GALAPAGOS COMMENTARY

POSSIBLE EFFECTS OF CLIMATE CHANGE ON THE POPULATIONS OF GALAPAGOS PINNIPEDS

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SUMMARY

The future of Galapagos Sea Lion *Zalophus wollebaeki* and Galapagos Fur Seal *Arctocephalus galapagoensis* populations was evaluated with reference to a conservative model of predicted climate change. Populations of both species will decrease during strong El Niño events and disease outbreaks will likely increase. Fur Seals may be exposed to a high risk of extinction if thermocline depth increases during extended warming events, since they can feed only near the surface and depend on upwelling. While predictions of the oceanographic conditions around Galapagos for the next 50 years remain uncertain, the combination of climate change and other human-induced threats (disease, disturbance, massacres and pollution) increases the need for conservation measures to protect these animals and their ecosystem.

RESUMEN

Posibles efectos del cambio climático en las poblaciones de pinnípedos de Galápagos. El futuro del Lobo marino de Galápagos *Zalophus wollebaeki* y del Lobo peletero de Galápagos *Arctocephalus galapagoensis* fue evaluado, utilizando como referencia un modelo conservativo de predicción sobre el cambio climático. Las poblaciones de ambas especies decrecerán durante eventos El Niño fuertes y posiblemente aumentarán los brotes de enfermedades. El Lobo peletero podría estar expuesto a un alto riesgo de extinción, si la profundidad de la termoclina se incrementa durante los eventos cálidos extensos, dado que estos animales sólo pueden alimentarse cerca a la superficie del océano y dependen del afloramiento. Mientras que el escenario oceanográfico de Galápagos para los siguientes 50 años encierra un alto grado de incertidumbre, la combinación del cambio climático y otras amenazas inducidas por los humanos (enfermedades, interacciones humanas, masacres y contaminación) aumenta la necesidad de medidas de conservación para proteger a estos animales y sus ecosistemas.

INTRODUCTION

The two endemic species of pinniped in the Galapagos Islands, the Galapagos Sea Lion *Zalophus wollebaeki* and the Galapagos Fur Seal *Arctocephalus galapagoensis*, are sympatric but occupy different habitats in the archipelago. Sea Lion colonies are found on sandy and rocky beaches near shallow waters all over the archipelago, whereas Fur Seal colonies occur on cliffs, near deep, cold waters. The largest Sea Lion colonies are located in the central and southern islands, whereas the Fur Seal breeding colonies are on the western and northern islands (Salazar 2002). Recent information on feeding ecology and diving behavior of the Galapagos Sea Lion revealed a wide range of use of the Galapagos Marine Reserve (GMR) waters and coastlines, and a high energetic cost of living in these environments (Wolf & Trillmich 2007, Villegas-Amtmann *et al.* 2008, Trillmich *et al.* 2008, Kunc & Wolf 2008). The populations of both species were recently estimated to have declined by 50 % in the past three generations and both were consequently considered Endangered by criterion A2a on the IUCN 2009 red list. Climate change and the increase of introduced species were the two key threats identified. The current population of the Galapagos Sea Lion is estimated at 18,000–20,000 animals and the Galapagos Fur Seal at 8,000–10,000, based on a census in 2001 (Salazar 2002) and recent unpublished data.

Today, climate change is recognized as a major environmental problem (Pachauri & Reisinger 2007). In Galapagos the climate predictions are uncertain, but even the most conservative models (*e.g*. the IPCC-Ar4 model:

Pachauri & Reisinger 2007) predict an increase in El Niño intensity (sea surface temperature anomalies of +3 to +6°C) and La Niña events. Liu (2010) predicted a "Mega El Niño event" by 2044 and variable La Niñas in the near future. Considering the effects of the 1997–8 strong El Niño on the Sea Lion population, which caused *c.* 90 % pup mortality, *c.* 67 % alpha male mortality and a 50 % population decrease (Salazar & Bustamante 2003), Sea Lions would be severely threatened under these predicted scenarios. During the 1982–3 major El Niño event both species suffered mortality rates of 30–40 % due to lack of food (Trillmich & Limberger 1985, Trillmich & Dellinger 1991). Since both species are top predators, they play an important role in the integrity of marine and coastal ecosystems (Fariña *et al.* 2003) and are indicators of changes in their environment.

