of interaction depend of species or environment.
110 of 121 birds adopted an Area-Restricted Search (ARS), and search radius was different between species. Discriminant Analysis on trip parameters indicated a segregation among species along a distance gradient. These differences are primary explained by the species factor but an influence of primary productivity was also detected. Once taking into account this species effect, a significant influence of oceanographic domains was noted on search radius.

Our study reveals that differences in foraging strategies of these seabirds are primarily due to species, but marine habitat plays also an important role.

Mon 11:40 – 12:00
Foraging in southern ocean by southern elephant seals: importance of Antarctic sea ice

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Southern elephant seals (Mirounga leonina) have a circumpolar distribution and breed on subantarctic Islands. In 2002-2004, five breeding females and seven juvenile males were fitted with SMRU ARGOS-CTD transmitters at Kerguelen Island, after they completed their moult. Over 55000 individual dive records collected were analysed. Six distinct dive types were described on the basis of parameters such as ascent and descent rates and the general shape of the dive profile. The changes in dive types, in drift rate in drift dives and in descent speed through the foraging trip were used to assess the spatial distribution of the foraging activity and foraging success. The CTD profiles obtained were used to characterize the oceanographic context of its foraging activity. Favorable foraging areas were associated with the Polar front for one female, while 10 individuals concentrated their foraging activity off and on the Antarctic shelf.
From April to August as sea ice extended, males and females adopted different foraging behavior. Both sexes were able to travel across heavy ice concentration, with one male crossing up to 600 km of sea-ice in less than 8 days to reach the Antarctic plateau in winter. However males remained on the continental shelf in 80 to 100 % ice concentration, while females moved northward with the extending sea ice and foraged in the marginal ice zone. Males favored Antarctic benthic foraging behavior and exhibited inter-trip fidelity to their foraging grounds, females targeted the marginal sea-ice zone and frontal structure. We hypothesized that differences in breeding constraint could explain these differences with females minimizing the risk of ice entrapment, which could prevent them to reach their breeding colony in time to give birth in contrast to the non breeding juvenile males. This study shows that Kerguelen elephant seal are Antarctic seals breeding on a subantarctic Island.

Mon 12:00 – 12:20
Analysis of telemetry data within a dynamic oceanographic context

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Our ability to model the individual habitat preferences of marine animals with telemetry data has been limited by the complexities of describing an ephemeral and dynamic seascape. We propose a new analytical framework for filtering, processing and analyzing telemetry data which allows for quantitative analysis of habitat preference within a dynamic oceanographic environment. Telemetry locations are filtered based on plausible animal travel speeds after taking account of the direction and velocity of ocean currents. Potential behavioral states along the animal's path of movement (i.e. migration vs. area restricted searching) are then identified based on variation in headings, turning angles and movement rates. Behavioral states, and transitions from one state to the next, are then examined with respect to features of this dynamic environment including both primary (e.g. bathymetry, sea surface temperature, chlorophyll concentration) and derived (distance to fronts, shelf breaks and shoreline) oceanographic products. Additionally, the telemetry tracks can be dissected to calculate the amount of time the tracked animals spent within different oceanic habitats (e.g., bathymetric domains, water masses). This facilitates the statistical analysis of animal preferences, by contrasting the use and availability of different habitat types. We describe construction of a toolbox built with Python and ArcGIS that automates the retrieval and geo-processing of these derived products. These analysis will provide the necessary data for a state-space model to explore the interactions between animal movement and environmental conditions.

Mon 14:20 – 14:40
Foraging habitat selection by northern gannets preying on cold-water fish in the Low Arctic

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Knowledge on the vertical and horizontal distribution of prey is essential for an understanding of the foraging patterns of marine predators. In a study on the northeastern shelf area of Newfoundland, eastern Canada, chick-rearing Northern Gannets (*Morus bassanus*) were equipped with GPS data loggers with high-speed temperature and pressure sensors . In parallel, a meso-scale survey of the horizontal and vertical distributions of Capelin (*Mallotus villosus*), the gannets staple prey, and of oceanographic parameters was conducted from research and commercial fishing vessels. Capelin were mainly concentrated in shallow water near the coast. Although breeding more than 50 km offshore, gannets foraged at coastal sites to exploit capelin shoals. By integrating meso-scale data on prey distribution and oceanography from vessel surveys with fine-scale data on behaviour, dive depths and water temperature from the data loggers, detailed insights on foraging habitat selection and foraging tactics of this avian predator was obtained.

Mon 14:40 – 15:00
Contrasting migration and over-wintering strategies in sympatric marine turtle species in the Mediterranean

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Adult marine turtles typically reproduce at distant breeding sites at variable intervals. For many species and populations, virtually nothing is known about the spatial distribution of adult foraging range, migratory routes taken and submergence behaviour during migration and at the feeding grounds. Here we present an overview of the results of satellite tracking of a relatively large number of two species from the same breeding sites in Northern Cyprus (n=9 loggerhead turtles *Caretta caretta* and n=11 Green turtles *Chelonia mydas*). The detailed reproductive history of many individuals is known, and we present the first ever investigation of the possible role of migratory distance in the modulation of breeding effort and frequency in this group. We track 6 individuals for two successive migrations to compare routes taken and show foraging site fidelity in both species. In addition, as a result of the deployment of SMRU SLDR's on 3 individuals, we are able to contrast the markedly different diving behaviour during over-wintering of the carnivorous loggerhead turtle with that of the herbivorous green turtle and for the first time demonstrate brumation dives. Using the Satellite Tracking and Analysis Tool (http://www.seaturtle.org/stat/) all spatial movements are contextualised with a wide range of static and dynamic oceanographic data layers including, bathymetry, sea surface temperature, chlorophyll and sea surface height.

Mon 15:00 – 15:20
Linking natural and electronic data records to determine the lifetime movements of fish

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Electronic data storage tags (DSTs) have successfully been used to study the migration patterns and population dynamics of a range of bottom dwelling fish, including rays, cod and plaice. DSTs allow continuous records to be made of ambient conditions experienced by free-swimming fish in their natural environment over periods of up to two repeat migration seasons, from which their geographical movements can be reconstructed. Most fish also record ambient conditions throughout their lifetimes by the accretion of calcium carbonate on their ear-stones or "otoliths". Recent studies have demonstrated that the chemical composition of otoliths reflects the environmental history of individual fish. Matching the DST data with otolith microchemistry may allow the retrospective positioning of the fish in space throughout their lifetimes. By linking the two state of the art techniques, we aim to provide information on fish population dynamics, which would be unattainable using conventional methods. Here we describe how the reconstructed movements of DST-tagged plaice and the chemical signatures (stable isotope and trace element profiles) laid down simultaneously in their otoliths have allowed the characterisation of annual migration routes and the assessment of past behaviour. Further comparison of the otolith cores with those of juvenile plaice collected from nursery areas around the North Sea will be used to determine the timing and source of recruitment to the adult stock, thereby linking for the first time studies of pre- and post-recruitment fish behaviour.

Mon 15:50 – 16:10

Individual dietary specialization and dive behaviour in the California sea otter: using archival time-depth data to detect alternative foraging strategies

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The existence of individual prey specializations has been reported for an ever growing number of taxa, and has important ramifications for our understanding of predator-prey dynamics. Unfortunately, documenting such specializations usually requires extensive longitudinal dietary information from many individuals, data which are often difficult or impossible to acquire from marine-living vertebrates. We use the California sea otter population as a case study to validate the use of archival time-depth data to detect and measure differences in foraging behaviour and diet. We collected observational foraging data from 60 radio-tagged sea otters over a three year period, in order to measure individual diets (N = 38,500 recorded prey captures). Individuals varied with respect to prey selection, and could be classified into one of three distinct dietary specializations. We simultaneously deployed archival time-depth recorders (Mk7 and Mk9 TDR's, Wildlife Computers, Redmond WA) on a sub-set of the study animals, and at present we have retrieved 25 of these records for analysis. Dietary specializations were clearly reflected by differences in diving behaviour, as measured by the TDR's. Dive duration and post-dive surface interval were related to differences in prey type and prey capture rate. Patterns of within-bout and between-bout variation in dive depth and dive duration were also characteristic of each prey specialization. Thus based solely on quantifiable traits of time-depth data that have been collected over an appropriate period (in this case 1 year per animal), it is possible to detect alternative foraging strategies in sea otter populations. This conclusion will likely apply to other diving vertebrates as well. Our ultimate goal must be to both recognize and incorporate such dietary variation into models of population-level and community-level dynamics.

Mon 16:10 – 16:30

Microgeographic variation in the foraging behaviour of two coastal seabirds

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Coastal seabirds are bound to be very dependent on local marine resources. We therefore hypothesize that the localization of the breeding colony will influence the foraging patterns of such predators. Using Time-Depth-Recorders (TDRs, MK7 and MK9), satellite transmitters (PTTs, Kiwisat 101) and radio-transmitters (VHF), we investigated foraging variation between colonies in two coastal seabirds, the Gentoo Penguin *Pygoscelis papua* and the Kerguelen Shag *Phalacrocorax verrucosus*. Thanks to dorsally attached devices, we described at-sea distribution and diving behaviour of Gentoo penguins in contrasted marine environments at Kerguelen Archipelago over the 2002 and 2003 breeding seasons. Unconventional ventral attachment of TDRs allowed us to investigate time budget and diving behaviour of Kerguelen shags breeding in the same contrasted environments as Gentoo penguins over the 2003 breeding season. Diving data were standardized depth-by-depth in order to provide an analysis independent from depth. For instance, we showed that Gentoo penguins exhibited at least two foraging strategies, depending from local conditions and particularly prey availability: large foraging ranges, long trips, long benthic dives on demersal fish at colonies facing the open sea *vs* small foraging ranges, short trips, short pelagic dives on swarming crustaceans at a colony protected in a closed bay. In both seabird species, variation in foraging strategies is also associated with extensive variation in morphological traits. This study highlights the importance of foraging plasticity as a fundamental aspect of life-history in coastal marine predators.

Mon 16:30 – 16:50

Wintering foraging strategies of European shags from long-term logger deployments: impacts on survival and future breeding

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In temperate regions, winter presents marine endotherms with a number of challenges. These include depressed prey abundance, increased daily energy requirements, higher frequency of extreme weather events and, for diurnal species, shortened daylength. Overcoming these constraints is critical to survival and future breeding. Biologging offers the opportunity to investigate over-wintering foraging dynamics in marine endotherms. We successfully deployed GLS-activity loggers over the winter on 20 European shags *Phalacrocorax aristotelis.* We aimed to test whether a) foraging time increases in winter, in particular during extreme weather, indicating a decline in foraging efficiency associated with poorer conditions and b) birds disperse south in winter to increase potential foraging time. Secondly, we examined whether over-wintering foraging time is related to breeding phenology and success in the following season. We found that foraging time of all instrumented birds increased in winter, particularly during periods of high onshore winds, to a peak of over 90% of available daylight during the winter solstice. There was no evidence that birds moved south. During February and March daily foraging time decreased and was correlated with subsequent timing of breeding, such that birds that spent less time foraging bred earlier. This suggests that foraging efficiency was higher in early breeders, which accords with previous studies that have shown that high quality individuals breed early. Our results provide new insights into the environmental and intrinsic drivers of survival and breeding, and demonstrate the potential of biologging in understanding life history strategies and population demography.

Mon 16:50 – 17:10

Examination of the foraging behaviour of the California sea lion: population differences and individual foraging strategies

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Although the California sea lion (CSL, *Zalophus californianus)* is the most abundant pinniped species along the West Coast of the United States and Mexico, surprisingly little information is available on its at-sea movements and diving behavior. This study examined the foraging behavior of CSLs at both the population and individual level. Research on sea otters has revealed the population is composed of animals that forage in fundamentally different ways. It is likely that this specialization occurs in other marine predators as well. In this study we compared two populations of CSLs and tested the hypothesis that individual specialization occurs within these populations. Habitat utilization, diving and foraging behavior were examined for 6 female CSLs at Los Islotes (LI), Mexico and 13 females at San Nicolas Island (SNI), CA. Animals were equipped with satellite tracking transmitters, time-depth and stomach temperature recorders. Satellite tags provided at-sea locations while dive recorders measured dive depths, durations and swim velocity. Stomach temperature data were used to identify feeding and calculate foraging success. We compared behavioral parameters including distances traveled, trip durations, transit rates, percent time diving, and mean dive depths and durations. On average females remained close to their island and displayed short foraging trips. The most significant differences between the populations were for the diving parameters analyzed, with dive depths and durations at LI significantly greater than those at SNI. Individuals within populations differed significantly in focal foraging areas, mean transit rate, and mean dive depths and durations. In both populations individuals returned to the same foraging area during sequential trips, indicating habitat and/or prey preference. This variation between individuals indicates foraging specialization within each population. Our data suggests summarizing population level behavior may overlook individual foraging strategies, which could be an important mechanism to reduce competition in a growing population of marine predators.

Mon 17:10 – 17:30

Telemetry reveals the pre-breeding foraging of male Antarctic fur seals

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Antarctic fur seals are one of the more abundant marine mammals in the northern Scotia Sea. Though a great deal is known about female animals, very little is known about males, particularly territorial males, due to the difficulty of restraining such large aggressive animals. However, with the recent development of improved handling methodologies and of satellite relayed time depth recorders (SLTDRs) we can now begin to investigate the foraging dynamics of this key demographic category of animal.
During October and November 2004 we tracked 14 male fur seals from Bird Island, South Georgia using a combination of ARGOS satellite transmitter tags and SLTDRs. This period was immediately prior to the fur seal breeding season that starts in mid November. Recorded location data showed that males undertook short foraging trips at this time, similar in scale to those undertaken by lactating females during the summer. However unlike females, males

constrained their foraging almost exclusively to the continental shelf region in relatively shallow water (generally depths of 350 m or less). With a larger body size, male fur seals are predicted to have a greater capacity for diving than do females. This was reflected by the significantly deeper maximum dive depth and longer maximum dive duration recorded during our studies. These increased diving capabilities potentially allow male fur seals to exploit prey that are unavailable to females and may help explain differences in their foraging behaviour. Indeed the information gathered from the new generation of SLTDRs will help to us to better understand the considerable sexual segregation observed in this species and allow us to reassess the impact of male fur seals in the Southern Ocean marine ecosystem.

