

LETTER

Timing of Protection of Critical Habitat Matters

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Abstract

With many conservation issues requiring urgent action, determining how much data are needed to inform good decisions is a common problem. We examine this problem in relation to the protection of critical habitat, the habitat required for species' recovery and persistence. The protection of critical habitat is an essential step in the threatened species recovery process. It is also one of the most contentious and protracted decisions faced by environmental agencies. Uncertainty about what constitutes critical habitat, and the challenges of balancing competing societal objectives and of protecting critical habitat once identified are stalling the recovery process. We offer insight into this challenge by investigating how long we can afford to spend identifying critical habitat before opportunities to recover a species are lost. We illustrate our decision model using Canada's threatened northern abalone (*Haliotis kamtschatkana*). Our method delivers the stopping time at which habitat protection must begin, despite uncertainty, in order to avoid an unacceptable risk of extinction.

Introduction

Protection of critical habitat is a key step in the recovery and conservation of threatened species. Protection of critical habitat is a legal obligation under Canada and the United States' respective environmental legislations, whereas in other countries such as Australia, it is optional. In Canada, the term critical habitat is legally defined as "habitat that is necessary for the survival or recovery of a listed wildlife species [plant, animal or other organism] and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species" (Canada, Species at Risk Act [SARA], SC 2002, c 29). Operationally, scientists have recommended that the term critical habitat be used to describe the minimum subset of habitat, or resources and conditions, needed to ensure species persistence over the long term (Hall *et al.* 1997; Rosenfeld & Hatfield 2006; Camaclang *et al.* 2015). Once identified, protection of critical habitat is generally achieved through the prohibition of activities

in these areas that will result in adverse impacts on the species.

A failure to identify and protect critical habitat can be the result of a lack of scientific information, but not always. Critical habitat to a threatened species recovery team means an essential resource for species conservation, but its meaning for other segments of society may be quite different. For example, the critical habitat of the woodland Caribou (*Rangifer tarandus*) overlaps with rich petroleum and forestry resources in Northern Canada (Schneider *et al.* 2010); the critical habitat of Canada's southern resident Killer whale population (*Orcinus orca*) is a lucrative commercial and recreational salmon fishing ground (Ford *et al.* 2009). These areas of land and sea are not just critical habitat for threatened species but they are highly contested areas for resource extraction, development, and recreation. It is no surprise then that the protection of critical habitat is one of the most contentious and protracted decisions faced by environmental agencies (Hagen & Hodges 2006). Both uncertainty of

Table 1 Comparison of critical habitat designations among United States, Canada, and Australia

Country	Name of act and year	No. of listed species	No. of listed species for which critical habitat identification is required	No. of species with finalized recovery plans	No. of critical habitat designations	Proportion of listed species with identified critical habitat (%)
Australia ¹	EPBC 1999	1,758	NA ^a	784	5	0.3
Canada ²	SARA 2002	521	373 ^b	240	47	12.8
USA ³	ESA 1973	1,568 ^c	1,568	1,129	704	44.9

¹<http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl>

²<http://sararegistry.gc.ca/>

³<http://ecos.fws.gov/ecos/home.action>

^aCritical habitat designation optional in Australia.

^bIncludes five extirpated species for which recovery is deemed feasible.

^cSpecies under U.S. jurisdiction only.

what constitutes critical habitat and lack of political will to protect identified critical habitat have stalled the recovery process (see Supporting Information). Using decision science thinking (Maguire 1986; Possingham & Shea 1999), we provide insight into this challenging problem through an examination of how long it makes sense to continue to learn about a species' critical habitat before switching our efforts to protecting critical habitat, even if our knowledge about critical habitat is incomplete.

As of 2015, critical habitat had been legally identified for 45% of listed species in the United States, 13% in Canada and less than 1% in Australia (Table 1). In Canada, a cautious approach to critical habitat designation has led to legal challenges against government agencies for failing to designate and protect critical habitat when it was known (e.g., Greater Sage-grouse *Centrocercus urophasianus*, Alberta Wilderness Association, *et al. v. Minister of Environment*, 2009 FC 710; Nooksack Dace *Rhinichthys cataractae*, Environmental Defence Canada, *et al. v. Minister of Fisheries and Oceans*, 2009 FC 878; Killer Whale: David Suzuki Foundation *v. Minister of Fisheries and Oceans*, 2010 FC 1233).