The same climate model (Pachauri & Reisinger 2007, Liu 2010, L. Xie pers. comm.) predicts high variability in precipitation and temperatures, with possible thermal shocks (abrupt changes of environmental temperatures), weakened upwelling and deepening of the thermocline. This model concords quite well with recent temperatures in Galapagos (1952–2007).

Here we examine the potential impacts of climate change on Galapagos Sea Lion and Fur Seal populations and propose management measures to improve their conservation status.

METHODS

At a workshop in 2009, an expert group addressed the likely impacts of climate change and other factors on pinniped populations in the Galapagos. Impacts were subjectively evaluated and scored as follows: no effect (0), positive effect (1 to 3), negative effect (–1 to –3) and unknown effect (?). The difference between 1, 2 and 3, positive or negative, depended on the estimated magnitude of effects with 1 as moderate, 2 as strong and 3 as very strong.

RESULTS

Previous studies show that strong El Niño events can decrease the population of Galapagos Sea Lions and Fur Seals by 50 %, and moderate events by 20 %. A very strong El Niño might cause a 60 % population loss for both species. An estimated recovery rate of 1000 Sea Lions and 500 Fur Seals per year, is based on population recovery estimates following the last El Niño events, with 20 % recovery during a moderate La Niña (2002–3), 50 % during strong La Niña (1998–9) and an assumed 60 % during extremely strong events.

Further threats such as diseases and human interactions may reduce recovery rates, and the resilience of the populations depends on conservation management. Since diseases and vectors may increase with increasing temperatures, and human impacts will likely increase with the growing human population in the Galapagos, but assuming also improved management, we set these impacts at 10 % for Sea Lions and 5 % for Fur Seals. The lower figure for Fur Seals is set since they are more isolated from such impacts than are Sea Lions. In 15 years, assuming further strong El Nino events, these impacts will decrease to 5 % and 1 % for Sea Lions and Fur Seals respectively, and in 50 years to 1 % and 0 %, because the low density of the remaining populations will reduce the likelihood of disease spread (and also assuming optimal management).

These effects are summarized in Table 1 and the impacts resulting from them are estimated in Table 2. Further strong El Niño events will severely impact both species. Some recovery will occur during La Niña events and in the following 15 years, but since continuous ocean warming may weaken future La Niñas, these benefits will be reduced as well. Deeper thermoclines and increasing water temperatures in the future will have moderate to very strong negative effects especially on Fur Seals. Further, thermal shocks have a strong impact on Sea Lions. Most of the effects associated with climate

Table 1. Population effects used for the construction of trends in Galapagos pinniped populations over the next 50 years.

		Sea Lion	Fur Seal
Estimated population size (2009) based on extrapolation from 2001 census and 2002–7 main colony surveys.		20000	10000
Estimated recovery rates after the last strong El Niño (1997–8).		1000 per year	500 per year
Estimated El Niño population decrease effects.	Moderate (e.g. 2004–5)	20 %	20 %
	Strong (1997–8)	50 %	50 %
	Mega (assumed)	60 %	70 %
Estimated La Niña population recovery effects.	Moderate (e.g. 2005–6)	20 %	20 %
	Strong (1998–9)	50 %	50 %
	Mega (assumed)	60 %	60 %
Other negative effects (diseases, pests, interaction with fisheries and tourism).	Present day	10 %	5 %
	+15 years	5 %*	1 %*
	+50 years	1 %**	0 %**

* With improved management; ** with optimal management.