TUESDAY 14 June

Tues 08:45 - 09:20
Plenary Talk: 'Make me one with everything' Appropriate technology for holographic biologging

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Biologging tools have made tremendous advances over the last decade, evolving from single sensor devices to multi-sensor programmable systems used in multi-scale and multi-animal studies. These studies can be considered holographic in the sense that they seek to reconstruct a meaningful portion of the behaviour and experience of an animal from multiple single dimensional measurements. Interestingly, this progress has largely been achieved with readily available components as development and deployment costs are too high to risk immature technology. Rather, we aim for appropriate technology: reliable sub-systems that can be implemented and characterised at moderate expense, that are well-matched to the scientific objective and experiment design, and that meet our ethical obligations when working with animals.
Two results from the DTAG project provide examples of progress towards holographic biologging and illustrate the idea of appropriate technology. The DTAG is a multi-sensor archival tag for marine mammals that records sound and orientation over periods of hours. A group of creative researchers have contributed to a growing set of results combining data from the rich sensor set to estimate parameters not explicitly measured, developing, in essence, virtual sensors. Blainville's beaked whale, a reclusive cetacean species, was first tagged using DTAGs in 2003 revealing both echolocation sound production and echoes from targets near the whale. Analysis of the interaction of the tagged whales with the echo field has provided the first view of biosonar-mediated echolocation in the wild from the viewpoint of the animal. The second study tested the social coordination of pilot whales by contemporaneous tagging of up to 5 individuals with stereo DTAGs. Vocalizations of tagged whales, recorded by tags on other animals, effectively create an acoustic-linked network providing accurate estimates of the relative location of tagged and untagged individuals. Knowing the relative movements of an entire group of animals as well as sparse but dense individual measurements provide a holographic view of social and foraging behaviour in these deep diving predators.
In developing the DTAG, we, like many others, have gained considerable experience about what does and doesn't work although this seldom enters the published record. This symposium is an excellent venue to propose the creation of a community resource for biologging systems, their design, use, verification, and analysis, and even meta-data products. Such an archive will help us improve our own success rate and will serve to define best practice and appropriate technology for newcomers to this growing field.

Tues 09:20 – 09:40
The life history transmitter: a new concept for long-term monitoring of oceanic vertebrates

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We present the first telemetry transmitter specifically designed for collecting vital data from marine vertebrates over extended periods, up to a decade. The implantable Life History Transmitter (LHX tag) records data throughout the life of a host animal. After the host animal dies, the tag is extruded, and, while floating in the ocean or lying on a beach, transmits previously stored data to orbiting satellites. For our initial applications on Steller sea lions, LHX tags will collect depth, temperature and light-level data. Following the death of the sea lion the LHX tag will be programmed to transmit the date and time of the animal's death, the body-temperature record of the animal for the 48 hours encompassing the time of death, and a week-by-week record of the cumulative vertical displacement of the animal (as a measure of its long-term dive effort). Examination of these data should provide insight into the cause of the death of the sea lion. For tags relying solely on end-of-deployment transmissions, reliability and proper recognition of the animal

state is crucial. LHX tags use heuristic tag state determination, in combination with error detection and fault tolerance measures, to increase tag reliability and likelihood of data recovery. To test efficacy of these reliability measures, extended deployments were simulated on a PC platform, as well as on the LHX tag in accelerated time. Implications arise when using LHX tags for survival rate estimation – one anticipated application of this new technology: Tag failure rate, although minimized, still needs to be accurately assessed, and the use of dual redundant implants is a central element in our planned research.

Tues 09:40 – 10:00
Towards development of "ecology tags" for large pelagic fishes

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The past 20 years has seen considerable progress in tracking the vertical and horizontal movements of large fishes in the open ocean. What is now required is a new generation of tags that will permit interpretation of previously observed behaviours. Of particular interest is knowing which behaviours are associated with feeding and when fish are schooling or associated with structures such as seamounts or fish aggregation devices (FADs). To this end, we are developing and testing tags that will indicate feeding periodicity and digestive function by measuring stomach pH and motility. We are also evaluating an intraperitonealy implanted "bioacoustic probe" for detecting schooling and associative behavior in fishes by recording the acoustic signatures associated with these phenomena. Swimming energetics and body orientation are being investigated using a prototype tag that incorporates accelerometers sensitive in three dimensions. All four tag types have been tested on free swimming sharks and tunas and show considerable promise for future deployment in the field and, in some cases, hybridisation into active transmitters. Examples of these data will be provided and discussed.

Tues 10:00 – 10:20
Autonomic computing in bio-logging

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IBM recently introduced the concept of autonomic computing (AC) for effective management of complex computational systems. AC emulates the ability of biological organisms to self-optimize, -configure, -protect, and heal, which leads to more dependable systems. We are pursuing the application of AC principles to bio-logging, to increase the dependability of telemetry devices and to facilitate the large-scale integration of stationary and animal-borne autonomous data collection systems. Using examples of current technology-development projects, we discuss how AC principles can enhance the dependability of even basic telemetry systems and networks.
The Satellite-Linked Data Acquisition and Photogrammetry (SLiDAP) network was designed to collect year-round spatial data from shore-based pinnipeds in remote locations. SLiDAP consists of a network of digital imaging stations with a distributed control system and an opportunistic architecture that combines autonomous operation with remote control capability. Individual SLiDAP stations within this network are comparable to autonomic elements; they implement system management in response to self- and ambient-monitoring, conduct self-repair and can remotely update themselves. They also self-configure and self-protect. Self-optimization is not implemented but planned for the future. SLiDAP stations establish and maintain links without relinquishing control even during remote access, equating the network to an autonomic system.
Long-term deployments of telemetry devices like Life History Transmitters also benefit from AC principles. In a simple form of autonomic behaviour, tags self-manage by testing sensors used in vital tag state determinations. Self-optimization, through dynamic reconfiguration of operational parameters, is being considered for future developments.

Tues 11:00 – 11:20
The evolution of an implantable argos satellite-monitored radio tag for the year-round monitoring of large whale movements and dive habits

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Tracking large whales with Argos satellite-monitored radio tags has previously been limited by large tag size and related difficulties in achieving long-term attachment. We have overcome many of these difficulties with the development of a smaller, implantable tag; and have achieved a tracking period of 20 months and attachment durations of over 3 years. This paper describes development of the Argos Data Collection and Location system technology over the past 25 years to track large whales. Our current tag design has little hydrodynamic drag, longer attachment duration, and can be implanted with a projectile applicator. The air-powered applicator system (ARTS; Heide-Jorgenson et al.) made consistent, complete application possible. We tag during close approaches to achieve a vertical antenna orientation and assure that the saltwater switch will be properly positioned to trigger for transmissions. Full depth tag deployment at distances of 2-5 m is achieved with 80-100 psi in the applicator's 70 cc pressure chamber for humpback, blue, and sperm whales. We have tagged 10 stocks of seven whale species using 5-7m boats, which make it possible to operate from shore-based logistics in good weather at modest cost. Under perfect conditions we have tagged up to 9 right whales, 8 sperm whales, or 6 blue whales in a single day. Of more than 300 tags deployed to date, we have lost <2% of tags to totally missed shots. New tags now allow us to study dive habits and in the future we expect GPS quality locations. We hope future tags will operate for multiple years so that natural variability in location preferences and behavioural habits can be linked to measurable environment attributes. Only by better understanding natural variability will it be possible to provide meaningful conclusions about whether observed changes are a result of anthropogenic activities.

Tues 11:20 – 11:40

How to get the most (or anything) out of GPS loggers: a case study with Snares penguins

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The Snares penguin (*Eudyptes robustus*) breeds only on the Snares Islands, a small archipelago about 200Km south of New Zealand's South Island. Despite its relative closeness to the mainland, working on the Snares represents a logistical challenge. The Snares are managed as minimum impact islands, which not only limits timing and length of visits but also restricts movements on site.
Between 2002 and 2004 we examined the foraging behaviour (foraging range and diving behaviour) of Snares Crested penguins during the late incubation and chick-guard stages. Due to the temporal and spatial limitations on the Snares, most of the conventional methods to track penguins (i.e. VHF or satellite telemetry) were inadequate for the proposed research. Instead we relied on newly developed GPS loggers (Earth&Ocean GPS-TDlog) which record geographic position and dive depth/temperature at set intervals. Data quality (i.e. number and temporal distribution of fixes during deployment) depended largely on programming of loggers as well as timing and location of deployment.
During the work we identified three key issues that have to be considered during deployments of GPS loggers on penguins: (1) reception of GPS devices after power-on, (2) finding adequate GPS logging intervals and (3) limited battery life. Using data recorded on Snares penguins we show the varying degrees of programming-dependent data quality and show how the effect of these issues can be minimized.

Tues 11:40 – 12:00

All washed up: a "pop-up and drift" approach to data recovery from archival tags on basking sharks using GSM mobile phone technology

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Archival tags are a valuable tool for learning about the movements and behaviour of fish in the open sea, providing important information about migrations, distribution and habitat use. But the major limitation of these tags is that they have to be retrieved so that the recorded data can be recovered. This restricts their use to situations where either there is a commercial fishery, or where the tags can be recovered by directed fishing.
This limitation has in part been overcome with the development of pop-up archival transmitting (PAT) tags that release from the fish at a pre-determined time, float to the sea surface and then transmit information via Argos. However, PAT tags remain limited because of Argos' restricted data transmission capacity and large time-series data sets still cannot be recovered this way.

Because the prevailing wind direction on the European continental shelf is from the south-west, surface-floating objects over much of the area have a high chance of drifting close to land where they should be within range of the terrestrial cellular telephone system. We have used this "pop-up and drift" concept in developing a new archival tag that includes a GSM (Global System for Mobile communication) telephone unit to transmit large data sets back to the lab. The data logging circuit is based on the CEFAS Mk 3 DST, while data transmission is achieved using the Siemens TC35 cellular GSM telephone engine. The pop-up function is achieved using an "electric match" that acts as the primary release mechanism. We will describe the design and development of the tag and present results from the first deployment of prototype devices on basking sharks off Plymouth in June 2004.

Tues 12:00 – 12:20
Energy efficient protocols for subcutaneous RF identification tags in marine mammals at remote sites

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Significant declines have occurred among many populations of Steller sea lions (*Eumetopias jubatus*), northern fur seals (*Callorhinus ursinus*) and harbour seals (*Phoca vitulina)* in Alaska since the late 1970s. Radio frequency (RF) tags could help to determine why their numbers have changed by monitoring the movements and survivorship of young animals – the age classes thought to be at greatest risk. Lengths of time that pinnipeds spend on shore and at sea can be determined using local base stations to monitor the presence or absence of known individuals. Presence and absence data can also be used to estimate survival rates. Unfortunately, tags glued to the fur of pinnipeds fall off when the animals molt or the hairs break and existing implantable RF tags are of limited life span, too large, or surgically too invasive for use in a young animal. We have developed a means of electronically monitoring immature individual pinnipeds by placing small RF tags under their skin. Considerations we have addressed include how such an implanted tag could be polled to overcome critical issues related to longevity (3 years), positive identification, battery and overall tag size, changing skin conditions, proximity of other tagged animals, mortality detection, migration patterns, attendance patterns, and implementation concerns. Design and implementation solutions are presented that will suggest wide applicability for monitoring the survivorship and attendance patterns of individually identifiable pinnipeds.

Tues 14:20 – 14:40
Analysis of marine telemetry data using hidden Markov models

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Currently there is a paucity of rigorous statistical methodology to categorize and predict behavioural data collected by electronic tags. Quantitative analysis of data recovered from electronic tags is complicated by its inherent autocorrelation and non-linearity. New types of statistical models are required if telemetry data is actually to be applied in quantitative decision making based on the movement and behaviour of pelagic species. We demonstrate a class of state-space model, known as Hidden Markov Models, appropriate for this task. Simulated data are used to introduce the analysis techniques which are then applied to analysis of movement and diving behaviour of data from southern bluefin tuna (*Thunnus macoyyii*). We also demonstrate how Hidden Markov Models can provide statistical inference techniques that allow comparison between the behaviour of different individuals and sets the stage for rigorous quantitative meta-analysis of electronic tag data.

Tues 14:40 – 15:00
Estimating animal space use and environmental preference from telemetry data

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A large portion of applied ecology investigates where organisms are found in space, why they are there and where else they could be. These questions are usually dealt by collecting data on spatial distribution, relating those to

environmental covariates, making population inferences and predicting distribution for areas in space or points in time where observations don't exist. Satellite telemetry devices provide a wealth of information on animal distribution and, potentially, environmental covariates. At the same time , satellite telemetry data offer unique statistical challenges. We present an overview of these problems, propose solutions and illustrate both using data collected from UK grey seals.

Tues 15:00 – 15:20
Clustering for more insight in summary data from satellite tags

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To limit the amount of data to be sent in marine mammal studies, dive data is often presented in summary data. For example in SRD's (Wildlife computers) dive depth and duration, and so called time at depth is presented in 4 periods of 6 hrs. Timing of these periods remains fixed during the course of the study.
For animals that are driven by other factors than daylight, and show irregular patterns such as harbour seals, it is difficult to identify behaviour groups (i.e. feeding, travelling or resting) based on these seemingly random collections of diving behaviour. It is possible though to statistically define clusters of periods based on for example dive duration. Despite lack of "ground truth" to actually correlate feeding or other behaviour to the dive histograms, periods of relative inactivity, intense activity and intermediate periods can be identified. These can then be linked to where the animal was located to explore where this behaviour has taken place.
Recently, seals were deployed with both a SRD and data loggers collecting detailed dive information (Dead Reckoners) and mouth movement (IMASEN). This provides for the "key" or the ground truth needed to actually define the behaviour types found in the clustering analysis and identify for example foraging areas. This can even be done in retrospect, using data collected during earlier studies.