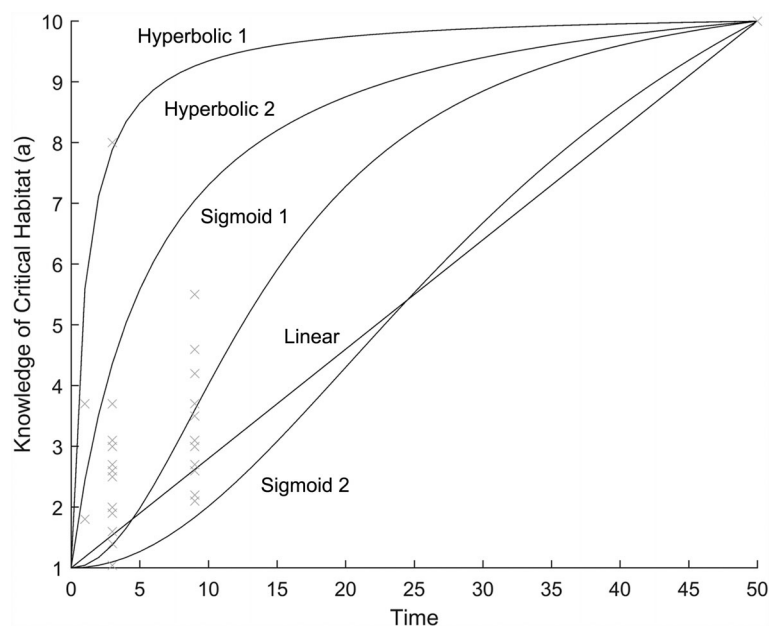
In practice, knowledge of the subsets of habitat needed to ensure species persistence over the long term is often not available. Instead, critical habitat determinations are made using measures of relative habitat importance (habitat occupancy, suitability, and quality) derived from survey data, museum records, and expert judgment (Camaclang 2015). A key limitation of this approach has been the inability to link population dynamics, and ultimately species persistence, to protection of critical habitat (Rosenfeld & Hatfield 2006; Camaclang *et al.* 2015). Where data are more plentiful, species distribution models (SDMs) can help differentiate habitat quality across a species range (Guisan *et al.* 2013) and combined

with population dynamics, SDMs can then be used to identify critical habitat (Heinrichs *et al.* 2010).

Conceptually, current approaches to identifying critical habitat are reasonable. In practice, however, they may fail to deliver the critical habitat delineations that are necessary to ultimately lead to the recovery and persistence of the species. This failure is in part because identifying the habitat needed to enable species persistence takes time, during which the species continues to decline. The time available to identify critical habitat without risking species extinction depends on the dynamics of the species, the severity of the threats it faces, and the rate at which we learn about critical habitat. In practice, determining and agreeing on what constitutes a species critical habitat may take far longer than the timeframe available to protect the species before threats such as exploitation, predation, and habitat loss lead to irreversible decline.

We present a novel rationale for deciding the timeframe under which identification and protection of critical habitat must take place by examining the relationship between learning about critical habitat and the population dynamic of a listed species and the threats to its persistence. As we learn about critical habitat through surveys, models, and expert judgment, uncertainty about critical habitat declines. But learning costs both time and money (Figure 1). Our approach assumes that while we are learning about critical habitat, no protection is taking place or is suboptimal, increasing the species' probability of extinction. Making a decision with insufficient information about critical habitat (high uncertainty) could jeopardize species persistence because the habitat protected is inadequate and/or inappropriate. Alternatively, delaying protection until sufficient information is known may come too late. Here, we present an approach for

Figure 1 Theoretical relationship between learning about critical habitat and time. For our analysis, we used two types of sigmoid, two types of hyperbolic, and one linear learning curve. The y axis represents our knowledge of critical habitat as expressed by “ a ” from the AUC of the ROC curve (Figure 2), where a value of $a = 10$ assumes over 91% ability to distinguish between critical and noncritical habitat and a value of $a = 1$, only 50%. Crosses represent values of “ a ” from ROC curves for 16 species of bird (Vernier *et al.* 2008) and four mammal species (Southgate *et al.* 2007). See Supporting Information.



assessing the trade-off between learning about critical habitat and protecting critical habitat.