Table 2. Estimates of the effects of climate change impacts on the pinniped populations in 2010, 2025 and 2060, based on the IPCC-Ar4 model (Pachauri & Reisinger 2007, Liu 2010). GSL = Galapagos Sea Lion; GFS = Galapagos Fur Seal.

Impact	Year	GSL	GFS	Impact	Year	GSL	GFS
Strongest El Niño events	2010	-1	-1	Upwelling reduction	2010	3	3
	2025	-2	-2		2025	-2	-3
	2060	-2	-3		2060	-2	-3
Variable La Niña events	2010	3	3	Sea level increase	2010	0	0
	2025	2	2		2025	-1	-1
	2060	1	1		2060	-2	-3
Thermal shock	2010	-1	?	Precipitation changes	2010	-1	?
	2025	-2	?		2025	-2	?
	2060	-2	?		2060	-3	?
Ocean acidification	2010	?	?	Wind changes	2010	0	0
	2025	-1	-1		2025	-1	-1
	2060	-2	-2		2060	-2	-2
Deepeningthermocline	2010	2	3	Current changes	2010	0	0
	2025	-1	-2		2025	-1	-2
	2060	-2	-3		2060	-2	-3
Surge increase	2010	0	?	Predation changes	2010	-1	-1
	2025	-1	-1		2025	-2	-2
	2060	-2	-1		2060	-1	-1
Water temperature increase	2010	3	3	Diseases and introduced species	2010	-1	0
	2025	-1	-2	increase	2025	-2	-2
	2060	-2	-3		2060	-3	-3
Air temperature increase	2010	-1	0	**Total**		**-42**	**-36**
	2025	-2	-1	**Subtotal negative**		**-56**	**-51**
	2060	-2	-2	**Subtotal positive**		**14**	**15**
				Subtotal unknown effect		**1**	**8**