Tues 15:50 – 16:10
Coupling satellite oceanography and satellite tracking to analyze navigation skills of leatherback turtles

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Sea turtles in general, and leatherback turtles (*Dermochelys coriacea*) in particular, prove to have impressive, but yet largely unexplained, navigation skills. In an attempt to elucidate some of the mechanisms at play, we analyze the trajectories of ten Argos-tracked female leatherback turtles migrating from their nesting beaches in French Guyana and Grenada (Caribbean) to remote oceanic foraging areas in the North Atlantic Ocean. The trajectories are analyzed together with the actual oceanic currents encountered by the turtles. The current speed and direction are estimated using the latest satellite oceanography techniques based on radar altimeter and scatterometer data.
The observed trajectories are essentially straight over thousands of kilometres in spite of the action of variable ocean currents that often tend to push the turtles away from their nearly direct route. Still small perturbations in the track linearity are observed. These perturbations and the corresponding variations in the apparent turtle speed appear to be largely correlated with the computed currents. Further analysis of these perturbations reveal that turtles react, in different ways, to current changes as they adapt their swimming direction and/or velocity to keep progressing in a quasi steady direction.
Based on such observations, one can devise and test simple mathematical models of the turtles' response to current changes under the control of likely orientation mechanisms, such as a capability to react to changes in the perceived geomagnetic field. Preliminary analysis of the model results provide new information on how sea turtles can possibly use selected orientation mechanisms to navigate along almost straight routes in the presence of variable ocean currents

Tues 16:10 – 16:30
Comparison of indirect measures of foraging location and extent via remote tracking

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Direct observation of foraging behaviour has proven to be problematic for many pelagic species. Several indirect methods utilizing remote-tracking data have been developed to locate likely foraging areas. Because these methods are often used independently, it is unclear whether they produce similar results. Here, I compare speed, turning angle, fractal, and first passage time analyses with respect to the identification of potential foraging locations and the spatial extent of foraging. Each of these approaches is used in conjunction with several filtering/modelling techniques to reveal the full range of outcomes. This comparison utilizes female Northern elephant seals tagged with both platform terminal transmitters (for ARGOS satellite locations) and light level recorders (for geo-location estimates), enabling the estimation of foraging areas from data sets with vastly different positional errors. I focus on female seals because their behaviour is likely not driven by topography: they are free to utilize a range of spatial scales.
To quantify the differences between these methods, I use three metrics: (1) the number of unique foraging areas identified, (2) the proportion of track overlap within each foraging area, and (3) the size of each foraging area.
As technological advances lead to smaller instruments that provide more accurate information, it will be possible for a larger number of pelagic species to be tracked. With the wide variety of tracking and analysis methods available it will be increasingly important to translate results between methodologies. This will allow researchers to continue to use those methods best suited for particular species or data-logger type and yet still make comparisons between species and/or studies.

WEDNESDAY 15 June

Wed 08:45 – 09:20
Plenary talk: Foraging behaviour and environmental conditions in seabirds

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With the remarkable development of biologging techniques over the past twenty years, our perception of the way marine predators forage has changed with the improvement of the accuracy of the tracking systems. Argos or geolocator systems have given us a clear view how marine animals search prey at large and medium scales, and today the use of GPS allows us to complement this view by providing information on the fine scale foraging behaviour of marine predators. Taking seabirds as an example, I show that with these techniques it is now possible to study how animals respond to the environment at a range of spatial scales, and to test some long-lasting hypotheses about the way animals should adjust their search effort. In a second part I test the hypothesis that since environment productivity and structure vary extensively between marine biomes, specific morphological and behavioural adaptations for foraging should exist between contrasting environments. I compare the morphological and foraging strategies of seabirds in two contrasting environments: tropical waters where productivity is low and the environment less structured, and sub polar region where productivity is higher and, particularly, enhanced in specific zones such as fronts or shelf edges.

Wed 09:20 – 09:40
Building capacity to manage, analyse and publicly share marine vertebrate tracking data and integrate movements with oceanographic data

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Many biologists interested in tracking marine vertebrates using the Argos system find it difficult to store, manipulate, analyse and successfully share their data. The Satellite Tracking and Analysis Tool (STAT), freely available on SEATURTLE.ORG, is a complete package designed specifically for handling marine vertebrate satellite telemetry data. The STAT system automatically downloads data from the Argos system, archives it into a relational database, backs up the database daily, and provides integrated tools for filtering, analysing, exporting, summarising and mapping data. Mapping functions include visualisation with x, y and z oceanographic data sets in both snapshot and animation form. The presentation graphically outlines the utility of the features and products and how they could be of utility to the wider bio-logging community. In addition, the STAT system provides a user-friendly interface for tracking projects with the public. The public web site allows visitors (more than 1.5 million visits) to follow individual projects through daily e-mail updates and provide financial support to these projects through an adoption program. To date more than $25K has been raised through the public adoption program. The presentation further reviews the progress made during the first 24 months of use and highlights what has been learned from the more than 370 animals (approximately 4% marine mammals, 85% turtles and 11% seabirds) and 160,000 data points collected in cooperation with 35 partners and

47 satellite tracking projects in more than 20 countries around the world. In addition, we address how STAT can be linked to wider data-sharing enterprises such as the Census of Marine Life (CoML) through the Ocean Biogeographic Information System (OBIS).

Wed 09:40 – 10:00
From form to function – determination of diving behaviour on the scale of individual dives

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Much work on pinniped behaviour at sea is based on consideration of dive profiles of depth against time, this information coming from loggers recording hydrostatic pressure. In recent years, however, advances in technology have allowed much additional information to be collected by loggers e.g. three-dimensional orientation with respect to gravity and the earth's magnetic field. The ability to resolve animal heading in 3-dimensions, together with depth and speed data, means that the 3-dimensional movements of animals wearing such systems can be determined. We present data obtained from the use of dead-reckoning systems deployed on South American sea lions (*Otaria flavescens*) and Harbour seals (*Phoca vitulina*) to highlight the importance and advantage of including such information in the determination of dive function as well as to further classify dive types.

Wed 10:00 – 10:20
All at sea with animal tracks and dead-reckoning solutions for the resolution of movement

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Determination of the movement of marine animals is logistically difficult and is currently primarily based on VHF and satellite-tracking telemetry, GPS, acoustic telemetry and geolocation, all of which have substantial limitations. A further, recent development, that of dead-reckoning, is being increasingly used to examine the fine-scale movement of animals underwater. The advantages and drawbacks of this approach are quite different to those incurred by the other methods. This paper considers the advances that dead-reckoning can bring to the study of marine animal movement and behaviour. Methods used in dead reckoning are presented and consideration is given to results derived from the use of dead reckoning on sea turtles, cetaceans, pinnipeds and penguins. Suggestions are made as to how movement data derived from dead-reckoners can be analysed using indices that allow interpretation over a large variety of temporal and spatial scales.

Wed 11:00 – 11:20
Diving behavior of Weddell seals based on three-dimensional movements paired with video recorded observations

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We classified Weddell seal (*Leptonychotes weddellii*) dives based on 58 spatial and temporal variables derived from three-dimensional movements and assigned functions to some of the resulting dive types based on video recorded behavior. The variables were measured or calculated from data obtained by attaching a video and data recorder to the backs of 10 adult Weddell seals diving from an isolated ice hole in McMurdo Sound, Antarctica. Our analysis revealed four types of dives. Type 1 dives were intermediate in duration (15.0 ± 4.2 min), deep (mean maximum depth = 378 ± 93 m) and had the steepest descent and ascent angles. Video recordings of the seals capturing prey, primarily small Antarctic silverfish (*Pleuragramma antarcticum*), confirmed these were foraging dives. Types 2, 3 and 4 dives formed a continuum from very short, low speed, non-linear dives that were close to the hole (Type 2) to progressively longer, higher speed, very linear dives that ranged as much as 3 km from the hole (Type 4) but remained relatively shallow (< 142 m) compared to Type 1 (foraging) dives. Type 2 dives were hypothesized to be related to hole-guarding behavior or the detection of other seals. Type 3 and 4 dives had characteristics suggestive of exploratory behavior. Swimming speed has long been considered an important indicator of the energetic cost of locomotion in marine mammals. However, we discovered that Weddell seals use different swimming modes (gliding, stroke-and-glide, constant stroking) that vary in energetic cost with little variation in speed. New information was also obtained about the vertical distribution, diel movements, and swimming behavior of silverfish, the most common prey of Weddell seals in McMurdo Sound. Silverfish

Wed 11:20 – 11:40

Hunting behaviour of Weddell seals (*Leptonychotes weddellii*) diving from an isolated hole in McMurdo Sound, Antarctica

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An animal-borne video system and data logger was used to reconstruct underwater movements of Weddell seals foraging on fishes from an isolated hole in the fast ice environment of McMurdo Sound, Antarctica. Underwater behavior was interpreted from 758 three-dimensional dives paths, which were reconstructed from time, speed, depth, and direction data recorded at a rate of 1 Hz, plus flipper stroke rate and synchronized video recordings from a head-mounted camera. Foraging dives had distinctive dive paths which were analyzed in detail to describe hunting behavior for piscine prey. Nine behavioral states were identified in 48 unsuccessful foraging dives based on combinations of swimming speed, stroking frequency, and geometry of dive paths. Five additional behavioral states were identified in 61 successful foraging dives. Most differences between successful and unsuccessful dives were consequences of a fish encounter, rather than indications of successful and unsuccessful hunting strategies. Only differences in the terminal stages of the dive (i.e. initial descent and final ascent) were significantly different and not directly related to the presence of fish encounters, though these differences did not explain foraging success. The dominant hunting sequence leading to the initial encounter with *Pleuragramma* during a dive was *meandering descent → descent → horizontal swimming → ascent → silverfish encounter*. Behavioral states and sequences were then interpreted in the context of a generalized foraging cycle (search, pursuit, attack, and handling) and time-activity and time-energy budgets were constructed for hunting seals

Wed 11:40 – 12:00

Feeding behaviour of penguins detected by oesophageal temperature: a three dimensional approach

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A central question in foraging studies is when and by how much do predators feed. Over the last decade several data logging systems have been developed and attached to free-ranging marine predators to monitor prey ingestion.

Recent monitoring of the oesophageal temperature of penguins has provided promising results. To obtain detailed insights into the feeding activity of penguins, we used fast-response temperature sensors in the oesophagus together with time depth recorders (king penguins, 3 seasons, 9 birds equipped) and speed-depth loggers (Adélie penguins, 1 season, 16 equipped birds). Oesophagus temperature loggers were attached to birds either using a non-invasive method or surgically implanted.
This approach has revealed many of the feeding strategies used by the penguins, especially how they might optimize prey capture rate at different spatial and temporal scales. The results presented here are discussed with respect to the predictions from energy maximizing behaviour.
At the level of a foraging trip, the feeding success of king penguins was highest when they were in their preferred feeding zone, i.e. in the oceanic frontal structures where prey availability is enhanced. Here, the number of successful dives and prey ingested per dive was at its peak (up to 96 % of successful dives and 15 ingestion events per dive) and dive rate also increased.
At a smaller time-scale, the number of prey caught per dive varied greatly over the day, being highest during daylight, high at dawn and dusk (32 % in king penguin) and low at night.
At the level of individual dives, penguins modified their dive angles, swim speed and post dive interval according to prey encounter rate. The duration of the time spent at the bottom was strongly related to the number of ingestion events. A significant proportion of ingestion events occurred during the ascent phase of dives (22 % and 55% in Adélie and king respectively). Furthermore, most ingestion events occurred while penguins were heading upward (60 % and 65 % respectively in Adélie and king penguins), giving support to the counter-shading hypothesis.
Although the monitoring of oesophagus temperature does have its limitations, this method has provided considerable information about the foraging decisions of diving predators.

Wed 12:00 – 12:20
Mouthing off about fish capture: jaw movements in pinnipeds reveal the real secrets of ingestion

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Determination of when and where animals feed and how much they consume is fundamental to understand their ecology and role in ecosystems. However, the lack of reliable data on feeding habits of wild animals, and particularly in marine endotherms, attests to the difficulty in doing this. A promising recent development proposes using a Hall sensor-magnet system (the inter-mandibular angle sensor IMASEN) attached to animals' jaws to elucidate feeding events. We conducted trials on captive pinnipeds by feeding IMASEN-equipped animals with prey to examine the utility of this system. Based on the results of this study we examined feeding events from free-ranging pinnipeds fitted with IMASENs and dead-reckoners and present data on prey capture and ingestion in relation to 3-dimensional movement patterns of the seals.

Wed 14:20 – 14:40
Stroking pattern and body angle in diving elephant seals

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Air-breathing aquatic animals that forage underwater must travel to foraging areas (horizontal direction) and dive to forage (vertical direction). To obtain prey most effectively and to reduce transport costs, air-breathing aquatic animals are expected to modulate their swim speed, body angle and locomotion activity. We used acceleration data loggers (W-PD2GT; Little Leonaldo, Co., Tokyo) to measure fine-scale movements during diving of elephant seals. Our aim was to determine how seals modulate swim speed, body angle and locomotory activity as they dive, forage and migrate at sea.

We attached data loggers to two premolt southern elephant seal juveniles at Kerguelen, Subantarctica in 2002 and two postbreeding northern elephant seal females at Año Nuevo, California in 2003, programmed to record depth, two-dimensional acceleration (stroke cycle frequency and body angle), swim speed and temperature.
Stroking patterns were different among seals and dive types. For example, prolonged gliding while descending was observed more frequently in postbreeding females (79.3% and 77.9%) than premolt juveniles (37.6% and 19.4%). Rates of descent and ascent in the water column during dives increased with increasing maximum dive depth due to changes in swim speed, descent and ascent angles, and stroke cycle frequencies. Vertical ascent speed was correlated significantly with number of jagged points at the bottom phase of dives. Seals that showed multi-jagged points at the bottom phase exhibited rapid vertical speed during ascent and subsequent descent. Seals can shorten travel time to the foraging depth by frequent stroking and assuming a steep body angle. These data suggest that seals decrease the time spent at the transit phase of dives when they are feeding.

Wed 14:40 – 15:00
Optimal stroke cycle frequency according to the body size of swimming animals

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This study makes a systematic comparison of the stroking movements for a variety of aquatic animals. Our goals are 1) to obtain the dominant stroke cycle frequency for each animal under natural conditions and 2) to explain the scaling relationship in view of optimal mechanical efficiency. Time-series data of acceleration were collected from a wide range of species of different body sizes (fish, reptiles, birds and mammals) with the same type of accelerometer (M-D2GT and W-PD2GT; Little Leonardo, Co., Tokyo). Power spectral density was calculated to obtain dominant stroke cycle frequencies for each animal. Due to large morphological differences between animals, body mass was used as an index of body size. The dominant stroke cycle frequency decreased linearly with body mass across a wide range of body mass on a log-log scale figure. Surprisingly the dominant frequency was well correlated with body mass in this morphologically and physiologically disparate sample. The dominant stroke cycle frequency related to body size is essential in minimizing locomotory energy consumption during both foraging dives and migration.