Methods

Learning about critical habitat

We simulate the rate at which we learn about critical habitat over time using theory from receiver operating characteristic (ROC) curves. ROC curves are increasingly being used to describe the predicted accuracy of species habitat maps (e.g., Burgman 2005; Vernier *et al.* 2008). The curve represents a plot of where the predicted habitat map correctly or incorrectly predicts the location of the species for different thresholds of acceptance, plotting the proportion of true positives (species occur where predicted) and false positives (species do not occur where predicted) (Figure 2). ROC curves can take any shape on the way from (0,0) to (1,1) and the area under the ROC curve (AUC) is used to assess the agreement between the truth (e.g., species presence/absence data) and the predicted model occurrence.

We use a family of ROC curves given by $y = x^{1/a}$, where y is the proportion of correctly predicted occurrence (true positives), in our case critical habitat and x is the proportion of incorrectly predicted occurrences (false positives), in our case noncritical habitat (Baxter & Possingham 2011). The area under the curve, $AUC = a/(a+1)$ increases with a . Following this, the higher the value of a , the better the predicted accuracy of the habitat map. A value of $a = 1$ implies that the predicted accuracy of

the map is no better than random ($AUC = 0.5$), whereas a value of 10 implies a map with over 91% discrimination between critical habitat and noncritical habitat (Figure 2). Because we do not know the functional form of the relationship between a —quality of the critical habitat map and time, we apply a range of possible relationships between the two. Once the decision is enacted to protect critical habitat, we apply ROC curves to determine the predicted accuracy of a map of critical habitat at that point in time, where the higher the value of a , the more we can correctly distinguish critical habitat from noncritical habitat.

We consider three main functional forms linking a and time: sigmoid, hyperbolic, and linear (Figure 1). For the sigmoid and hyperbolic functions, we examine two possible forms of each, representing different rates of learning about critical habitat over a 50 year time horizon. Under the hyperbolic form, knowledge gains are realized quickly, with most knowledge accrued within the first 5 years. Under the sigmoid forms, in contrast, the rate of learning is initially slower and represents cases where there is a time lag between initial investment in surveying and learning about critical habitat. Under the linear form, the rate of learning is constant over the 50 year time frame, but faster in the first few years compared to the sigmoid forms. For all functional forms, we assume that after 50 years of data collection, the discrimination of our critical habitat model will be over 91% accurate (Figure 1). In summary, we assume the more that is known about critical habitat, the better the critical habitat determination and probability of species recovery;

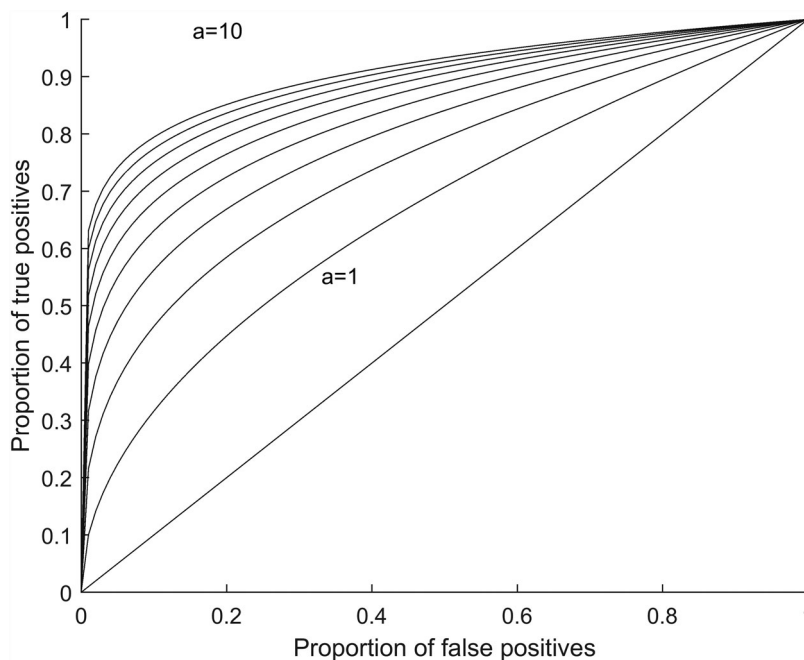


Figure 2 Receiver operator characteristic (ROC) curves in the form $y = x^{1/a}$ can represent the predicted accuracy of a species critical habitat map. ROC curves can take any shape between (0,0) and (1,1) and the area under the curve ($AUC = a/(a+1)$) is used to measure the “quality of the habitat map” with values closer to 1 indicating the best maps. A value of $a = 1$ corresponds to 50% accuracy of the map (random), whereas a value of 10 indicates a critical habitat map with >91% accuracy (i.e., ability to distinguish between true positives and false positives), after Baxter & Possingham (2011).

however, learning about critical habitat takes time and the longer it takes to identify and protect critical habitat, the higher the risk of species extinction.

