1. FINAL PUBLISHABLE SUMMARY REPORT

The Intergovernmental Panel on Climate Change (IPCC 2007) has highlighted an urgent need to assess how ecosystems respond to climate change. Polar ecosystems are highly sensitive ecosystems making them valuable sentinels of the health of our planet. Indeed, some of the strongest signals of global change come from polar regions (Hoegh-Guldberg & Bruno 2010), and several long-term monitoring studies suggest that the climate patterns of the past few decades may be anomalous when compared with earlier climate variation (Hughes 2000). Numerous models predict an increase in climate anomalies, related to anthropogenic activities, in the next decades (IPCC 2007). Changes in the extent of sea-ice in the Arctic and the Antarctic might affect zooplankton availability, fish distribution and abundance, and the access of seabirds to their prey (Ainley 2002, Gilchrist et al. 2004). Beyond the impact of changes in mean weather parameters, another very important aspect of environmental disturbance is that extreme events, to which populations are more sensitive, are likely to increase in frequency under the effects of global changes (Parmesan et al. 2000). This project was thus a tremendous opportunity to tackle one of the most important questions relating to the inevitable global changes that will occur in the next decades: how wildlife is able to respond to environmental stress (at local- and large- scales) and how to manage both wildlife and economic activities in key world areas; thus questions that are relevant at the scientific level as well as the societal level.

Global change has profound ecological consequences on the population dynamics of long-lived organisms, such as most seabird species. Also, climate change will alter the evolutionary forces acting on species' demographic strategies and life history traits, as these have evolved to cope with the range of environmental fluctuations experienced in the past. This is especially important in long-lived species (e.g. Cairns 1992, Stenseth et al. 2002, 2004), which are typically the upper trophic level predators in ecosystems. Top-predators are therefore considered to be key indicators of short- and long-term changes in food-webs and food availability (Le Maho et al. 1993, Boyd et al. 2001, Voigt et al. 2003), as they integrate and amplify the effects of climatic forcing on lower levels of food chains (Croxall et al. 2002, Frederiksen et al. 2004). They are also suitable for studying whether the effects of climate change on top predators may be mitigated by (i) phenotypic plasticity (morphological, physiological, behavioural traits) and (ii) microevolutionary changes. Such studies require advanced knowledge of evolutionary and functional ecology, population dynamics, physical oceanography, computer sciences and statistics: all of which were uniquely available at the Centre for Ecological and Evolutionary Synthesis where this EVOLBIRD Marie Curie project took place.

Moreover, the comparison between the evolution of life history strategies of polar long-lived species in both hemispheres can provide supplementary elements for a better understanding of ecosystem functioning. In that context, I decided to focused my EVOLBIRD project on the Southern Ocean (penguin populations) and on the Barents Sea/Arctic Ocean (kittiwake and guillemot populations). The geography of the two polar regions is different: the Arctic is a perennial frozen sea surrounded by urbanized and industrialized continents, whereas Antarctica is an ice-covered continent isolated from other areas by the Southern Ocean. In addition, the southern hemisphere is subjected to fewer anthropogenic impacts (such as fisheries harvests and pollution) than the northern hemisphere.

The main aims of the EVOLBIRD Marie Curie project were (i) to identify the mechanisms through which environmental variability affects age-specific survival, recruitment parameters and breeding performance of polar seabirds, (ii) to determine the vital rates that contribute most to fitness, and (iii) to model the population dynamics of these species in order to predict population trends in relation to climatic changes.

To summarize the main results obtained during the project:

First, most available information on penguin population dynamics is based on the controversial use of flipper bands. However, we showed that banding of free-ranging king penguins *Aptenodytes patagonicus* impairs both survival and reproduction, ultimately affecting population growth rate (Saraux et al. 2011). One of our major findings was also that responses of flipper-banded penguins to climate variability (i.e. changes in sea surface temperature and in the Southern Oscillation index) differ from those of non-banded birds, meaning that our understanding of the effects of climate change on marine ecosystems based on flipper-band data must be reconsidered. These deleterious effects, which also have serious ethical implications, can however be avoided with alternative methods, such as radiofrequency identification techniques (Le Maho et al. 2011).

Thus, based on more than 10 years of automatic monitoring of over 3000 individuals, we investigated the effects of environmental conditions and individual pre-fledging traits on the post-fledging return of these non-banded king penguins to their natal colony (Saraux et al. 2011, Le Bohec et al. *in prep*). Juvenile king penguins returned exclusively within one of the three austral summers following their departure. A key finding is that return rates (range 68–87%) were much higher than previously assumed for this species. Such high figures might suggest little juvenile dispersal and selection that occurs mostly prior to fledging in king penguins. We found that local survival was lower during their first year spent at sea while learning to forage for the first time, suggesting that lower quality individuals may disappear from cohorts especially during this first stressful event after fledging (i.e. the selection hypothesis). However, it might also result from an increase in foraging performance of individuals as they gain experience (i.e. the constraint hypothesis, Le Vaillant et al. *submitted*). Moreover, we observed a huge variance in survival during this first year in comparison with the other age classes. This variation between cohorts might be explained by the impact of the environment on specific (and maybe more sensitive) subsets of the population or at decisive phases of the life cycle. For instance, the environment could have an important effect on birds during their first year (growth) or during their second year (when learning how to fish). We indeed showed that pre-fledging condition had a strong quadratic impact on juvenile return rates. As expected, cohorts reared in very unfavourable years exhibited low return rates, but surprisingly so did those fledged under very favourable conditions. However, juvenile sojourns away from the colony were shorter under warm conditions and subsequent return rates were higher, suggesting a positive effect of climate warming.