Wed 15:00 – 15:20
Activities during foraging trip of streaked shearwaters: insights yielded by using acceleration data loggers

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A pair of streaked shearwater, *Calonectris leucomelas*, makes either one-day short foraging trips, or long trips lasting 7-10days during a breeding season. However there are little information on fine scale behaviours throughout their foraging trips. We monitored the flight and diving behaviours of streaked shearwaters using miniature data loggers (M190L-D2GT, Little Leonardo Co.Ltd), to reconstruct the time budget and to understand their flight abilities. Field study was conducted at breeding colony (39°18´N , 141°58´E) on Sangan Island, Iwate Prefecture Japan in September, 2004. Data loggers were attached to six birds on their belly to record depth, two-dimensional accelerations (parallel and perpendicular to the body trunk), and temperature. Five of them were retrieved. According to the obtained data, the activities during a foraging trip is divided into some phases: flapping, gliding, diving, resting at the water surface,

moving on the land. Especially undulation of the accelerations data in flying periods, these birds mixed flapping and gliding. Power Spectral Density, calculated from time series data, showed that each bird had a dominant frequency of stroking ranging 4.1~4.5Hz. There was significant relationship between body mass and the dominant stroke frequency (Spearman R= 0.1 N=5, P<0.05) Heavier birds had lower frequencies and lighter birds had higher frequencies. This result suspects that they stroked with optimal frequency for energy efficiency according to their body size.

Wed 15:50 – 16:10
Blubber and buoyancy in Baikal seals, *Phoca sibirica*, a marine mammal in freshwater

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Buoyancy plays a significant role in the energy budgets of diving animals and is largely affected by proportion of lipid tissue in the body, with fatter animals being more positive buoyant. Baikal seals (*Phoca sibirica*) are interesting models to examine the relationship between buoyancy and blubber contents in marine mammals because they inhabit a freshwater lake, Lake Baikal. The buoyant force acting on the animals is different from the case of seawater (i.e. ~30g/l less positive than seawater). We attached a data logger to a free-ranging male Baikal seal to monitor diving depths, swimming speeds, flipper strokes and body angles during dives. We obtained 24 h diving data including 114 dives with a mean maximum dive depth of 77.7 m. During descent of each dive, it stopped stroking at ~20 m depth and shifted to passive gliding phase to a maximum dive depth, during which phase speed increased up to approximately 1.4 m s^{-1} as a result of the strong negative buoyancy. Biomechanical calculations using the glide phases yield the estimated body tissue density of the seal of 1004.6 kg m^{-3}, which is consistent with average blubber ratio of 47 ± 4% measured from 15 dead Baikal seals. Blubber contents of Baikal seals are significantly higher than those of ringed seals (*Phoca hispida*), marine counterpart of Baikal seals. Model simulations show that these high blubber contents of Baikal seals would prevent them from gliding during descent in seawater. Our results suggest that higher fatness of Baikal seals is an adaptation to the freshwater habitat, Lake Baikal.

Wed 16:10 – 16:30
Swimming porpoises acoustically inspect areas that lie ahead in advance

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Detecting objects in their paths is a fundamental perceptional function of moving organisms. Potential risks and rewards, such as prey, predators, conspecifics, or non-biological obstacles, must be detected so that an animal can modify its behaviour accordingly. However, to date few studies have looked at how animals in the wild focus their attention. Dolphins and porpoises are known to actively use sonar, or echolocation. A newly developed miniature data logger attached to a porpoise allows for individual recording of acoustical search efforts and inspection distance based on echolocation. In this study, we analysed the biosonar behaviour of eight free-ranging finless porpoises (*Neophocaena phocaenoides*) and demonstrated that these animals inspect the area ahead of them before swimming silently into it. The porpoises inspected distances up to 77 m, whereas their swimming distance without using sonar was less than 20 m. The inspection distance was long enough to ensure a wide safety margin before facing real risks or rewards. Once a potential prey item was detected, porpoises adjusted their inspection distance from the remote target throughout their approach.

THURSDAY 16 June

Thurs 08:45 – 09:20
Plenary talk: Bio-logging of physiological parameters in higher marine vertebrates

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Physiological bio-logging techniques have been developed and utilized in both the medical and biological fields. This review highlights the application of such techniques to free-ranging animals and, in particular, higher marine vertebrates. Techniques range from radio and satellite telemetry to the use of analog and digital recorders. In the field of diving physiology, such devices have been applied to captive animals in tanks, to trained animals at sea, and to free-diving animals, either free-ranging at sea, in translocation experiments at sea, or at isolated dive holes in Antarctica. Advantages and limitations of each approach are considered in relation to 1) attachment and insertion of sensors, 2) fragility and durability of physiological sensors, 3) memory and data storage capacity, and 4) data retrieval and removal of sensors.

Thurs 09:20 – 09:40
Alternative thermoregulatory strategies in king penguins at sea: physiological adjustments and energetics in relation with sustained diving activity versus interbout resting

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The aim of this study was to link thermoregulatory strategies with different levels of energy expenditure in the king penguin (*Aptenodytes patagonicus*). We relate temperatures in different regions of the body in birds at sea with average heart rate, and thus rate of oxygen consumption, to estimate and model the energetic cost of different activities at sea. The king penguin is one of the diving species where experimental measurements of diving energetics, and thus theoretical aerobic diving performance, are not in accordance with behavioural observations. Therefore, the use of bio-logging techniques with free ranging individuals is of key importance if we are to understand the adjustments that occur in these animals when they are at sea.
The use of data-loggers (J.P. Gendner, CEPE Strasbourg-F, A.J. Woakes, School of Biosciences Birmingham-GB & Wildlife computers-USA) recording body temperatures, heart rate and environmental features (ambient temperature, pressure), enabled us to elucidate the possible energy-sparing strategies of these animals during diving, as well as demonstrate high levels of energy expenditure during resting at sea.
The results are from 18 penguins over 2 years. There were reductions in temperature from different regions of the body during underwater foraging. Although temperature drops in the peripheral tissues (up to -20°C) were not unexpected, even the locomotory muscles underwent temperature reductions during diving (up to -4°C compared to resting value). Surprisingly, resting periods, generally over night, were characterized by high body temperatures, even in the peripheral tissues (skin: 36°C in water at 4°C).

Thurs 09:40 – 10:00
Thermoregulation in the diving king penguin. A complex feature: what is known and what is unexplained

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This presentation makes a synthesis of a long-term study upon the complex thermoregulatory plasticity in the king penguin while foraging at sea. Our goal was to understand how the great drops in body temperature are achieved, adjusted and regulated and how they may explain the ability of this species to prolong dives far beyond their theoretical aerobic limit. Even if the occurrence of a true hypothermia (i.e. drop of temperature in the body core) is clearly demonstrated in this penguin species, some contradictory results and unpublished observations lack a reasonable explanation. These contradictory results can be explained by:
(1) different potential problems of sampling biological data ;
(2) potential unknown adaptations (anatomical, physiological or behavioural).
After considering these explanations, a general view is emerging that may explain why such thermoregulatory plasticity is a key to the energetic strategy of this fascinating endothermic diver.

Thurs 10:00 – 10:20
Year-round behaviour and energetics of macaroni penguins

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Macaroni penguins are one of the principal consumers of Antarctic krill in the Scotia Sea. The aim of our project is to estimate the resource requirements of macaroni penguins at different times of year and in years of contrasting resource availability. We used miniature data loggers to record heart rate (f_H), abdominal temperature, body attitude and diving depth. Heart rate was used to estimate the rate of oxygen consumption ($\dot{V}_{O_2}$), and hence metabolic rate and rate of food consumption, while diving depth was used to indicate which parts of the water column the penguins used. Our analyses have allowed us to make the first accurate estimates of year-round energy expenditure for free-ranging animals and to study their energetics and behaviour during the long winter migration, which was previously impossible. Mean metabolic rate varied significantly between the two years studied, from 7.74 ± 0.69 to 10.62 ± 0.72 W kg^{-1} y^{-1}. To satisfy this energetic demand, a pair of macaroni penguins would have to consume between 576 ± 51 and 790 ± 54 kg of crustacean prey per year. Other analyses have focussed on variability and flexibility in foraging behaviour which may drive these changes in energy expenditure. Diving behaviour is far more consistent between years but varies substantially within a year. Macaroni penguins dive deeper and for longer during the winter months than they do during their breeding season and possess adaptive diving capabilities far in excess of our previous understanding, which was based on data from the breeding period only.

Thurs 11:00 – 11:20
Emperor penguin heart rate profiles during dives, surface intervals and rest periods: the value of digital ECG records

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In divers, heart rate (HR) is considered indicative of the rates of blood O_2 transport and blood O_2 store depletion. It is therefore key to determination of dive duration and to rates of metabolism during dives, surface intervals and rest periods. In order to examine HR profiles of emperor penguins (*Aptenodytes forsteri*) during dives, surface intervals and rest periods, a digital ECG recorder and TDR were deployed on birds diving at an isolated dive hole in McMurdo Sound, Antarctica. Analysis of diving data revealed dive HRs (total number of beats in a dive / dive duration) ranging from 97 beats min^{-1} (bpm) for a 2.3-min dive to 27 bpm for an 18-min dive. The decrease in HR was progressive with minor fluctuations throughout the dive until the onset of an ascent tachycardia. For example, a HR of 6 bpm occurred during the 15th minute of the 18-min dive. In contrast, surface-interval HRs were high, 185 to 206 bpm during the last minute before a dive and 120 to 181 bpm in the first minute after a dive. During overnight rest periods, HR calculated over ten-minute intervals in three birds was 84 $\pm$ 11 bpm (mean $\pm$ S.D.). During these rest periods, sinus arrhythmia patterns occurred in all birds at frequencies of 3-8 min^{-1}. These heart profiles provide greater detail than previously collected, averaged-HR data and reveal 1) a progressive bradycardia to extreme levels as dive duration increases, 2) pre- and post-dive HRs which are among the highest HRs recorded in emperor penguins, and 3) a sinus arrhythmia pattern in birds at rest which may reflect respiratory frequency.

Thurs 11:20 – 11:40

Use of an indwelling oxygen electrode probe to measure air sac P_{O2} in diving emperor penguins

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In order to determine the rate and magnitude of respiratory O_2 depletion during dives of emperor penguins (*Aptenodytes forsteri*), air sac P_{O2} was recorded using a small oxygen electrode inserted percutaneously into the posterior thoracic air sac and connected to a recorder attached to the bird's back. The results obtained from 73 dives of four birds diving at an experimental dive hole were evaluated with respect to hypoxic tolerance, the aerobic dive limit (ADL), and previously measured field metabolic rates (FMR). 55% of dives were greater in duration than the previously measured 5.6-min ADL. P_{O2} and depth profiles revealed compression hyperoxia and gradual O_2 depletion during dives. 42% of final P_{O2}s during the dives (recorded during the last 15 s of ascent) were < 20 mm Hg, which suggests a remarkable hypoxic tolerance in emperor penguins. Incomplete air sac O_2 depletion in many dives longer than the ADL also demonstrated that the onset of post-dive blood lactate accumulation is not associated with complete O_2 store depletion in emperors. Respiratory O_2 store depletion rates, based on the change in O_2 fraction during a dive and previously measured diving respiratory volume, ranged from 1 to 5 ml O_2 kg^{-1} min^{-1}, and decreased exponentially with diving duration. The mean value, 2.1 $\pm$ 0.8 ml O_2 kg^{-1} min^{-1}, was 1) 5-40% of previously measured respiratory O_2 depletion rates during forced submersions and simulated dives, 2) about one-third the predicted total body resting metabolic rate, and 3) about 10% of the measured FMR. These findings are consistent with a low total body metabolic rate during the dive. Funded by NSF grant OPP-0229638 and a NDSEG Fellowship (Meir).

Thurs 11:40 – 12:00

Movement patterns, diving behaviour and thermal biology of Atlantic bluefin tuna on their spawning grounds

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Electronic tags that archive or transmit stored data to satellites have advanced the mapping of habitats utilized by highly migratory fish in pelagic ecosystems. Here we report on the electronic tagging of 875 Atlantic bluefin tuna in the western Atlantic Ocean. Electronic tags have demonstrated the extensive migrations of individual Atlantic bluefin tuna. Geoposition data delineate two populations that overlap on northern north Atlantic foraging grounds, one utilizing spawning grounds in the Gulf of Mexico and another from the Mediterranean Sea. Both populations show fidelity in successive years to their respective spawning grounds. As the fish enter the western spawning grounds in the Gulf of Mexico, they exhibited deep diving (>500 m) for prolonged periods. However, once they are on their spawning grounds along the slope waters of the northern Gulf waters, their diving becomes much shallower, especially at night. The bluefin tunas on their breeding grounds occupy relatively warm water and exhibit elevated peritoneal temperatures. The capacity to describe the breeding behaviour is significant for identifying breeding area reserves for giant bluefin tuna.

Thurs 12:00 – 12:20

Using infra red thermography to examine surface effects of instrument attachment on grey seals (*Halichoerus grypus*)

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Previous research has highlighted the importance of minimising hydrodynamic drag from instruments fitted to marine mammals. However, little attention has been given to establishing how surface mounted data-loggers may influence the thermal characteristics of the skin or pelage. The aim of this study was to examine the effect of instruments on the surface temperature and heat flux at the site of attachment. Infra red (IR) thermography was used to record the surface temperature of juvenile grey seals (*Halichoerus grypus*) that had been fitted with heart rate and time depth recorders. IR images were taken of animals in captivity before and following a short period of swimming. Results show that around attachment sites the surface temperature was significantly higher, indicating relatively high rates of heat loss than from surrounding tissue. The heat flux from these areas made an important contribution to total exchange from the body. These preliminary findings suggest that IR thermography is a useful tool to study the ways in which instruments influence insulation, heat loss and hence metabolic costs of study animals.