When to protect critical habitat for northern abalone

Our objective is to ensure the persistence of a threatened species by maximizing species density over a 50 year time horizon given the population dynamic of the species and uncertainty about how we learn about critical habitat. To solve this problem, we undertake the following steps: (1) Build a stochastic population model for the threatened species. (2) Define the relationship between learning about critical habitat and time. (3) Determine the actions (e.g., survey, protect) that will be applied. (4) Assess which stopping time is optimal to maximize the expected population density of the target species over time through an exhaustive search of simulations of the relationship between the species population dynamic, the relationship between learning and time, and the actions taken.

We applied our decision model to the northern abalone (*Haliotis kamtschatkana*). Northern abalone was listed as threatened in 1999 under Canada’s Species at Risk Act (SARA 2002) and endangered in 2006 under the IUCN Red List of Endangered Species. Northern abalone is a patchily distributed mollusk with a historic range from Alaska to Baja California. The bulk of its population now occurs between Alaska and Washington state (Estes & VanBlaricom 1985). Commercial harvests of northern

abalone began in British Columbia in the early 1900s and catches peaked in 1978 at 433 tons per year. Catches then began a dramatic decline until the fishery was closed in 1990 to allow recovery (Jubinville 2000). Since fishery closure, northern abalone populations have failed to recover (Lessard *et al.* 2007; Chadès *et al.* 2012). This failure has been attributed largely to illegal abalone harvest, herein called poaching (Gardner *et al.* 2000; Jubinville 2000) and, to a lesser extent, predation by recovering sea otter populations (Watson 2000; Tinker *et al.* 2007), Allee effects (Stierhoff *et al.* 2012), and ocean acidification associated with climate change (Crim *et al.* 2011).

We built two density-dependent stage-structured matrix models for northern abalone populations within the Pacific Rim National Park (PRNP) of British Columbia (BC). The first model represents the dynamic of the northern abalone population in the critical habitat. The second model simulates the dynamic of the population in the noncritical habitat. Our population density objective is averaged over critical and noncritical habitat over a 50-year time horizon (see Supporting Information).

Poaching of abalone is a key threat to its recovery (Gardner *et al.* 2000; Jubinville 2000). We modeled poaching activity with mean removal rates varying stochastically from 10% to 50% of the population per year (Zhang *et al.* 2007). We factored in an Allee effect by assuming population extinction below a threshold of 0.15 abalone/m².

We consider two possible decisions a manager can take with respect to critical habitat and species status. The first

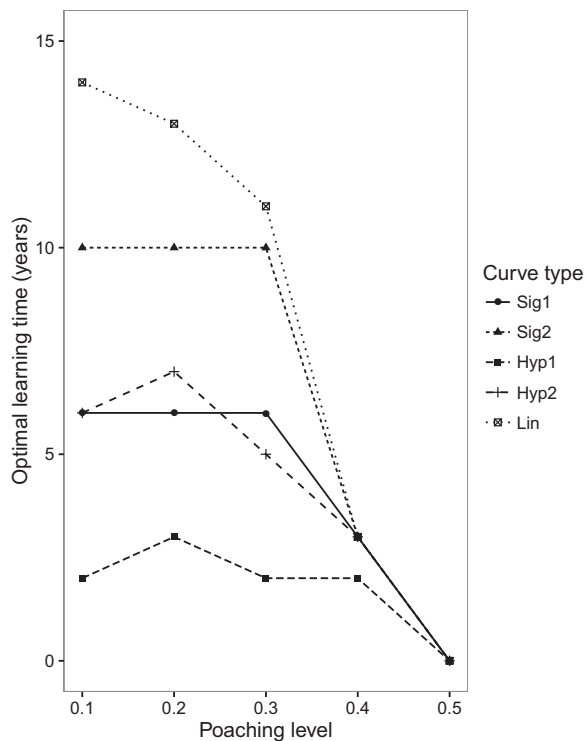


Figure 3 The number of years spent learning to maximize the average abalone density over 50 years for different poaching levels (varying stochastically between 10% and 50%) and types of learning curves.

decision is to “survey” and learn about critical habitat (increase the AUC). The second decision is to “protect” critical habitat, as best we understand it at that time. We assume that “protection” will ensure that the current threat of poaching is reduced by 75% in the protected habitat. Effectiveness of antipoaching measures increase with concordant investment on enforcement (Hilborn *et al.* 2006), but these measures are unlikely to ever be 100% effective. In this formulation of the problem, once the action of “protect” has been chosen, the action of surveying cannot be reinstated. Our model assumes that there is a fixed management area and/or budget and that the decision to “survey” is designed to increase the amount of critical habitat versus noncritical habitat that makes up this fixed management area.

