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It is a great honor to speak to this important group of regulators, managers, scientists, and policy-makers. Thank you for the invitation. You all have a grand challenge before you – to preserve and protect the very fabric of life in the face of widespread and daunting threats. Despite this overwhelming task that confronts you, I hope you will learn some useful information and hear some hope and opportunity in my presentation today. My primary goal is to characterize the state of wildlife science as it relates to climate change, and I will use this information to suggest a spectrum of conservation approaches at the end of my remarks.

Climate change

Among climate scientists, consensus has been growing for decades that human emissions of greenhouse gases are fundamentally altering our atmosphere and our global climate. The Nobel-prize winning, Intergovernmental Panel on Climate Change says that warming of 2.5 - 6.4 degrees C on average worldwide is “likely” to occur by 2100.

Now, don’t get me wrong, despite this consensus, there is plenty of controversy – how much warming will affect storm systems or will it be manifest in different regions, for example. **But there is little dispute that climate is changing and as climate is such a critical factor in the calculus of biology, these changes are affecting organisms worldwide**.

There is one new point that has arisen recently from IPCC scientists that I’d like to briefly discuss because it represents a big concern for biologists. These scientists have noted that emissions are actually trending above the business-as-usual trajectory. Until the economic downturn in late 2008, emissions since 2000 have been above the worst-case scenario, a scenario called A1FI that the IPCC uses in its model simulations. [A1FI (for fossil intensive) would result in CO_2 concentrations in the atmosphere of 950 ppm by 2100] Following an economic rebound, recent trends suggest that we could reach an atmospheric CO_2 concentration of 1000 ppm within this century. That’s more than 3-times pre-industrial levels and higher than has occurred in the last 400,000 years.

This number –1000 ppm -- is scary. Climatologists are worried that this level of atmospheric change could drive the climate over a catastrophic threshold, pushing us outside that envelope of “likely” temperature change that the IPCC projects; that is, above 6 degrees C. Under this catastrophic scenario, forget about species dependent on sea ice, and it is impossible to imagine that all of the world’s montane species could fit in the Himalayas.

To avoid this catastrophic change and to achieve some emissions scenario lower than the business as usual case, we must dramatically reduce greenhouse gas emissions – and soon. The perturbation of climate change to living organisms will be smaller if greenhouse gases equilibrate at lower values. **Therefore, greenhouse gas emission reduction has to be cornerstone of conservation and wildlife protection in the coming decades.**

While we work toward emission reduction, however, the climate steadily shifts – already changing about 0.6 degrees C since the 1970s. And you all have to deal with the consequences of those changes. Let me tell you a few things that scientists have learned about these consequences.

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Impacts of climate change on biodiversity
On the surface of it, we know quite a lot about the relationship between biodiversity and climate. For example, we know that many species shifted their distributions in response to climatic change during the last ice age. (Note that warming following the last glaciation was similar in magnitude to what we expect by 2100, and, of course, there were no cities or agriculture standing in the way of shifting species.)

We also know that many species are affected by temperature and precipitation – that populations of insects and disease, for example, wax and wane with changing conditions. We've heard lately that North America's salvation in the swine flu epidemic is that flu does not transmit well in warm, summer weather.

Despite the importance of climate to biology, we sometimes are surprised by the resilience of populations and species to climate – their ability to persist through heat waves or hard freezes, for example. We know that the geographic distribution of species is often limited by climatic tolerance, but ornamentals or relic populations thrive in strange places.

Therefore, we use imperfect information to make projections about the future of biodiversity; these projections are useful and important, but they are controversial and continually evolving. **In contrast to projections, some of the best scientific information that we have about the biological effects of climate change are observational studies of ecological responses that have already taken place or mechanistic studies that explore the relationship between climatic factors and ecological systems**. From these studies, scientists have revealed the signature of climatic change on biology, but we have much to learn. One thing that ecologists are currently debating is how extensive species' extinction risk will be under climate change. But there is **very broad agreement that climate change will enhance other threats to biodiversity and that a variety of broad ecological impacts – from changes in population size to changes in ecosystem function – will be widespread**.

Three examples

There are surprisingly few examples of species that have gone extinct in response to climate change. This is likely because human-caused climate change is just getting started and we lack good monitoring information to know if species are declining. Proving the causal relationship between climate change and extinction – to the exclusion of other factors – is also very difficult.

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One of the best-known cases of reported extinction due to climate change is the **golden toad**, a Costa Rican species thought to have gone extinct as [1987] El Nino reduced rainfall, and directly increased mortality, and elevated temperatures affected the incidence of disease and the action of pollutants. Some scientists have disputed the causal link between climate change and the extinction of the golden toad, however, arguing that disease and other lethal factors would have occurred without a strong El Nino [Bd/chytrid fungus]. Nonetheless, this remains one of our best examples of possible climate-driven extinction, despite persistent debate.