Thurs 14:20 – 14:40

Foraging ecology of the endangered Abbott's booby–first data for an effective protection

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The Abbott's Booby (*Papasula abbotti*), endemic to Christmas Island, Indian Ocean, is one of the most endangered seabird species in the world. The population size is estimated at only 5000 individuals and numbers are decreasing. Interaction with fisheries and overfishing are thought to be major threats to the species. However, the Abbott's Booby is one of the least known seabirds worldwide and there is virtually no information on which to base an effective management and protection at sea. In the present study we succeeded in collecting data on the foraging ecology of the booby during the 2004 breeding season. Habitat utilisation, diving performance and activity patterns were determined using GPS- and GPS-depth-loggers. This, the first detailed data on the foraging ecology of this species, will be presented at the conference. The results already raise concerns about on-going fisheries projects and new proposals off Christmas Island.

Thurs 14:40 – 15:00

Wintering distribution and activity patterns of white-chinned petrels from South Georgia: individual strategies and implications for conservation

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Geolocation or Global Location Sensing (GLS), although less accurate than as other approaches, is a powerful technique for determining the distribution of highly pelagic marine species. The white-chinned petrel *Procellaria aequinoctialis* is a medium-sized procellariiform seabird with a circumpolar subAntarctic breeding distribution. White-chinned petrels feed during both day and night, in many cases on discards, are highly manoeuvrable and aggressive in competing for bait, and have amongst the highest incidental mortality rates in fisheries of any seabird. Although they remain abundant, the few census data suggest a rapid decline. Using combined GLS and immersion loggers, we determined the movements and activity patterns of white-chinned petrels from South Georgia throughout the annual cycle, including the first description of the wintering range of this species from any site. All birds migrated to Patagonian Shelf and shelf-break waters, in some cases to as far north as the Uruguayan coast. Most remained there throughout the winter, but a minority (20%) spent the latter months in the Humboldt Current (Chile), before returning directly to South Georgia at the start of the following breeding season. One bird tracked over two years adopted this second strategy in both winters, and also showed consistency in the timing of the return migration to South Georgia, but not the date of its first arrival off Chile. Despite the distance involved, birds commuted to similar feeding sites on the Patagonian Shelf during their long incubation foraging trips. Fishing effort and seabird bycatch rates are high in this region. Now that we have identified the provenance of many of the birds that are being killed, the status of the white-chinned petrel population at South Georgia should be viewed with considerable conservation concern.

Thurs 15:00 – 15:20

Using telemetry to reduce the by-catch of long-lived marine vertebrates

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The unintended by-catch of long-lived marine species in fishing gear is an important global conservation issue. One suite of management approaches used frequently to address this problem restricts or modifies fishing practices in areas where the probability of by-catch is believed to be high. Information on the distribution and behavior of the by-caught species is obviously a desirable component of any such scheme, but such observations are often lacking. We describe a spatially explicit approach which combines data on the distribution of fishing effort and observations of the distribution of by-catch species derived from satellite telemetry. We provide two examples in which we examined the spatial overlap of long-lived marine vertebrates and commercial gillnet fisheries. In the first study, we tracked 17 harbour porpoises (*Phocoena phocoena*) in the Gulf of Maine between 1995 and 1999. We conducted a *post-hoc* analysis to predict the probability of by-catch, based on the spatial and temporal distribution of porpoises and fishing effort using a predator-prey model. The results of this analysis were limited somewhat because the telemetry program was designed for other purposes. We then used the same model to investigate real-time interactions between three species of sea turtles (*Caretta caretta*, *Chelonia mydas*, and *Lepidochelys kempii*) and a gillnet fishery in Pamlico Sound, North Carolina in 2002 and 2003. In this latter study, our telemetry deployments (n = 45) were intended specifically to assess existing fisheries conservation measures. In both cases, we were able to predict the spatial distribution of by-catch and evaluate management measures. We suggest that this approach offers a powerful tool to managers faced with the need to reduce by-catch. The utility of the approach could be further improved if telemetry studies were conducted prior to the establishment of management measures.

Thurs 15:50 – 16:25

Plenary talk: Future directions and challenges for biologging sciences

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Most studies involving the use of biologgers aim to obtain behavioural, physiological or energetic data from animals in their natural environment. In other words to discover where animals go, what they do, how they are able to do what they do and the energy cost of doing so. As such, we should be in a position to test many of the models produced by theoretical biologists in real rather than in contrived conditions. These objectives define the requirements of the biologgers. As well as the functioning of the logger itself, i.e., its storage capacity, ability for onboard pre-processing of data and longevity, it is the range of sensors, means of obtaining the data and means of attachment of the logger to the animal that are the future challenges. In order to understand how animals function in their natural environment, it is essential that the loggers themselves have minimal adverse effects, so how they are attached to the animals is of crucial importance. As these challenges are met, a potential danger is that there will be a temptation to collect data for its own sake, rather than posing significant questions to answer or hypotheses to test. In addition, the size of the data sets will become ever larger and difficult to analyse and interpret. When studying wild animals in their natural environment, it is difficult to set up an experiment in the traditional sense, with all potential variables being controlled except those being investigated. Therefore it is much more likely that unforeseen data will be obtained that require *post-hoc* rationalisation. In a way, this is one of the exciting aspects of using biologgers, the discovery of the unexpected and sometimes, the overturning of dogma.

POSTER PRESENTATIONS

ECOLOGY

P-01. Elephant seal-borne miniturized CTDs provide an unprecedented number of temperature and salinity profiles for the poorly known southern Indian Ocean

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Operational oceanography aims at setting a global network of measurements for observing, modelling and predicting in near-real-time the state of the world ocean. Input data originate from satellite measurements of surface parameters, and from *in situ* subsurface observations from research vessels and autonomous profiling floats. Still, in the remote Southern Ocean, data collection is limited by logistic difficulties and by sea-ice extension, especially in winter**.** We show here how elephant seals from Kerguelen Islands equipped with miniaturized CTDs (Conductivity-Temperature-Depth devices) to study their marine ecology provide an unprecedented amount of high quality temperature and salinity profiles for the Indian sector of the Southern Ocean, otherwise poorly sampled.
Before deployments, miniaturized CTDs were laboratory calibrated and tested at sea against conventional CTDs. The geographical distribution of profiles obtained over 6 months by 10 seals foraging between Kerguelen Island and the antarctic pack-ice (600 m deep in average) is presented. A comparison with historical profiles from the GODAE (Global Ocean Data Assimilation Experiment) database shows that the contribution of elephant seals is massive, especially in the pack-ice zone where they forage during winter and where historical data are very limited. A total of 1070 profiles were collected by the seals between 45 and 60°S (vs. 1570 historical profiles), while between 60 °S and the continent, 2300 profiles were collected, twelve times the number of existing profiles (185). Examples of vertical section of temperature and salinity are also presented.
These data are now integrated on a daily basis in global databases for operational oceanography (such as GODAE/Coriolis) which will contribute to much better understanding of the Southern Ocean and its climatic variability.

P-02. Time and space, the final frontiers? Foraging behaviour of northern elephant seals (*Mirounga angustirostris*) related to oceanographic features at different spatial and temporal scales

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Female northern elephant seals spend up to 10 months of the year foraging in the North Pacific. Our ability to understand their behaviour during this time has been greatly enhanced by technological advances. Here we examine the influence of oceanographic variables on foraging behaviour at different temporal and spatial resolutions. We compared foraging behaviour of animals using coarse resolution environmental data collected by satellites and fine resolution data collected by bio-logging instruments on the animals themselves. Taking satellite tracks and dive data from 14 adult females from 1995 and 1996 behaviour at sea was divided into foraging and non-foraging based on transit speed between locations (foraging = transit speed <0.4m/s) at the coarse scale. This gave us a 2-day average of behaviour that matched well with the resolution of the satellite data. At the fine scale the shapes of individual dives were used to identify foraging, giving us a temporal and spatial resolution that is more biologically relevant to the animal. Satellite data on sea surface height, sea surface temperature (SST) and temperature gradients was used in a logistic regression analysis, which showed that SST was significantly correlated with foraging behavior at the coarse scale. Indicating that even at a gross scale, thermal structure is influential on foraging. The results of the fine scale analysis also confirmed the importance of temperature in relation to foraging behaviour. This study shows that, for animals foraging at large scales, coarse resolution data can be used to obtain an accurate idea of what may be important in foraging behaviour; and direct the focus of more detailed analyses.

P-03. The post-breeding distribution of adult and juvenile Antarctic fur seals (*A. gazella*) from South Georgia

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Despite comprehensive studies detailing the foraging behaviour of Antarctic fur seals during the breeding season, little is known of the post breeding and post weaning behaviour of adult seals and their pups. The aim of this study was to review recent distribution information from the post-breeding period, when seals are predominantly absent from the breeding beaches and foraging in oceanic areas.
ARGOS satellite tags were deployed upon post breeding adult fur seals and post-weaning pups between 2002 and 2004 from Bird Island, South Georgia. Winter distribution tracks were also obtained for female fur seals using recently developed, low cost, geographical location system devices deployed during winter 2003.
Results showed that both male and female post-weaning pups foraged in generally similar areas, to the east of Bird Island. Sexual segregation was more pronounced in adults. Females foraged to the west of the island, with some travelling towards the Patagonian Shelf, in a similar pattern to that previously reported by Boyd et al (2002). However, during our study the highest density of females was observed foraging in the same location that breeding females use throughout the summer. Post breeding males foraged towards the South Orkney Islands as also previously noted by Boyd et al (1998).
Samples collected at Bird Island throughout the study period indicated that though krill were still present in the diet, they were a less abundant component than compared with the summer period. This would suggest that the wider foraging distribution observed during the study is reflected in the diet. Some implications for the commercial harvest of krill are also considered in light of these results.

P-04. Diving behaviour of male and female southern elephant seals

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Elephant seals are the most sexually dimorphic of all Pinnipeds, an adult male may be 10 times that of a female. What is the possible effect of this in relation to foraging and diving behaviour?
We recorded the at-sea migrations and foraging behavior of 20 (10 males; 10 females) 5-year-old southern elephant seals using two approaches. Pressure housed Telonics ST-10 satellite transmitters (PTT) were attached with epoxy glue to the heads of 4 males and Mk7 geo-location time-depth recorder (GLTDR) and VHF transmitter packages were attached to the dorsal mid-line of all 20 seals. In this way some migration paths could be determined by either geolocation and/or satellite telemetry while the diving behavior was recorded with the GLTDR.
One female and one, or two, males were located in the same 300 km2 at the same time on 6 occasions. Stepwise discriminant function analyses indicated that there were significant differences in the diving behaviour. Most females (5 out of 6) made deeper dives than the males; although females made longer dives than males in only 3 out of 6 comparisons.
In early April 1999, female seal B533 and males B290 and C242 were located within the Dumont D'Urville Sea close to the Antarctic continent, where they made predominantly flat-bottom (benthic) dives. Female B533 showed a diurnally influenced behaviour while the males continually dived to a predetermine depth (the sea floor). In mid-April, male C026 and female B279 dived almost in synchrony in the pelagic open ocean north of the Ross Sea where their locations overlapped.
These findings suggest that at age 5 both sexes of southern elephant seals may be feeding in the same foraging area or not; but that females foraging over the Antarctic continental shelf may be more opportunistic feeders than males are.

TECHNOLOGY AND ANALYSIS

P-05. The effect of logger size and position on the diving performance of the smallest penguin (*Eudyptula minor*)

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The development of bio-logging science has improved our ability to study a large array of marine animals in their environment over the past decades. However, attaching data-loggers on the backs of streamlined swimmers can increase the animals' drag which affects the birds swimming performance. Biologists have strived to minimise the size and the frontal surface area of loggers to reduce drag. The best position suggested for placement of the loggers was the lower back in order to reduce the drag on the animal's body but there have been very few attempts to determine how loggers modify the activity of the animals at sea.
We used time-depth recorders (TDRs) to test the effect of positioning and logger size on the diving behaviour of Little penguins *Eudyptula minor* in their natural environment. Here, 36 penguins were equipped with small and large (3.4% and 4.9 % of the penguins' frontal surface area respectively) TDRs placed on the lower or middle back. We tested the hypothesis that the swimming (surface time, maximum depth, hourly diving rate) and foraging (body mass gain, percentage of hunting diving time) performance of penguins with large, middle-placed loggers was more affected than penguins with small, lower-placed loggers. We found that penguins equipped with small TDRs which were placed on the middle back dived deeper than penguins with large TDRs and also that females with large loggers descended at greater rates than females with small loggers. The positioning had a significant effect on the large TDR group but less in the small TDR group. Penguins with a greater degree of impairment appeared to work harder during their daily trip than less-impaired birds but their parental effort remained unaffected within a single trip. Future studies should focus on the cumulative effect of loggers on the parental provisioning effort.

P-06. Error measures from template-fit geolocation based on light

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An outstanding issue with light-based geolocation methods is the estimation of error size. The template-fit method offers two relevant error measures, the fit residual and the covariance matrix; this paper reports an investigation of their properties when tested against the Shaw Island historical set of blue-light irradiance data taken by archival tags (Lotek LTD750) on land (48.57°N, 122.94°W)
The template-fit method matches a geophysically-derived model to observed twilight irradiance data vs. time, adjusting the model parameters – latitude, longitude and cloudiness – for best fit. The best-fit parameter values are taken as position estimates.
Contrary to the usual assumptions, noise in irradiance field data is neither equivariant, nor independent, nor Gaussian. As a result the statistical behaviour of the fit residual is only approximately chi-squared with only a small number of apparent degrees of freedom, thus reflecting the strongly correlated noise.
Nonetheless the residual remains a useful measure of the degree to which the model can account for observed data from any particular day. It can be used for automatically detecting outlier bad days that are seriously perturbed by weather changes during twilight and pruning them from the position record. In addition, the error in any given day's longitude results is also correlated with the size of the rms residual.
Similarly, elements of the covariance matrix do not have their usual interpretation; nonetheless the diagonal element associated with latitude does usefully reflect the geometric ill-conditioning that leads to poor performance of all light-based latitude methods on the winter side of an equinox. The product of fit residual and covariance estimate form a useful error estimate for any day's latitude.
Recent work on extending the template fit method, which was completed after the abstract deadline, will also be discussed.