We ran 10,000 simulations for each of the five combinations of learning curves with the stochastic population model over a 50 year time horizon and determined the optimal time to switch resources from learning about to protecting critical habitat with varying poaching intensity (see Supporting Information for more information on simulation and model assumptions). All models were run in MatLab version R2011b (code available upon request).

Results

As the level of threat to the abalone population increases, it is better to protect rather than learn about critical habitat, even if our knowledge of critical habitat is incomplete (Figure 3). We find that irrespective of learning curve type, the time that can be afforded to learning about critical habitat declines rapidly as the level of threat via poaching exceeds 20–30%. In other words, getting the timing of protection right becomes paramount as the risk of extinction increases (Figure 3, Figure S1). The type of learning curve also influences the time available before a decision to protect must be made. Where the rate of learning is rapid initially (e.g., hyperbolic curves 1 & 2, sigmoid 1 Figure 3, Figure S2), and poaching ranges between 10% and 30%, decisions regarding protection of critical habitat should be made early (between 3 and 7 years where protection time is equal to learning time plus 1), whereas when the learning is slower (linear, sigmoid 2 Figure 3, Figure S2), more time is required (10–14 years) to learn the equivalent amount about critical habitat. Once the level of poaching exceeds 30%, the time that can be afforded to learning drops dramatically for all curves except hyperbolic 1. Once poaching reaches 40%, little time can be afforded to learning irrespective of learning curve type and our chance of saving the population from extinction depends on a rapid decision to protect, even if our knowledge about critical habitat is uncertain.

Examining a single simulation of the northern abalone population over one learning curve (sigmoid 1) reveals its population trajectory in critical and noncritical habitat, the optimal time to protect critical habitat, and our ability to distinguish between critical and noncritical habitat at that point in time (Figure 4). In this example, the optimal time to protect critical habitat for northern abalone is 7 years, at which time our ability to distinguish between critical and noncritical habitat is 86%.

Finally, we assess the benefit in terms of improvement in abalone density, we can expect by waiting and learning for the optimal number of years before protecting critical habitat compared to making a decision to protect immediately based on no knowledge of where critical habitat is (at best 50% chance of being able to distinguish between critical and noncritical habitat) (Figure 5). Under the fast learning curves (hyperbolic 1, hyperbolic 2, sigmoid 1), the benefit of acting optimally increases with poaching level up to a level of 40%, whereas under the slower learning curves (linear, sigmoid 2), the benefit peaks at 30% then declines to zero for all learning curves as poaching reaches 50%. At 50% poaching, the population declines below 0.15 abalones/m², the threshold