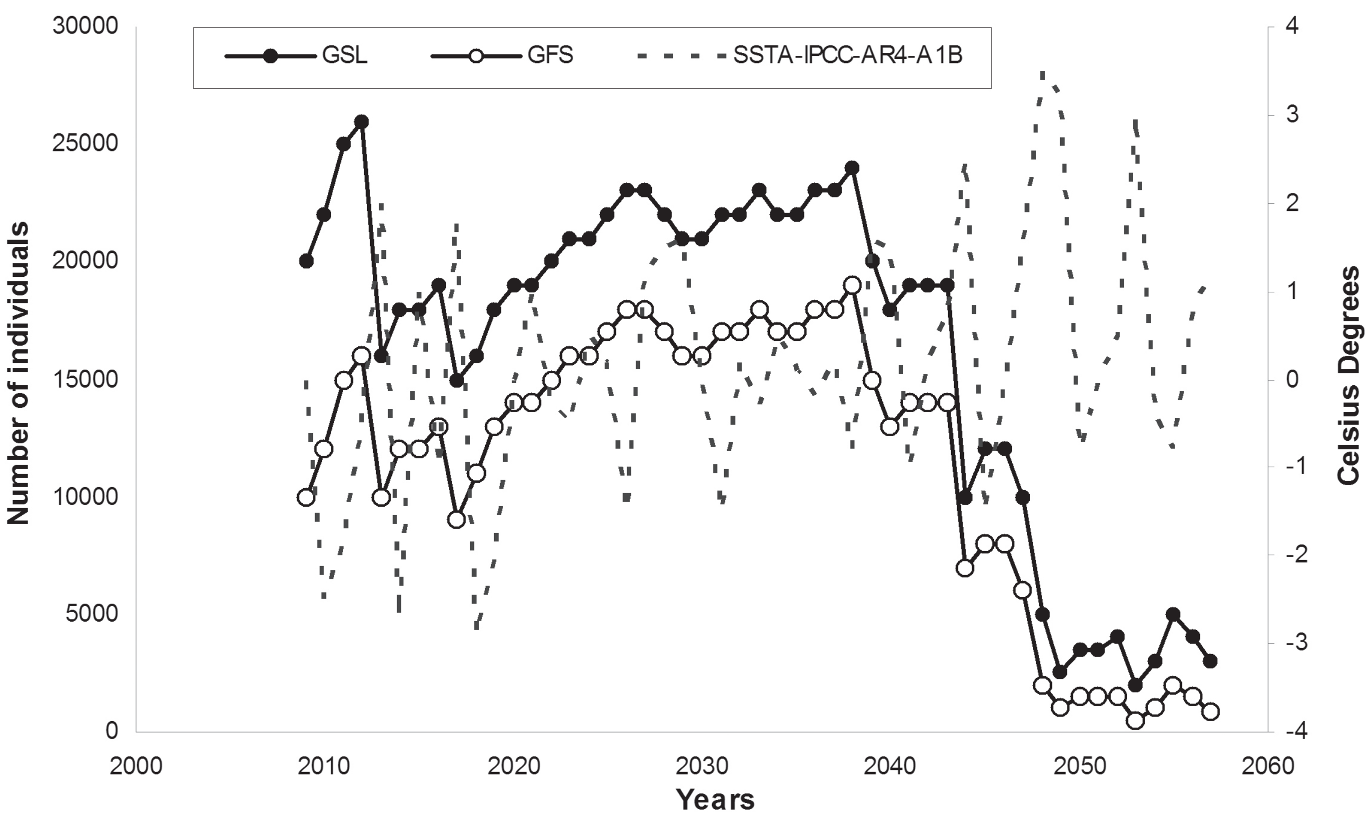

Figure 1. Possible population trends of the Galapagos Sea Lion (GSL) and the Galapagos Fur Seal (GFS) for the next 50 years in response to possible effects of climate change. The dashed line shows the predicted sea surface temperature anomalies by the model (Pachauri & Reisinger 2007, Liu 2010).

change were negative. Some, such as the effects of thermal shock and rainfall changes on Fur Seals and the consequences of ocean acidification for both species, are essentially unknown. Positive scores were mostly related to present oceanographic conditions and to La Niña effects, although the uncertainty of La Niña events in the future reduces them in the middle and long term. When all impacts are summed, the overall consequences of climate change are negative.

Using the effects estimated in Table 2 and the estimated percentages of impact of these effects, we predicted population trends for both species (Fig. 1). Both species show great population fluctuations, with reductions occurring especially during strong El Niño events. During the decade 2010–20, under presumed persistence of cold conditions, an increase to 25,000 Sea Lions and 15,000 Fur Seals seems probable. Declines could occur during weak to moderate El Niños, followed by slow recovery during the subsequent 10–15 years. Assuming weak to moderate El Niño events in 2013 and 2017, and warmer conditions from 2026 to 2029 (Liu 2010, L. Xie pers. comm.), the estimated populations in 2029 would be close to 21,000 Sea Lions and 16,000 Fur Seals. A predicted "Mega El Niño" would cause a major drop by 2040, with 60 % reduction for the Sea Lion and 70 % for the Fur Seal. Based on this model, by 2060 there might be only 3000–5000 Sea Lions and 800–1000 Fur Seals left (Fig. 1).

DISCUSSION

The population predictions outlined above were exploratory, using present population numbers, and without taking into account the high variability in dynamics between colonies which was evident during the 1997–8 El Niño, when most of the Sea Lion colonies decreased but others (*e.g.* Mosquera islet) acted as refuges, with adults increasing and *c*. 10 % of pups born at the end of 1997 surviving. Population decrease as measured in Galapagos during El Niño events includes both mortality and long distance displacement, as confirmed by more frequent sightings of Galapagos Sea Lions and Fur Seals off the continental coast of Ecuador during events (Palacios *et al*. 1997, Capella *et al*. 2001, Félix *et al*. 2007); however, our model does not take this into account. Further, the complex effects of global warming on ocean ecosystems, and the lack of data for pinniped birth and mortality rates during changing El Niño–La Niña conditions, limit prediction of trends in the populations and future consequences for these species. And so far there is little information on ecosystem effects of ocean warming and acidification, which adds uncertainty to our predictions. Over-fishing is also not addressed here and a fisheries collapse as predicted for 2048 by FAO (Worm *et al.* 2006) would dramatically affect the food sources of both Galapagos pinnipeds.