P-07. Investigating the use of GSM mobile phone and GPS to track a coastal odontocete, Heaviside's dolphin, a preliminary report

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The aim of this study was to develop a cheaper tracking alternative to ARGOS based satellite telemetry with a comparable range and possibly an increased accuracy to enable us to investigate the movements and range of Heaviside's dolphin, a coastal odontocete endemic to south western Africa. The extremely powerful and diverse functions of GSM (Global System for Mobile Communications) mobile phone technology have recently been turned to the advantage of biologists wanting to track animals. GPRS (General Packet Radio Services) and SMS (Short Message

Service) have been successfully used to download a variety of data, especially locality, from terrestrial animals via GSM networks. Only recently have advances allowed us to move this technology to the oceans (McConnell et al, 2004). Standard GPS and GSM units would not work on a small cetacean due to the registration period of both units being considerably longer than the brief period in which the dolphin and tag are exposed to signal from either GPS satellites or cell antennae. However, new fast tracking GPS units can, with post processing of data, acquire position considerably quicker (<1sec), albeit with slightly less precision (~50m) than standard GPS units. We have combined existing technologies in a novel configuration to create a fin-mounted, pop-off archival floating tag that will download data (position from a fast tracking GPS) via GPRS once released from the animal. A second method of tracking is currently being investigated, the use of Location Based Services to track the GSM unit alone by triangulation from known positions of antennae. Tag design and considerations will be discussed as well as results of initial tagging data and future goals of the study.

P-08. Animal Tracking Spatial Environment Analyser (AT SEA)

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The collection, management, visualisation and analysis of animal movement and related spatial datasets are plagued by a lack of consistent, flexible software tools. Published data are often analysed with different, and difficult to replicate, approaches, compromising comparative studies.
AT SEA is an open-source, highly generic and modular data manipulation platform. The system is graphically driven and intuitive to use. Modules that contain specific data processing or visualisation functionality appear as boxes, with data that moves between boxes appearing as arrows. A user constructs their modularised analysis / data handling system and can save, alter and pass their work on to other users just like any other type of document. The system reacts in real time across all modules such that, for example, alterations in data processing steps are immediately represented in tables, maps or spatial statistics. In addition to its generic components, AT SEA will readily interface to and make use of the functionality provided by existing packages such as databases systems and analysis platforms like R. While the initial focus is on developing interpolation and analysis systems for animal tracking data, it is envisaged that this system will be widely applicable to a large range of discontinuous spatial data.

P-09. Assessing actual movements of ARGOS tracked marine animals: a novel approach

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Satellite tracking is widely used for monitoring free ranging animals at spatial and temporal scales that enable to link animal's movements to environmental conditions. Changes in animal's movement patterns (e.g. in terms of speed, degree of directionality) have been used as a cue to assess animal's behaviour in order to discriminate travelling from foraging. Among the numerous goals of such an approach, one aim is to discriminate migration routes and foraging grounds, in order to better assess the habitat of the considered species.
In a moving environment (such as water and air), the apparent movement of an animal (AppMov) results from the combination of the actual movement of the animal (ActMov) and movements of the surrounding water or atmospheric masses (EnvMov), such as AppMov=ActMov+EnvMov. Accordingly, the apparent degree of directionality of an apparent track does not necessarily reflect the actual animal's behaviour, i.e. the actual directionality of the actual movement of the animal. Though not ignored this has not been quantitatively investigated so far.
Here, we analyzed the apparent reconstructed route of a leatherback turtle *Dermochelys coriacea* from the northern Atlantic ocean, obtained from ARGOS tracking. This apparent route shows two main patterns of movements, with several directional sections commonly considered as travelling, alternating with several non directional sections, commonly considered as foraging. However, when the contemporaneous sea surface currents derived from altimetry were taken into account, we show that the changes of the actual movements of the turtle only consists in only two long directional/travelling sections separated by a single, but also long, non directional/foraging section. This analysis shows the significant effects of environmental physical constraints (for instance surface currents) on sea turtle movements. It suggests that studies investigating marine animals' behaviour based on tracking data should systematically consider the possible impact of ocean dynamics on the inferred behaviour.

P-10. Relaying dive profiles for marine animals via the Argos satellite system

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To circumvent the limited bandwidth of the Argos satellite system, novel compression techniques for relaying depth data have been developed to allow reconstruction of dive profiles. Here we validate this approach by simultaneously deploying two instruments onto a deep diving marine animal: a satellite tag incorporating these on-board compression techniques along with a traditional TDR. In this way we show the utility of these new techniques for obtaining behavioural data from remote locations over extended temporal and spatial scales.

P-11. MANTA: The marine animal tracking apparatus

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MANTA is a marine animal tracking and data-telemetry system which integrates acoustic transponder, underwater modem, data-logging, GPS, and VHF telemetry technologies. This system differs from existing tag-based, marine animal tracking technologies in that it incorporates several complementary technologies allowing tagged marine animals to be tracked underwater in real-time, three-dimensionally, and at very high spatial resolution (i.e. +/- a few meters). The primary application of MANTA is for detailed real-time monitoring and data-collection of animal movements, behaviors (including vocalizations), physiology, as well as for collection of oceanographic data directly from tagged marine vertebrates (e.g. whales, pinnipeds, elasmobranchs, sea turtles etc.). Location information is processed in real-time on a "surface station" located onboard a tracking vessel. Location data includes the animal's latitude, longitude, and depth (+/- 1m) and can be updated every few seconds. Standard VHF telemetry allows animals to be tracked while at the surface and when animals are beyond the tracking range of the acoustic system. In addition, data can be collected from up to 6 sensors (e.g. accelerometer, thermistor, etc.) that can be integrated on the tag. Furthermore, data from the MANTA tag can be acoustically telemetered (at limited bit-rates) to the surface via an underwater modem and/or logged internally on FLASH memory modules. The current version of the tag has an integrated accelerometer (to derive pitch & roll). A prototype acoustic "event detector" also has been developed and improvements to processing and data-storage capabilities are planned. Examples are provided of data collected from test deployments on blue whales in Monterey Bay, California. [Work Funded by U.S. Office of Naval Research]

P-12. A new approach to tag design in dolphins telemetry

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Bio-logging and/or radio-telemetry has proved itself as a powerful methodology for studying cetacean biology. The tag carried by dolphins can include different sets of the sensors depending on the research goals. However, despite remarkable progress in microelectronics and miniaturization of loggers and transmitters, tags on dolphins are still problematic, for two main reasons: 1) tags are not carefully constructed to minimize drag and are thus likely to increase the energy expenditure of swimming, and 2) dolphins may feel discomfort due to extra loads on the dorsal fin tissues. A new approach to the construction of telemetry tag for small cetaceans is proposed. According to this, tag design should be based on peculiarities of anatomy and hydrodynamics of selected species. The optimal tag should minimize its affect on the dolphin behavior and be constructed well enough for long-term data acquisition. This compromise can be reached by the construction of the low-drag tag with advanced energy budget. The shape and mechanical properties of a tag should correspond to the range of deformations and natural loads on the dorsal fin during the maneuvers. The parametric models imitating natural flexibility of the dorsal fin were constructed and computer fluid dynamics tests of the dorsal fin were carried out. Data obtained are used in tag design as well as in ground of the additional source of power of a tag. The flow-surface interface of the tag can be used as additional source of power, making contribution to the energy budget of a tag. Utilization of piezoelectric transducers enables increasing of tag longevity without additional battery, i.e. without additional weight and drag of the device.

P-13. Objective classification of dive shapes from satellite relay data recorders

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With every dive, air-breathing marine predators must choose how they allocate their limited time under the surface. These choices reflect the trade-offs between physiological limits and the spatial organization of their prey. Standardized measures of shape, derived from time-depth trajectory data, are one metric used to describe these choices. Ideally, shape of individual dives should be determined objectively, to avoid bias, improve reproducibility and permit comparisons among different studies. Previous objective analyses of dive shape have been made using data from archival time-depth recorders (TDR), which must be recovered from study animals in order to retrieve the data collected. Because recovery of instruments is not feasible in all cases, shape classification techniques that can be applied to data from satellite tags would be useful. Here we report on a modification to the multivariate K-means clustering method, an approach frequently used in the classification of dive shape from archival TDR data, that allows it to be used with the discrete, generalized dive profiles reported by Satellite Relay Data Recorders (SRDL). We then apply the results to understand the foraging behaviour of Steller sea lions (SSL, *Eumetopias jubatus*) in Alaska. Objective classification of 14,500 dives recorded from 24 sea lions yielded 5 distinct dive shapes, which were classified with 91% accuracy. This objective classification allows SSL diving to be examined in the context of foraging upon patchy prey, and also provided a standard metric by which SSL behaviour might be compared to other air-breathing marine predators. More broadly, our modification of this analysis technique permits researchers forced to study diving using satellite-relay technology to take better advantage of the extensive body of biological and ecological interpretation built upon archival TDR data.

P-14. Comparative performance of current generation geolocating archival tags

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For the past several years, we have conducted experiments with both wild and captive tropical tunas, using surgically-implanted geolocating archival tags manufactured by two companies: Lotek Wireless, Inc. and Wildlife Computers, Inc. These tags, based on different architectures, have evolved over this time period, and it is important to document the comparative performances of the current generation of the two tags. First, quantitative evaluations of sensor performance for depth, temperature, and light have been conducted through replicate trials of five tags of each type (Lotek's LTD 2310 and Wildlife Computers' Mk9) simultaneously through hydrocasts to nearly 500 m with a calibrated Seabird SBE39 time/temperature/depth probe in the equatorial eastern Pacific Ocean (EEPO). Accuracy and precision of depth and temperature sensors, and sensitivity of light sensors were determined. Second, accuracy and precision of geolocation estimates from the two types of geolocating archival tags were evaluated from recoveries of tags previously implanted in bigeye tuna (*Thunnus obsesus*) in the EEPO and from tags previously implanted in captive yellowfin tuna (*T. albacares*) held for prolonged periods at the IATTC Achotines Laboratory, in the Republic of Panama.

PHYSIOLOGY

P-15. Factors influencing the prediction of field-metabolic rate in a reptile

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Direct measurements of the rate of oxygen consumption (VO^2) in the field are usually impractical, so several studies of endotherms have utilized heart rate (f_H) as a correlate of VO^2 due to the tight relationship that typically exists between the two variables. There have been several reports, however, where the relationship between f_H and VO^2 changes or disassociates under certain circumstances such as digestion or thermoregulation. This may be further confounded in

ectothermic vertebrates, which experience relatively large fluctuations in body temperature (T_b). The aim of the present study was to characterize in Rosenberg's goanna (*Varanus rosenbergi*) the relationship that exists between T_b, f_H and VO^2 at rest and at different levels of exercise, during periods of heating and cooling, and following ingestion of a meal. The combination of T_b and f_H were accurate at predicting VO^2 of animals at different levels of exercise and recovery, and during the postprandial period. Predictions of VO^2 became less accurate during periods of relatively rapid heating when f_H and blood flow increase for thermoregulatory purposes with no associated increase in VO^2 To counter this, f_H was excluded from the prediction equation when the rate of heating exceeded 20% of the maximum attainable rate, and VO^2 was predicted using T_b alone. The resultant prediction equation was validated on seven animals that were allowed to thermoregulate behaviourally, and the mean predicted VO^2 (VO^2_{pred}) was not significantly different from the mean measured VO^2 (VO^2_{meas}) for fasting or postprandial lizards. Furthermore, a plot of VO^2_{pred} as a function of VO^2_{meas} averaged over 1 h intervals resulted in a linear regression that was not significantly different from the line of equality, indicating that the principles outlined in the present study can be utilized accurately to predict field energetics of free-ranging ectothermic vertebrates.

P-16. Energy savings and parental effort in breeding Adélie penguins

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Adélie penguins are faced to high energetic cost of reproduction, as they often breed 2 chicks that have to be grown up in 45 to 60 days during the short Antarctic summer. Although Adélie penguin breeding strategy is biparental, previous studies show differences in male and female energy expenditure along their breeding cycle.
We investigated the energy saving mechanisms of both partners of a breeding pair, fasting on the colony and foraging at sea, linked to their different parental investment and behaviour, during incubation and chick rearing. Two pairs of Adélie penguins in summer 2000-01 and 1 pair in 2001-02 were equipped with one external data loggers measuring depth, and one internal data loggers measuring subcutaneous, peripheral, and deep body temperature.
We show that during their fast on the colony, deep body temperature of male and female Adélie penguin decreases, explaining their low metabolic rate during incubation. While at sea, their mean body temperatures are lower during diving bouts than resting phases. Furthermore, their deep body temperature decreases along their diving bouts, possibly permitting them to increase their foraging efficiency. Though no differences are noticed in male and female diving behaviour during the incubation foraging trip, one male dived deeper and longer than females, which spent longer time at sea during the chick rearing foraging trips. An original foraging strategy has been used by the two pairs during the first season, as they increased their number of dives during the last days of their trip, preferentially diving from 22.00 pm to 03.00 am. This nocturnal diving pattern could be used to optimize their foraging efficiency in order to increase the quantity of food delivered to their chick.
Thus, both physiological mechanism, by reducing their energetic investment, and variable behavioural strategies seem to enhance Adélie penguins breeding success.

P-17. Physiological thermoregulation assisted by thermal inertia in gigantic ectothermic fish

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It is indicated that some sharks have body temperatures thermoconserving or thermoregulating mechanisms associated with large vertical ambient temperature change. However, the mechanisms for the sharks moving through the natural environments have not been clarified. Body temperature data telemetered from a free-ranging blue shark, *Prinoca glauca* (weighted 100 kg), were used to demonstrate physiological thermoregulation, developing a mathematical model which can separate the effects of physiological thermoregulation and those of physical thermal inertia. The result indicates that the changes in artery blood flow in the blue shark are assisted by the large thermal inertia in response to quickly changing ambient temperatures. Further, the blue shark returns to cooler depths before body temperature is recovered to the same level of the surface temperature, indicating that this behavior contributes to the rate of body temperature recovery maximized.

P-18. Spectral characteristics in heart rate variability as an index of physiological condition of fish attached micro data logger

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Continuous up to almost 10 days time series of HR of free swimming red sea bream in the net pen was obtained by micro data logger. Spectral analysis of HR variability was performed using FFT and Autoregressive (AR) methods. The FFT was used to reveal ultradian periodicities and 1/f fluctuations, while the AR was used for high frequency component showing autonomic nervous activity. Notable peak at 11.1 h period was observed until 7 days after releasing, whereas those spectral peaks vanished in the following days. The power spectral densities computed for every one day period revealed the existence of 1/f fractal of which slope around -1, from the day 1 to day 7. Also there were some spectral peaks at around 0.01 and 0.1 cycle/beats in the spectra by AR method until the day 7 which exhibit vagal tonus, whereas all power spectra disappeared after the day 7. It was noted that some physiological changes have occurred on the fish as the time elapsed after releasing, as indicated by the existence of 1/f fluctuations, frequency components of HR variability and visible erosion at the injured portion caused by attached logger.