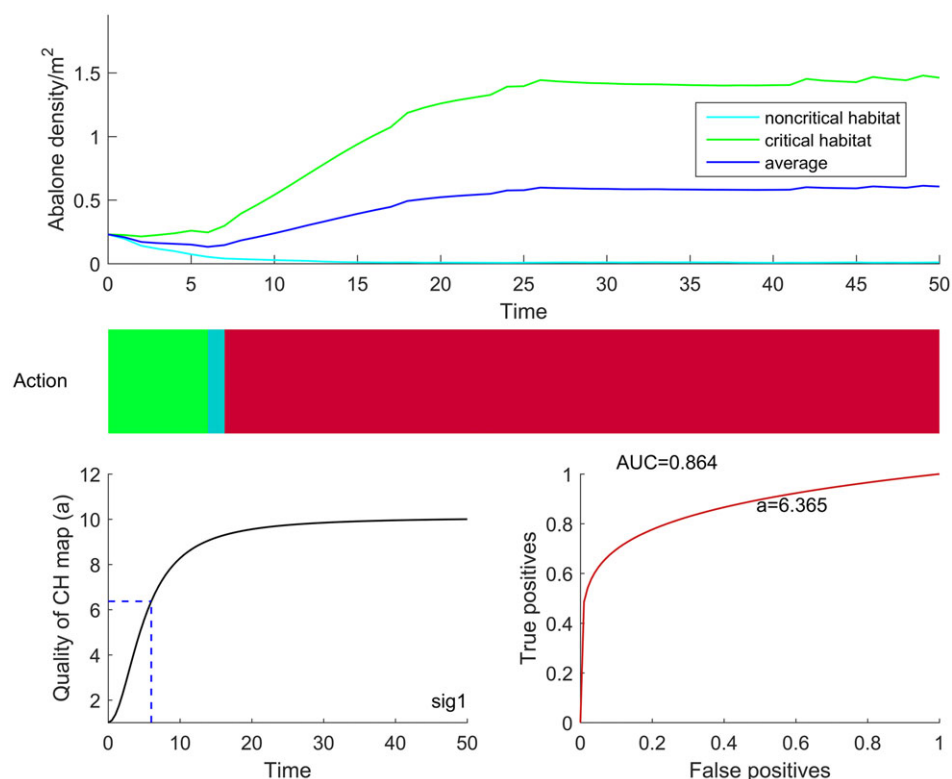


Figure 4 Results of a simulation of the relationship between knowledge of critical habitat, learning curve (sigmoid curve 1) and resulting abalone density. Starting from the top, the first graph represents the northern abalone population density for critical habitat (green line) and noncritical habitat (light blue line) and the average of the two (dark blue line). The second graph represents the best decisions to take over 50 years based on the optimal strategy, where green is “survey and learn about critical habitat” and blue is “protect critical habitat.” After a decision to “protect” is made, red represents continued protection of critical habitat. The bottom graph on the left represents the relationship between the quality of the critical habitat map a and time for the learning curve sigmoid curve 1. The blue dotted line represents the quality of the critical habitat map “ a ” at the optimal stopping time to protect critical habitat. The bottom graph on the right represents the ROC curve that corresponds to the quality of critical habitat protected “ $a = 6.365$ ” at the end of the 50 year time horizon. In this simulation, there was an 86% ability to distinguish between critical and noncritical habitat after the optimal learning time (5 years).

at which Allee effects are expected to lead to impaired recruitment and ultimately extinction.

Discussion

The identification and protection of critical habitat poses substantial logistical and legal challenges (Clark *et al.* 2002; VanderZwaag & Huchings 2005). Most of the discussion to date regarding critical habitat has centered on fine-tuning the guidelines for critical habitat to make it more legally and scientifically workable (e.g., Sidle 1987; Sinden 2004; Hagen & Hodges 2006; Rosenfeld & Hatfield 2006). We add a new perspective, one that considers the time constraint under which decisions about critical habitat protection must be made in order to avoid species extinction. We discover that where the threat to species persistence is high, decisions to protect critical

habitat must be made rapidly even if our knowledge of critical habitat at that point in time is uncertain.

Taking an early decision may appear counterintuitive in situations where there is a perceived or real lack of information regarding what constitutes a species’ critical habitat. Acting quickly could also be construed as flying in the face of evidence-based decision making, which suggests that more evidence is always better especially where decisions are likely to come under intense scrutiny (Sutherland *et al.* 2004). However, waiting for perfect information takes time and can lead to a rapid decline in the species and possible extinction as a result of continuing threatening processes (Martin *et al.* 2012b). What is often needed, is good enough information based on the best available evidence of the day, whether it be empirical, elicited from experts, or a combination (Martin *et al.* 2012a). In cases where the level of threat is great,