Regardless of the cohort, we found birds attempting to breed for the first time between 2 and 3 years old. Among our cohorts that were fully recruited (which is between 6-8 years), the mean age at the first breeding attempt is 4 years old (in contrast with the mean age at 6 years old found in the literature). Then, by looking at factors explaining variation in this age at first breeding, our best model predicts that Sex, First experience at sea and Climate were the primary factors affecting age at first breeding. Females appear to start breeding earlier than males. The shorter their first trip at sea, the earlier birds start to breed. And the better the conditions during growth, the later they start to breed. That last pattern might be explained by the fact that during better environmental conditions, a larger number of chicks survive the winter, even weaker ones, thus there is a greater heterogeneity of individual quality for these cohorts, and we probably have a greater proportion of lower quality individuals, which drives the mean start of reproduction later.

Then, using the vital rates described above (age-specific breeding success and survival rate), I was able to build a stage-classified life cycle matrix (also called a Leslie's transition matrix), and found that the population growth rate is more affected by variation in adult survival than by the other vital rates (Le Bohec et al. *in prep*). Not a surprising result, in accordance with life history theory (suggesting that the population is strongly sensitive to changes in adult parameters, especially survival). However, we can also see the importance of early age survival on the population growth rate, meaning that we should pay more attention to this subset of populations when looking at the effects of climate on population dynamics. I also discovered that population growth rate is mainly sensitive to changes in temperature-dependent parameters such as the survival and breeding success of adult birds, but also post-fledging survival. Population projections were then simulated according to several IPCC warming scenarios. These projections indicate that the colony would reach quasi-extinction (a decline of 90% of the initial population size) before the end of the 21st century. At the current rate of global changes, king penguins will probably not be able to cope and reverse the predicted population decline with micro-evolutionary changes or behavioral adjustments.

The same analyses are currently being performed for the black-legged kittiwake *Rissa tridactyla* breeding in Kharlov Island on the coast of the Barents Sea. The number of chicks per nest and survival probabilities were estimated between 1970-1999. Leslie matrix models are currently used to understand the relative importance of juvenile survival on population dynamics of kittiwakes and the influence of environmental fluctuations on the temporal variation in this vital rate.

My secondary objective was to explore the adaptive responses of seabird populations to different environmental changes through microevolutionary processes. Thus, I started a study in order to i) identify the genetic structure and diversity of penguin colonies, and ii) evaluate gene flow between colonies within and between Archipelagos (fragmentation, isolation, continuous process). To investigate the first question, our study was based on 8 microsatellite loci and was performed using precisely geolocated samples within a continuous sub-section of the colony of La Baie du Marin (Crozet Archipelago). We found no evidence for strong structuring at the sub-colony level: although a number of spatially restricted areas have higher-than-random inbreeding and relatedness levels, the overall colony appears to be near-pan-mictic, with no obvious effect of philopatry on genetic and spatial structure. To explore gene flow between populations, blood samples were collected last season 2011/2012 in different penguin colonies and different subAntarctic archipelagos.

Studies on marine ecosystem dynamics are few and, especially for the Southern Ocean, the time series are short and quantitative knowledge of the dynamics of interactions between predators, their prey, and the environment remains very limited. In this context, the EVOLBIRD project was focused on the Austral marine ecosystem, which was especially valuable due to the absence of direct, intensive human pressure on food stocks. Moreover, by using state-of-the-art technology, this project addressed major methodological and scientific issues. On the other hand, working in the Barents Sea, in which anthropogenic factors (such as fishery pressure) are especially strong, constitutes an exceptional opportunity to explore anthropogenic impacts, since the last article from the project includes a unique demographic database of a top seabird predator, a concomitant dataset of fish stocks, and up-to-date modelling techniques. Thus, the EVOLBIRD Marie Curie project improved the knowledge in marine ecology and should help lead to relevant marine ecosystem management strategies that satisfy both ecological and economical criteria. Moreover, in contributing to the understanding of the Antarctic and Arctic ecosystems and their responses to climate variability, this international and multidisciplinary project directly meets both European priorities regarding 'Environment' (a priority area for FP7 with different aspects that match the present project: 'Climate change', 'Conservation and sustainable management of natural and man-made resources and biodiversity', 'Environmental technologies for observation', 'Earth and ocean observation systems, monitoring methods for the environment and sustainable development') and international priorities as defined by the Convention of Rio on biological diversity, IPCC (Intergovernmental Panel on Climate Change) and ICSU (International Council for Science).