However, it is clear that the survival of Sea Lions and Fur Seals will be threatened by strong warming events. Other threats, such as diseases, the growing human population on the Galapagos, perceived conflicts between pinnipeds and fishing activities, and pollution in colonies close by human settlements, add to these problems. Besides direct disturbance of Sea Lion colonies on populated islands, or Sea Lions being fed by fishermen in Pelican Bay on Santa Cruz, where humans or pets constantly interfere with natural behavior, they also increase the threat of infectious diseases such as canine distemper, morbilivirus and others, which are transmitted by introduced animals such as dogs, cats and rats (Salazar 2002, Alava & Salazar 2006). Since Fur Seals tend to live on isolated sites and uninhabited islands, such impacts on them are less severe, but they are more susceptible to warming events because of their diving behavior and consequent high mortality El Niño events (Trillmich & Limberger 1985, Trillmich & Dellinger 1991). For Fur Seals the changes in colony size during El Niño events are dramatic, since young animals lack the diving abilities to provide for their energy requirements (Horning & Trillmich 1997) and females cannot compensate by providing more milk during warmer conditions when prey is less available, even by exceeding their normal foraging time or depth (Trillmich 1990). An additional threat to them may be the squid fishery along the border of the GMR but its effects are as yet unknown (Merlen & Salazar 2007).

The Sea Lion's diversity of prey and capacity to switch between feeding areas could cushion it against the effects of El Niño events and warming oceans, and there is evidence of a positive El Niño effect on genetic variation (Salazar & Bustamante 2003). However, the more specialized Fur Seal depends on upwelling close to its colonies and would have severe difficulty adapting to warming oceans. Since Fur Seals feed on vertically migrating fish and cephalopods (Dellinger & Trillmich 1999), their prey may greatly decrease as ocean temperatures increase and the thermocline deepens (Rosa *et al*. 2008). There is also evidence that ocean acidification may reduce squid abundance by reducing oxygen availability (Rosa & Seibel 2008).

Given that infectious diseases tend to increase in warmer ocean environments (Harvell *et al*. 2002), the eye fluke *Philophthalmus zalophi* and other diseases such as skin ulcers in Sea Lion pups (Merlen & Salazar 2007) present another concern; but infectious diseases in Galapagos pinnipeds need more research to determine their present and potential population impacts.

From 1995 to May 2008, naturalist guides and others reported 654 pinnipeds with signs of health problems and injuries. About 90 % of these reports refer to Galapagos Sea Lions, with intentional attack by people accounting for 54 %, including the slaughter of 53 individuals on Pinta Island in 2007. Besides, 85 % of the Sea Lion breeding colonies are used as visitor sites (Salazar 2002) and require strict management. Female Sea Lions use several resting areas other than breeding colonies (Villegas-Amtmann *et al.* 2008), which implies that management strategies should not be limited to breeding colonies but should include the entire coastline of the GMR.

Present management decisions influence the future of Galapagos pinnipeds and their resilience to warming oceans. The workshop made the following recommendations: re-establish continuous monitoring of the colonies of both species, focusing on pup counts and five-yearly population censuses; conduct studies on the health status of pets and the risk of disease transfer between pets and sea lions; improve control of alien species such as flies, dogs, cats, rats and others that could act as vectors of disease; and educate local communities to increase respect for Sea Lions in human environments and foster their conservation especially in relation to fisheries, tourism and attacks.

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