BEHAVIOUR

P-19. Differences in diving behavior of sperm whales between two areas, off Kii Peninsula and off Bonin Islands, Japan

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The sperm whale (Physeter macrocephalus) is one of the deepest diving marine mammals. In recent years, sperm whales have been reported to dive greater than 400m with instruments attached to the whales. However, little is known about how their diving behavior may relate with their ocean environment. In the present study we compared their diving behavior between two areas, off Kii Peninsula (southeast of Osaka) and off Bonin Islands (south of Tokyo 1,000km), Japan. We discuss the relationship of their diving behavior with two oceanographically discrete waters masses. Some sperm whales migrate into the waters off Kii Peninsula in late spring to summer and are frequently observed on the edge of the Kuroshio Current, while others are observed off Bonin Islands throughout a year. In 2000 and 2004 we obtained interesting diving records of swimming speed, depth and water temperature of sperm whales from the attached data loggers at the these two areas. A total of 182 hours of diving data was obtained from ten sperm whales in the two areas, off Kii Peninsula (n=4) and off Bonin Islands (n=6). The whales at both locations were diving almost continuously within the range of 400 – 1,300 m. A significant difference in diurnal pattern of diving profiles of whales with similar total body lengths between the two areas was observed, but not in dive duration and maximum depth. Off Bonin Islands, sperm whales make dives between 800 – 1,300 m during the day, but they did not exceed 600 m at the night. In contrast, off Kii Peninsula each individual showed similar diving pattern between both day and night. We suggest that this diving difference between the two areas is due to differences of diurnal distribution of their prey.

P-20. Individual foraging strategies in Australasian gannets (*Morus serrator*)

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The individual foraging behaviour of Australasian gannets (*Morus serrator*) was studied using GPS and time-depth recorders. Gannets were found to forage at average maximum distances of 49 km (± 39 km) from the colony, with total foraging path lengths of 143 km (± 108 km) and foraging trip durations of 13.9 h (± 11 h). During foraging trips gannets spent on average 48.7% (± 17.6) of the time flying and made 37 (± 30.4) dives per trip, with an average maximum depth of 3.6 m (± 1 m). However, considerable variation in individual foraging strategies were recorded and these will be discussed in relation to individuals age, breeding experience and sex.

P-21. Attendance patterns of juvenile Steller sea lions (*Eumetopias jubatus)* derived from satellite dive recorders (SDRs): a comparison between declining and increasing populations

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Attendance patterns of juvenile Steller sea lions were determined to assess changes in behaviour potentially related to development of diving ability. Durations of time on shore and at sea were calculated using satellite dive recorders deployed between 2000-2002, and compared between two genetically distinct populations; one increasing (Eastern stock; *n*=66) and one (Western stock; *n*=63) that experienced an 80% decline in population since the mid-1970's. The data represented a 24-hr period divided into 72 20-min increments indicating whether an animal was hauled out (dry) or at sea (wet). Due to the large amount of data received, we developed an algorithm to determine arrival and departure time and duration of each wet and dry event, automating the process of describing attendance behaviour. The time apportioned between land and sea was described on a per trip basis (rather than a 24-hour cycle) and durations ranged from a few hours to several days. Patterns were compared among sex, geographic regions, year, and age (5 - 37 months) using repeated measures ANOVA. Individuals from the Western population tended to haul out just after sunrise and departure times coincided with dusk. In SE Alaska, arrivals and departures occurred throughout the day and were not related to crepuscular period. Mean duration on shore did not differ among sex, region, year, or age. Time spent at sea varied among individuals from both populations and were significantly longer in the Central Aleutian Islands than in the Eastern Aleutian Islands ($P = 0.007$), Central Gulf of Alaska ($P = 0.032$), and SE Alaska ($P = 0.02$). Development of independence as inferred from significant increases in time spent at sea occurs approximately 10 months later in individuals from the Eastern stock. This seems to indicate environmental and developmental differences between the populations.

P-22. Seasonal migration and diving behavior of Caspian seals, *Phoca caspica*

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The Caspian Seal (*Phoca caspica*) is an endemic species living in the Caspian Sea. We have investigated their seasonal migration and diving movements which have not been previously studied in detail. Argos satellite transmitters (Telonics ST-6 PTT) were attached to these seals. Seals were all tagged on Pearl Island, Russia in the northern Caspian Sea. In 1998 and 2000, the migration and movements of 5 adult male seals (body length: 104-117cm) and 5 adult female seals (body length: 105-125cm) were monitored from autumn through spring for a total of 202 days. Data collected from the transmitters shows seal migration throughout the whole of the Caspian Sea. The four main migration patterns were: 1) movement north to Baku (Azerbaijan) along the western coast, 2) movement north to the coast of Turkmenistan along the eastern coast, 3) movement to the northeastern coast of Kazakhstan, and 4) movement around the northern center part of the Caspian Sea. Seals in the former two patterns migrated southward along coasts, and their dives were mostly to a depth of 0-75m, a few exceeding 200m. The data did not show any difference between dives during the day and night. Monitoring of one seal (body length: 114cm, male) in a shallow area on the west side of the Caspian Sea showed shallow dives (0-10m). This seal then moved south to an area deeper than the northern part of the Caspian Sea, and its dives deepened there. Another seal (body length: 117cm, male) moved to the east side and also made shallow dives (0-25m). As this seal remained offshore for a few months, it probably was only hauling out on sandbars.

P-23. Fine-scale analysis of acceleration and flipper strokes to assess locomotor work on different scales of the foraging trip. Case of the king penguin.

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Within the framework of a long-term study on diving energetics in king penguins *Aptenodytes patagonicus*, in the present study we attempted to characterise the mechanical work of swimming on different scales during a foraging trip at sea. For this purpose, 5 breeding birds were equipped with custom-made high-capacity storage data loggers (J.P. Gendner, CEPE Strasbourg). During the foraging trip, these loggers continuously recorded pressure and water temperature at 0.5 Hz. Twice daily, we also recorded flipper stroke movements (Hall sensor and magnet) and 2D-accelerations, along the tail-to-head (surge) and ventral-to-dorsal (heave) axes, for 60 min, at a frequency of 32-64 Hz. Besides the analyses of diving patterns (maximal depth, diving duration, bottom profile and prey pursuits), we developed a model to assess the locomotor work on the scale of individual wing strokes. These high frequency data analyses were processed with customized MATLAB (6.5) programs. This allowed us to reconstitute, within the different phases of a dive as well as on a wider scale, the work invested in locomotion and the part devoted to overcome the external forces opposed to progression in water. It was thus possible to investigate how diving patterns and body condition (adiposity and initial density) affected the mechanical work associated with diving in this large penguin species during different phases of its long foraging trip at sea.

P-24. Swimming speed and foraging strategies of northern elephant seals, *Mirounga angustirostris*

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The northern elephant seal, *Mirounga angustirostris,* is a deep, continuous diver. This species consistently exceeds calculated aerobic dive limits. In this study we examined swimming speed as a key variable to successful foraging strategies between adult males and females and adult and juvenile females. Foraging strategies were determined using a combination of speed, time, and depth data from data logging equipment carried by the seals. Adults were also equipped with satellite transmitters for accurate location data. In addition, ultrasonic and morphological measurements were taken with mass to determine buoyancy from body composition upon departure and return from foraging migrations. Mean swim speeds were similar across all classes despite significantly different predicted MCT calculations. Buoyancy appeared to affect two-dimensional dive shapes and seals' ability to utilize extended gliding behaviors between the surface and deep water foraging zones. Contrary to model predictions from previous investigations, seals did not reduce swimming speed with increased dive depth and retained bottom durations of dives irrespective of depth. Unknown behavioural and physiological adjustments appear to allow juveniles and adults to defend time in the foraging zone irrespective of swimming speed on descent. The two – dimensional shapes of dives varied between sexes and age classes, but all individuals exhibited characteristic dives and their putative functions. Cycles of acceleration and deceleration were present in all study groups. Individual variation within classes and across dive types was significant. Sex differences in diving behaviours and between young and adult females were significant.

P-25. Seasonal migration of thornback rays and implications for closure management

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Thornback rays (*Raja clavata* L.) are thought to form local sub-populations, between which little exchange of individuals is thought to occur. This feature of the biology of thornback rays coupled with late maturation and low fecundity make these fish highly vulnerable to localised extinction due to fishery exploitation. A significant decline in the abundance of a range of commercially exploited elasmobranchs has further highlighted a growing need for sustainable management strategies. Here we describe the results of a study in which 197 thornback rays were tagged with electronic data storage tags and released in the Thames Estuary (United Kingdom). The movements of the fish throughout their liberty period were reconstructed using a method of geolocation based on tidal data recorded when rays remained on the sea-bed over a full tidal-cycle. Contrary to predictions based on conventional tagging experiments, our

results show that rays are not restricted to the Thames Estuary, but move more widely in the southern North Sea, with a seasonal pattern of migration. Geo-spatial analytical techniques were applied to integrate seasonal fish distribution data with a spatial and temporal analysis of catch and fishing effort data. The impact of closed areas in the Thames Estuary is considered in terms of the likely conserving effect on ray stocks and the potential benefits to the commercial fishery in terms of increased ray stock biomass and yield.

P-26. Flipper or foot: which works best against buoyancy?

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Buoyancy is a major determinant of the locomotor cost for diving animals. As seabirds have large amount of air in the feathers and respiratory system, they should work hard against buoyancy to descend the water column. However, work against buoyancy becomes minimal below the depth at which most of the air spaces in the body have been compressed. None-the-less, shallow divers should work against buoyancy during both the descent and bottom phases of their dives. We deployed miniaturized depth-acceleration recorders on free-ranging foot-propelled divers (great cormorants *Phalacrocorax carbo*) and flipper-propelled divers (little penguins *Eudyptula minor*) foraging in shallow waters, to monitor their diving strategies and determine how these birds manage to swim against buoyancy using these two contrasted locomotory modes. Cormorants decreased both stroke frequency and amplitude during descent and maintained a constant swim speed. In contrast, penguins did not change their stroke frequency or amplitude and as a result their swim speed increased during the descent. During the bottom phase, cormorants did not stroke much and headed towards the bottom, while penguins were actively stroking maintaining a horizontal position throughout the bottom phase. Furthermore, intensive acceleration periods during bottom phase were recorded often for penguins but rarely for cormorants. Great cormorants and little penguins used different strategies to feed underwater and counteract the effect of buoyancy. Great cormorants seems less active than Little penguins while underwater, adopting in that an energy-saving strategy, which could relate to dietary difference, to high energy costs for thermoregulation and low prey abundance at the birds feeding grounds in Greenland.

P-27. Diel movement patterns of the Japanese flounder, *Paralichthys olivaceus*: time or energy minimization?

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Japanese flounder Paralichthys olivaceus occupies an important ecological niche as a benthic predatory fish in the coastal marine ecosystem of Japan. To analyse the movement pattern and migratory strategies during the feeding season, two types of data-logger (W-PD2GT and UWE-DT/NIPR-DT; Little Leonardo, Co., Tokyo) were used on 31 Japanese flounder. Sixteen adult flounder were tagged with depth/temperature data-loggers, fifteen with depth/tailbeat/body angle/speed data-logger, and released off the coast of Tsugaru Strait, near the northern part of Honshu Island, Japan, between 21 October and 11 November 2000 and 12 and 21 October 2002. Of these, thirteen were retrieved. Tailbeat-and-glide behaviour during swimming was the predominant migratory strategy during the night. Also, during the day, and at night, only beat (continuous tailbeating) behaviour was used. In tailbeat-and-gliding, Japanese flounder minimized energy consumption per distance. On the other hands, our results suggested that they minimized time per distance, adopting only beat behaviour. The time-depth profiles also showed strong patterns of diel activity. They are more active at night than during the day. The daytime inactivity of adult flounders might be a mechanism for avoiding diurnally active predators, such as seals, or might result from the 'sit-and-wait' predatory habit of adult flounders. In contrast, the increased nocturnal activity of adult flounders might involve movement to exploit other patches, because there is no feeding at night. During the feeding season, adult Japanese flounders feed during the day using a sit-and-wait strategy or make short-range movements within a local patch, while they exhibit long-range movements at night with the highest oscillations and longest duration of swimming off the seabed.

P-28. Homing behaviour of chum salmon from coast to river in Otsuchi Bay area revealed by newly developed temperature/depth/acceleration/geomagnetic micro data logger

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The homing migration of adult chum salmon (*Oncorhychus keta*) along the northern coasts of Japan is well documented. Several behavioural studies using archival tags and micro data loggers have provided fine scale information of vertical movements and environmental variations encountered by individuals during their oceanic and coastal migration. However, there is still little information of their horizontal positions as well as their environmental choices, which are indispensable for better understanding of their homing behaviour, due to difficulties encountered while tracking free-ranging individuals at the sea. To obtain this essential information, we used the newly developed micro data loggers (2M2GDT loggers) for salmon, which contained temperature, depth, acceleration and geomagnetic sensors. The geomagnetic sensors recorded the heading of the free-ranging fish, and therefore their horizontal movement and directional choices could be estimated. The 2M2GDT loggers were 20mm in diameter, 117mm in length, weighing 28.3g in water. In early December 2004, five mature chum salmon were tagged with 2M2GDT loggers and released in Otsuchi Bay located at Sanriku coast, northeastern part of Honshu Island. After 3 days a female individual (fork length 73.5cm, body weight 4800g) entered the set net located at the mouth of the bay, and after 4 days another male individual (fork length 71.0cm, body weight 3790g) entered the set net located at Otsuchi River. The salmon repeated vertical movements as usual, while moving around the deeper bay mouth area. In contrast, when entering to the shallower area inside the bay, he showed frequent and shallow vertical movements. He did not enter river directly but made detour movement along the river water in surface, while showing unique shallow movement. Our data showed the actual geographical and environmental choices of the homing chum salmon in Otsuchi Bay.