Some authors have projected that as many as a 1/3 of species could face extinction from climate change as warming progresses in the coming decades. These are projections, however, and are therefore based on simplifying assumptions.

As we lower the bar from species extinction to changes in population dynamics or to population extinction, there are more examples and known case studies. There also is greater confidence among ecologists that significant population perturbation and population extinction will occur from climate change.

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For example, co-authors and I demonstrated that two populations of the endangered **Bay checkerspot butterfly** of central, coastal California went extinct in response to changing climatic conditions in the form of a more variable climate that brought frequent years of drought and deluge. Extreme rainfall conditions (low or high) accelerated the development of plants relative to caterpillars, and caterpillars ran out of food as summer drought approached. It's important to know in this example that habitat loss and habitat degradation from invasive species isolated and diminished these populations. Thus, climate change may have been the final nail in the coffin, an additional stress that already-endangered populations could not handle. This case study also is interesting because the Bay checkerspot is a subspecies near the geographic center of the species' range. This suggests that its not just marginal or peripheral populations that could be affected by climatic change.

One of the best-documented changes in biological systems in response to climate change, however, are shifts in species' geographic distributions – where a species lives on the surface of the earth. These observations prove that biological systems are sensitive to climatic factors.

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Consider a study published by Allison Perry and colleagues in 2005 showing that **bottom-dwelling fishes in the North Sea**, both exploited and unexploited species, have shifted in mean latitude or depth [or both] over the last 25 years. All but one shifted northward, and of the 15 species that shifted, they moved 172 km on average. Every year, we see increases in the number of studies – like this one – that observes range change and links that change to climate.

These observations lead us to a new, important challenge – predicting which species have the capacity for range change and which do not. For most species, range change is the primary mechanism by which we'll avoid declines and extinction and maintain ecosystem services and species interactions. [Of course, for some species – pest species and disease vectors – we don't want range shifts to occur, and mangers are interested in strategies that would reduce range spread.] In the case of the North Sea, species with faster life cycles and smaller body sizes shifted more than other species. We need this type of generalization for a broad range of taxonomic groups to enable projections of future range change.

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Our studies in Garry oak ecosystems
In my own research group, we are working to understand the factors that limit geographic range change so that we can build better generalities and predictions about which species will shift and which will not.

Our study system – the beautiful oak savanna ecosystems of western North America, spans all national jurisdictions represented here today. It ranges from Baja California, through California, Oregon, and Washington, and into southwestern British Columbia, particularly Vancouver Island. In the northern portion of this ecoregion, there is a single species of oak that co-occurs with many flowering plants and other grassland animals. We call this northern version a "Garry oak ecosystem" as articulated, for example, by Canada's Garry Oak Ecosystem Recovery Team.

We have found several interesting things in this ecosystem – some of which raise important points for you to consider in your deliberations over the coming days.

Specifically, we asked if populations of two contrasting, Garry oak butterflies at the northern edge of their range would benefit from warming; thus facilitating a northward range expansion. What we found was a very complicated answer.

For caterpillars of both of our study species, the answer was "yes": warming enhances growth, reduces development time, and increases survivorship. That's good news for populations near the northern range boundary. But for overwintering individuals of one of the species, we found local adaptation, that warmer temperatures increased energy use in northern individuals in a way that was detrimental. The percentage change of energy losses in the winter was similar in magnitude to percentage gains in the summer.

In this species, as well, the northern range boundary of the butterfly overlaps with the northern range limit of its host plant – therefore, there's nowhere for the butterfly to go until its host goes first.

In our second study species, we also found a signal relating to host plant usage. In this case, we found that the best host species for the butterfly under historic conditions at the northern range boundary was the worst host under warmer conditions. And the worst host under historic conditions was the best host under warm temperatures. This suggests that changes in populations are indirectly mediated by resource availability. It also suggests a potential role for conservation – preserving and enhancing populations of the host plant that enhances future butterfly populations.

Let me reiterate what I've told you so far… We know relatively little about the rate of extinction due to climate change and whether or not climate change has caused extinctions of species so far, though we anticipate extinctions given the amount of projected climatic change, its rate, and the overall importance of climate in living systems. We have high confidence that climate change is and has caused populations to go extinct and changes population size; decreases in populations are the precursor to species' extinction. We also have high confidence that the timing of species has changed in response to climate change and this affects species interactions. And our research has suggested specific mechanisms that will slow down geographic range change, including different responses and tolerances in different life stages, local adaptation, and changing species interactions.

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Possible courses of action
The challenge for you all is what to do about the changes that I have just described: how to anticipate them, how to reduce the magnitude of them, and in some cases, how to reverse negative effects.