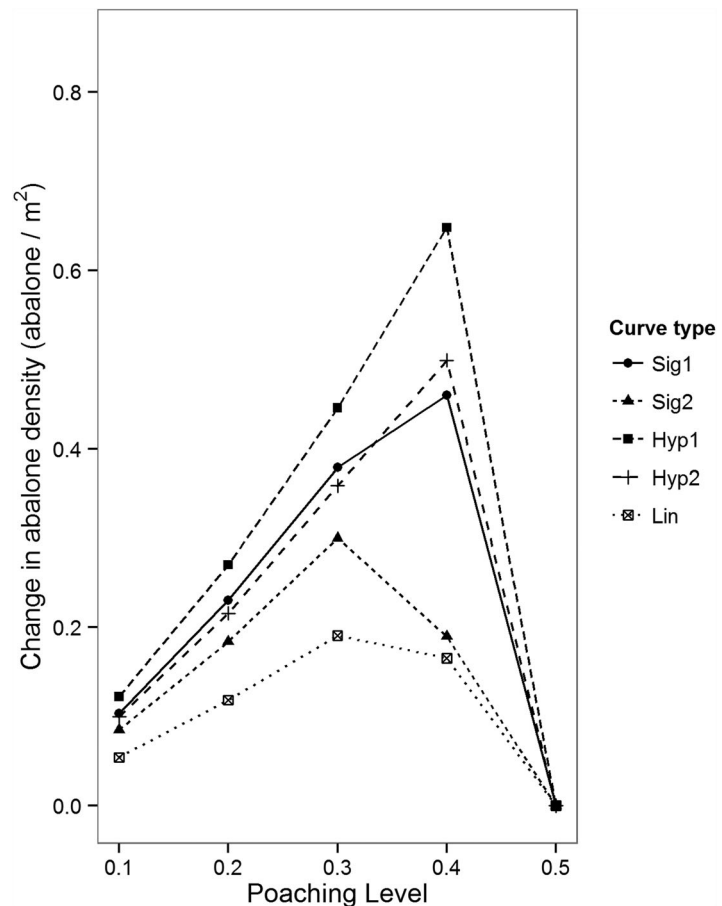


Figure 5 The change in expected abalone density over 50 years averaged across critical and noncritical habitat (in abalone per m^2) obtained by spending the optimal amount of time learning before protecting critical habitat for different levels of poaching (varying stochastically between 10% and 50%).

we are left with two options: make a critical habitat designation rapidly and assume that at worst we are able to discern between critical and noncritical habitat $\geq 50\%$ of the time; or accept that the cost and time to learn about a species' critical habitat is too great, and therefore scarce conservation resources could be better allocated on conservation efforts for a different species where the probability of successful identification of critical habitat and subsequent species recovery is greater (McIntyre *et al.* 1992; Bottrill *et al.* 2008).

Our illustration of the trade-off between learning about and protecting critical habitat raises several further questions. First, we assume that the hypothetical relationships between learning about critical habitat and time are sensible and that at worst they represent the bounds between best and worst case scenarios for the species in question. Despite decades of monitoring thousands of species, we know very little about the relationship between time and knowledge gain with respect to species habitat requirements. If we are to make rational decisions about species recovery and conservation we need to document the relationship between investment in surveying and knowl-

edge gain. Research tackling this question is finding that decisions can be made much sooner and with less data than we might expect (Grantham *et al.* 2008; Baxter & Possingham 2011), even when species are difficult to detect (Chadès *et al.* 2011).

Second, we assume that once critical habitat is protected, there will be a corresponding reduction in the processes causing species to decline. However, again, we have little published information on species recovery as a result of conservation actions, despite decades of active conservation measures being carried out. We do know, however, that there can be significant time lags between conservation action and species recovery (Mac Nally 2008). In the case of reducing poaching pressure on northern abalone, we account for the time lag between poaching reduction and population recovery within the population model, but we assume that there is a direct and proportional benefit to the population; however, this may not always be the case. For northern abalone recovery, protection of critical habitat will have to include greater surveillance to reduce illegal poaching.

Finally, we are aware that our analysis does not take into account costs to individuals or to society from constraining human extractive and/or recreation uses to protect an endangered species in its critical habitat. Such an analysis would entail comparative valuation of endangered species populations relative to the individual and societal values placed on human uses of critical habitat, a challenging social balancing act.

Conclusion

It may be tempting to assume that more information is of value for its own sake, in a decision-making context information has value only when it leads to a change in actions taken, specifically, a change with enough benefit to species protection to outweigh the cost of obtaining the information. In the often contentious environment of endangered species decision making, parties who benefit from delay in taking action often lobby strategically for more information, not because they are concerned for the efficacy of protective actions but because their interests are best served by delaying protection as long as possible. In this environment, reminding everyone that more information does not always translate into more efficacious action may help strike a better balance between action and research. When it comes to species conservation, time is the resource that matters most. It is also the resource we cannot get more of.

Acknowledgments

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Table S1. Abalone population parameters: age-specific lengths, fertilities (millions of eggs produced per female),

survival rates, densities and fecundities, where $s_{juv} = 5.42 \times 10^{-7}$.

Figure S1. Average abalone density over 50 years for each stopping time used in the simulations.

Figure S2. Optimal number of years to spend learning before protecting critical habitats for different learning curves.

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