P-29. Short-term effects of suction cup tagging on the deep-diving behaviour of sperm whales

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We have used a 12-m cantilevered pole system operated from a rigid-hull inflatable boat to attach archival tags to over 70 sperm whales using suction cups. Tagged whales typically make minor short-term responses that are visible from the surface. To evaluate whether our tagging system might influence sperm whale behaviour beyond immediate visible reactions, we examined dive duration, buzz rates, and pitching movements from fluking for 24 and 13 sperm whales for which we obtained two and four or more dives, respectively. Relative to the second dive post tagging, the first dive had a shorter duration (-7.3%, paired t_{23} = -2.45, P=0.024), lower bottom-phase buzz rate (-14.4%, t_{22} = -2.17, P=0.041), and a non-significant decrease in pitching movements (-4.9%, t_{23} = -1.49, P=0.15). Using repeated measures ANOVA, dives 2-4 did not differ for buzz rates or pitching movements (buzz-rate: $F_{2,11}$ = 0.240, P=0.79; pitching-energy: $F_{2,11}$ = 0.148, P=0.86), though dive 4 was somewhat shorter than dives 2 and 3 ($F_{2,11}$ =3.81, P=0.055). These results indicate that behaviour during the first recorded dive was influenced by tagging, though subsequent dives were relatively unaffected. Our results confirm the importance of evaluating effects of instrument attachment on behaviours under study.

P-30. Vertical movement of Mekong giant catfish *Pangasianodon gigas* limited by the hypoxic waters in the reservoir

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In order to understand the moving behavior of Mekong giant catfish *Pangasianodon gigas* in relation to the water temperature and dissolved oxygen (DO) conditions in a reservoir, Thailand, two catfish were monitored using Depth-

Temperature data loggers (UME 190DT, Little Leonardo, Tokyo, Japan) which were attached with a brand-new time-scheduled release system. The release system automatically detached the loggers from the catfish 5 days after deployment. Then we searched for VHF radio signals and found a logger approximately 2.2 km away from the release point. The other was never found because it was hidden by a dense cover of floating waterweeds. The logger that was recovered provided depth and temperature data for approximately 98 hours. Results from the data analyses found that the fish spent more than 99 % of their time above the depth of 3 m. The fish made only 4 deep vertical movements greater than 5 m and the maximum swimming depth was 5.6 m. The difference of the ambient temperature during these movements ranged from 1.7 to 2.0 ^{o}C. The stable temperature might have little effect on the catfish behavior. During our experiment period, there was no thermocline although DO stratification was built up at the depth of 4 m, and the DO below 4 m deep was uniformly less than 10 %. These results indicated that the DO stratification limited the vertical movement of the catfish. Furthermore, in 4 deep movements the descent rates were significantly lower than the ascent rate for each movement, respectively, which indicated that the fish might display the avoidance movement from the hypoxic waters.

P-31. Bio-logging science research in ocean research institute, the University of Tokyo, Japan

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Bio-logging science is the interesting scientific field as a new step in the discovery of diving behaviour and ecology of aquatic animals, and the physical and chemical environment in the ocean. Staff of Ocean Research Institute (ORI), the University of Tokyo, Japan have studied underwater behaviour of various kinds of aquatic animals such as seals, whales, fish, sea turtles, and sea birds, and their environmental conditions using the advanced data and camera loggers by Little Leonardo Cooperation with cooperation of the Bio-logging Institute (BLI), Japan. We can cover the environmental factors such as depth, temperature, salinity, and the specific diving characteristics such as speed, acceleration, angle of head, three-dimensional swimming route of aquatic animals every second interval. Through the camera loggers we can also get the direct information on how the aquatic animals feed the prey species, form the school, and change colour pattern depending on physiological condition every 30 second interval. The above information provides the new knowledge of diving behaviour and ecological characteristics of aquatic animals and their environmental conditions, and the meaningful suggestion for future direction of the oceanography. In this presentation, we report scientific activities of ORI and its future scope. In the recent investigations, we had the interesting hot topics as follows; (1) different diving behaviour of Baikal seals between day and night, (2) specific deep dive of sperm whales in Japanese waters, (3) unique invertebrate fauna under the ice shelf of about 150m-depth observed through camera loggers set on Weddell seals in the Antarctic Ocean, and (4) characteristics of home coming behaviour of chum salmons for breeding and their colour pattern change with maturing in the northern Pacific coast of Japan.

P-32. Estimates of prey richness using diving profiles in Weddell seals: comparison with the estimates using image data

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Diving animals such as seabirds and marine mammals are top predators foraging under water and play an important role in the marine ecosystems through foraging behaviour. Recently developed animal borne digital video or still cameras have made it possible to directly observe and estimate the prey richness of a foraging patch with simultaneously recorded diving profiles. Optimal foraging theory suggests that patch residence time should be affected both by the time it takes to travel to a prey patch and the richness of the patch. Therefore, diving profiles obtained by animal borne depth and time instruments may be used to calculate a relative index of the richness of a prey patch used by diving animals in the water column. We tested this hypothesis by comparing the indices of prey richness estimated from both dive profiles and image data using adult female Weddell seals (*Leptonychotes weddellii*) at breeding colonies in Antarctica. There

was a positive correlation between these two values, indicating that dive profiles can be used effectively to calculate a relative index of prey richness at a prey patch used by diving animals.

P-33. Large amount of visual image may support our understanding on underwater remote lives and environment

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Bio-logging is emerging as a tool in animal biology much as genomics has emerged as a tool in the study of cellular and organ function (Boyd et al.2004) and further development of new tools are strongly expected for sensing biological complexity in remoteness (Kooyman 2004, Naito 2004). In general data integration increase, accordingly numerous new ideas are developed, most of which need to be tested in the fields. However before to develop new ideas, we need to develop our visual images on the living lives and its surrounding environment as we have not seen those living features and we are much depending on visual information. Large amount of visual images give us reliable support in developing ideas or test the ideas as visual images itself is integrated information in nature as a whole. Thus we developed a new digital image still logger (DSL) with large memory capacity.
Size: 22mm ×135mm, Lens: standard (55mm), Censor: CMOS image censer, Resolution: 1280×1024 (1.3MG pixel) or 640 ×480, Data compression: JPEG, Color resolution:24bits, Focus: 4.4mm F2.8, Angle: 52°(lateral), Range: 50cm~∞, Light measurement: TTL, Exposure: ALC, White balance: Auto, Depth censer: 0~380m (500m anti-pressure), Temperature censer: -20~50°C, Single image size (RGB): 1280 ×1024 ×3byte, Data size: 7000~10000 or more (by the compression rate)

P-34. Residency and depth movements of a coastal group of Atlantic cod (*Gadus morhua* L)

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Atlantic cod stocks are subdivided into geographically and biologically discrete populations: some being locally resident, others migratory. The reasons for the variation in migration pattern and the consequences it may have for population structuring is poorly understood. We studied a group of cod from the coastal waters of the Shetland Isles in the northern North Sea. During the spawning season, electronic tags that record depth and temperature over time were implanted into 133 individuals and the fish released within a few kilometres of where they were captured. Thirty-nine cod have been recaptured up to 608 days later, throughout the year and, in all but two cases, within 15 km of their release site. Geolocation methods based on temperature and bathymetry also suggested that the cod had a limited home range, remaining resident year-round in coastal waters. The cod were deeper during the winter and moved to shallower water in late spring and summer. They showed diel, fortnightly and monthly cycles in depth movement that varied much within and between individuals over the season. Residency and the individual variability in vertical movement may reflect a combination of locally complex depth strata, variable seabed substrate and the wide range of seasonally available prey resources.

P-35. Heart rate of foraging cape gannets

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Free-ranging gannets are known from doubly-labelled water studies to have a very high FMR, resulting from their use of costly flapping flight coupled with underwater wing flapping during plunge-dives. We used accelerometers and electrocardiogram recorders attached to free-living Cape Gannets (*Morus capensis*) in logging systems to examine how

heart rate generally varies according to activity, but specifically to look at differences in heart rate as a function of the degree to which the birds divided their time into gliding and flapping flight. The heart rates of Cape gannets did not change much when birds were resting on their nests (197.4 bpm), on land (215.4 bpm), resting at sea (208.9 bpm), in flap flight (230.90 bpm), in glide flight (211.6 bpm), in pre-dive flight (including flap and glide, 222.9 bpm), during the underwater phase (215.7 bpm) and at the sea surface following the dive (215.7 bpm). HR during flapping was significantly higher than during gliding although the difference in average heart rate was only 9.3 %. A peak-by-peak analysis revealed that the heart rate dropped as soon as the birds stopped flapping their wings. Using published data on the field metabolic rates (FMR) and resting metabolic rate (RMR) of these birds together with some assumptions about how heart rate might scale with energy expenditure, we derive values of the energetic cost of flapping versus gliding flight.

P-36. Monitoring on valve movement of the pen shell under natural condition

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Pen shell (*Atrina pectinata*) is one of the most important bivalves on fisheries in Ariake bay in Kyusyu Island, Japan. The Pen shell production in Ariake bay has been decreasing since the 1960's and the mechanism for the decrease remains unclear. Many aspects of their biology and physiology have been relatively well studied; however, little is known about their behaviour in relation to environmental factors under natural conditions. To evaluate the effect of environmental change on the Pen shell, we monitored the valve movement of the Pen shell using newly developed data-logger. The eight shells were used to monitor their valve movement from Aug.24 to Sep.8 2004 at the station off Ohura, in Ariake Bay. A Hall sensor connected to the data logger and a magnet was glued to shell valve. Then the shells were transplanted on the sea floor and the data logger was buried near the shells.
We found two patterns of valve movement, first the multi close-open action and second the single close-open action. The multi close-open action was most frequent just after shells were transplanted. This action revealed burrowing behaviour after transplantation. The single close-open action was frequent during storms. This action thought to be a reaction for high turbidity or wave disturbances.
Our result suggests that the valve movement can be a possible indicator for normal or abnormal state of the Pen shell.

P-37. A passive acoustical monitoring method applied to observation and abundance estimation of finless porpoises

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Arrays of three to five acoustic data loggers were stationed straightly across the main channel of the Tian-E-Zhou Oxbow of China's Yangtze River to record sonar signals of free-ranging finless porpoises (*Neophocaena phocaenoides*). The acoustical observation, concurrent with visual observations was conducted on 20-22 October 2003 and 17-19 October 2004. In total, 316 finless porpoises were sighted by visual observations and 7041 sonar signals were recorded during a total of 42-hour observations. The acoustic data loggers could record ultrasonic signals of porpoises clearly, and could detect the attendance of porpoises with a correct detection level of 77.6% and a false alarm level of 5.8% within an effective distance of 150-meter. A positive linear correlation between the number of recorded signals and the group size of sighted porpoises was found. Results indicated the stationed passive acoustical observation method was effective both in detecting the presence of porpoises and estimating the group size.

P-38. Swim speed and regulation of stroke in wing-propelling divers: a comparison among alcids and a penguin

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Diving seabirds experience large buoyancy and drag. These physical constraints and foraging patterns vary greatly among alcids and penguins. We collected data on body angle, swim speed and wing stroke of free-ranging thick-billed murres, common murres, rhinoceros auklet, razorbills and little penguins. Acceleration and depth were sampled at 32 or 64 Hz and 1Hz, respectively, using data-loggers. Low and high frequency components of acceleration provided estimates of body angle and wing stroke, respectively. Swim speed was estimated using body angle and depth change rate. Thick-billed and common murres made vertical dives but dives of the other three species were oblique. Swim speed during descent was higher for little penguins than murres and razorbills, with rhinoceros auklets having the lowest swim speed. During descent, little penguins made forward thrusts on both the up- and down stroke irrespective of dive depth. Thick-billed murres, common murres and rhinoceros auklets made forward thrusts on both the up- and down stroke in shallow depths but only on the down-stroke in deep depths. There was a smaller range of surge acceleration associated with strokes in little penguins than alcids indicating that penguins swim more steadily.

P-39. Dispersal and diving behavior of male California sea lion (*Zalophus californianus*)

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California sea lions are ubiquitous along the West Coast of North America, yet little information is published on the dispersal, diving behaviour, and foraging strategies of male sea lions following the breeding season in southern California. Satellite relay data loggers were used to track the movement and diving behaviour of male sea lions for up to 4 months during the fall and winter of 2003-04. Twenty-two male sea lions (15 adult and 7 subadult) were tagged in Central California for 945 days yielding 11,152 locations and 51,920 dives. At-sea movements of sea lions were largely confined to the continental shelf region with animals dispersing northward and southward along the California coast. This is in contrast to their previously described and expected northward migration along the entire West Coast of North America. Sea lions spent the majority of their time hauled out (49.7%), followed by swimming at the surface (31.8%), and the remainder of time diving (18.5%). Consistent with the shallow continental shelf, mean individual dive depths ranged from 19m to 96m, with 86% of all dives less than 50m. While only 2.5% dives were greater than 150m representing off the shelf dives, 6 individuals exceeded 450m with a maximum depth of 575m, the deepest recorded for this species. Mean individual dive duration ranged from 0.8 to 3.4 minutes, while the maximum dive duration ranged from 2.7 to 20.1 minutes, the longest recorded for this species. Dive patterns and dive depths indicated that individual animals used one of three foraging strategies. The behaviour measured in this study indicates that male sea lions regularly dive shallow consistent with other otarrids; however, their dispersal rather than migration, unexpected occasional deep and long dives, and individual foraging strategies indicate different and more complex behaviour than previously considered.

P-40. Development of flying and plunging performance in the juvenile brown booby

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How do birds acquire flight and foraging skills after fledging? This issue is important, as it is closely related to variation in the duration of offspring care, the causes of which remain unknown. In this study, we hand-raised hatchling brown boobies, *Sula leucogaster*, and attached an acceleration data logger to each bird at fledging to record its movements: after fledging, the juveniles made round-trips between the sea and nest, and begged for food from researchers (surrogate parents), during which the development of flight and foraging behaviour was recorded by the data logger. In addition, we attached the acceleration data loggers on the adult brown boobies in the field and compared the flight and foraging performance with that of juveniles. The acceleration data loggers allowed us to quantify precisely the time spent foraging, flapping, gliding and resting. The duration of foraging trips and proportion of time spent gliding during flight increased with the number of days since fledging, whereas the proportion of time spent in flight decreased. This indicates that brown boobies gradually acquire efficient flight skills during the post-fledging period, which might be the proximate cause of the long post-fledging care period in this species.

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