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As I see it, there is a spectrum of approaches or ways of envisioning conservation under climate change. **Each of these approaches has pros and cons with respect to cost, likely effectiveness, and potential for incidental damage.** Let me be clear that I do not advocate for any particular approach, but I do advocate that the full spectrum be evaluated and we that

begin testing some of these approaches now because time is running short.

The first strategy in the spectrum I call **"established" conservation biology**. This includes all of the strategies that we already know are effective but involves doing them more and better to help reduce the impacts of climate change. This includes approaches such as habitat preservation, maintaining connectivity between populations, minimizing the impact of invasive species, and so on.

A second strategy for conservation under climate change is **managing for resistance**. By this I mean taking some more extraordinary steps to enable a species to persist in an area where it may be diminished by climate change. Imagine irrigating a plant population, for example, that is susceptible to drought or stocking a habitat with key resources that are otherwise diminished by climate change.

A third strategy is **corridors** – corridors on a grander scale than we typically consider. This strategy would provide habitat linkages over many hundreds or thousands of kilometers to facilitate range shifts. There may be some creative ways of building temporary corridors for some species given existing land use policies, but otherwise this strategy could be costly. The other concern about corridors is that they provide habitat for the spread of undesirable species.

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A fourth strategy is **managed relocation** (or assisted migration or assisted colonization). Managed relocation is the movement of a species from one place where it historically occurs to another, new area where we predict that it could occur in the future. This strategy is controversial, but what I think is interesting is how it forces to think about the scale of the problem – how far are we willing to go to help a species under climate change? My guess is that for a small subset of species – at least for some stakeholders and in some areas – managed relocation will be pursued. So we better dust off our risk assessment hats and get ready to deal with this possibility. Managed relocation might be pursued for endangered species conservation, or it might be pursued by others for other goals and have incidental effects on endangered species conservation.

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The other interesting thing about managed relocation is that it points our how incredibly naïve we are about how ecosystems function. Consider a species that we are studying my group, the **jumping gall wasp**. This gall wasp is a specialist on white oak. It ranges historically from Texas to Washington and lives in the Garry oak ecosystem that I mentioned earlier – only it never occurred on Vancouver Island and the surrounding islands. About 25 years ago, the wasp showed up in a park in Victoria, BC [1983] and has been spreading ever since. The interesting thing is that in its native range – which is essentially the same ecosystem – it occurs at relatively low density; but where it has expanded its range – again, on the same host in the same ecosystem type – it occurs at high

density, scorches oak leaves, and has a negative effect on native oak herbivores. This is an example of a simple, poleward range shift from one ecosystem to another, similar ecosystem, but the dynamics of the wasp in its native and invaded range are quite different. This is the type of surprising change in a species' ecology that we expect to occur naturally under climate change and may occur particularly with managed relocation.

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A fifth and final strategy –as I see it – is **ex situ conservation**. Like corridors, think about ex situ conservation on a grander scale that we have envisioned it before. This is a very costly approach, but for some species it might be necessary to enable longer-term planning.

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Deciding among these conservation options
These five options are not mutually exclusive, and deciding on the balance of them will be just as challenging as deciding among them. **One important point is that the precautionary principle does not work in addressing this spectrum of scenarios**. **There are potential risks of pursuing each of these courses of action *and* risks of not pursuing them.**

As I see it, one of the biggest challenges for science is sorting species into those that are likely to survive without much assistance, those for which limited assistance will sufficient, and those for which intensive efforts are necessary. Another challenge is figuring out which species would benefit from which approach and which approach is potentially too risky for which species.

Perhaps I can return 10 years and tell you some results of research on these topics. But then again, in those 10 years, the climate will have changed considerably, and thus we need to take some action very soon.

We need new/more adaptive management
One necessity that I see on the horizon as it relates to climate change is a new role for adaptive management. Adaptive management is the process of monitoring that feeds into decision-making, resulting in modified goals and actions whose results are in turn monitored. **Without true adaptive management, none of the strategies that I just outlined are likely to be successful.** The scientific and management community has talked a lot about adaptive management, but under climate change we must actually do it – and fund it.

My final point is that the relationship between biodiversity and climate change is not purely scientific. We cannot manage wildlife under climate change without asking ourselves questions such as: What kind of world do we want to live in, where it is reasonable to take risks, and how much are we willing to invest to help wildlife "adapt" to climate change?

Science alone cannot answer these questions. Science can tell us what is possible and what isn't; it can illuminate the landscape of risk; but it cannot tell us what to do.

As those people responsible for the future of wildlife on this continent, I ask you – what world do you want to live in?

Thank you very much for your time and attention. Best of luck to you all in your deliberations in the coming days, and best wishes for your future endeavors on the important and emerging issue of global climate change.

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