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August 2007

## REDUCING RISK AND ENHANCING EFFICIENCY IN NON-NATIVE VERTEBRATE REMOVAL EFFORTS ON ISLANDS: A 25 YEAR MULTI-TAXA RETROSPECTIVE FROM SANTA CRUZ ISLAND, CALIFORNIA

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# REDUCING RISK AND ENHANCING EFFICIENCY IN NON-NATIVE VERTEBRATE REMOVAL EFFORTS ON ISLANDS: A 25 YEAR MULTI-TAXA RETROSPECTIVE FROM SANTA CRUZ ISLAND, CALIFORNIA

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**Abstract:** Effective conservation of native biodiversity on islands often requires the eradication of destructive non-native vertebrates. There are risks in conducting an eradication project, however, including the risk that the effort will fail to remove all the individuals, and the risk that the removal of the species will trigger ecological cascades with unanticipated and undesired consequences. Managers must plan to reduce such risks, and also maximize the return on investment of the limited conservation resources available for restoration programs. I discuss four vertebrate removal projects implemented on Santa Cruz Island, CA, over the past 25 years: sheep, golden eagles, pigs, and wild turkey. Collectively, these projects illustrate general principles for reducing risks inherent in eradication projects and for enhancing efficiencies in delivering conservation outcomes. Lessons from this case study – such as the value of disciplined engagement of the target population, strategic sequencing of restoration projects, and intensification of effort through the application of advanced technologies – can be applied to help accelerate the restoration of island ecosystems elsewhere and so the conservation of highly imperiled island biota.

**Key Words:** eradication, golden eagle, hyperpredation, invasive species, island conservation, mesopredator release, pig, sheep, turkey.

Managing Vertebrate Invasive Species: Proceedings of an International Symposium (G. W. Witmer, W. C. Pitt, K. A. Fagerstone, Eds). USDA/APHIS/WS, National Wildlife Research Center, Fort Collins, CO. 2007.

## INTRODUCTION

Non-native vertebrate species can pose a significant threat to island ecosystems and it is often necessary to eradicate them to prevent extinctions of unique native biota (GISD 2007, Reaser et al. 2007). When planning and implementing an eradication effort, however, managers must contend with a variety of risks. One risk is that the removal effort will ultimately fail, due in part to the great difficulty of detecting animals at low abundance; individuals that escape detection could repopulate the island. Another risk, ironically, is a risk in success. Because eradication efforts are targeted at species posing substantive threat to island resources, their removal can cause a fundamental shift in community dynamics and perhaps ecosystem function of an island. Through such cascades, undesired effects may result. While some undesired effects might be predictable, others – owing to the limitations of our ecological understanding – may be wholly unanticipated. While island managers may be motivated by the desired effects they hope to accrue through eradication, they must also be prepared to detect

and manage the undesired, and sometimes unanticipated, effects.

Santa Cruz Island, approximately 40 km off the coast of Santa Barbara, CA, USA, has been the focus of intensive restoration efforts for over 25 years. The island is comprised of two rugged mountain ranges flanking a central valley; the on-island road network is minimal and unreliable under rainy conditions. The Nature Conservancy (TNC) assumed conservation management of 90% of the island in 1978, and currently owns 76% of the 243 km<sup>2</sup> island. The United States National Park Service (NPS) now owns the remainder. NPS and TNC manage the island in partnership.

Much of the restoration effort to date has focused on removal of non-native species – legacies of an earlier ranching era. By looking across this multi-taxa and multi-decade restoration program, some strategic principles emerge for reducing risk and enhancing efficiency in vertebrate removal efforts that might have application for other island systems. This is not to say that this series of projects collectively exemplifies best practice. Rather, like all such efforts, these projects provide an opportunity to review different approaches and their outcomes, so that future

projects might adaptively benefit from that experience. The Santa Cruz Island case study does illustrate the complexity of ecological relationships that needs to be considered in order to enhance the likelihood of success in a removal effort, and to manage an island through the transition precipitated by a species' removal. This history also illuminates the value of, and approaches for, seeking enhanced efficiency in the implementation of removal programs, not only as a means to achieve better return on investment of limited conservation funds, but also as a risk reduction strategy.

## REMOVAL EFFORTS

Below, I present issues pertaining to efforts to remove four vertebrate species from Santa Cruz Island. For each, I provide brief background on the removal approach and the current status of the removal effort. In the synthesis section that follows, I discuss general observations regarding investment and ecological risk that might have application for projects elsewhere, including the role that programmatic efficiency can play in reducing such risks.

### Sheep Removal

Sheep (*Ovis aries*) were introduced to Santa Cruz Island in the 1850s, with devastating ecological consequences: destruction of unique native vegetation, destabilization of slopes, loss of soils, and more (Van Vuren 1981). The eradication of sheep on the island occurred in two phases. The first phase occurred between 1981-1989, when TNC removed over 37,000 sheep from 90% of the island, using mostly volunteer ground-based hunters working pasture by pasture (Schuyler 1993). The second phase occurred between 1997-2000 when NPS removed sheep from the remaining 10% of the island. Because those sheep were considered property of the previous owner, NPS was required to live capture them for transport to the mainland. Although it was originally estimated that approximately 3,000 sheep occurred on that portion of the island, NPS removed over 9,200. While this discrepancy may represent a difficulty of estimating populations, it might better indicate the difficulty of keeping pace with replacement using live capture as a removal technique. During the interval between the two removal phases, hundreds of sheep crossed to TNC's "sheep-free" side of the fence, and vigilant monitoring and continued hunting was required to protect the Phase I investment. In the end, it is not known how many

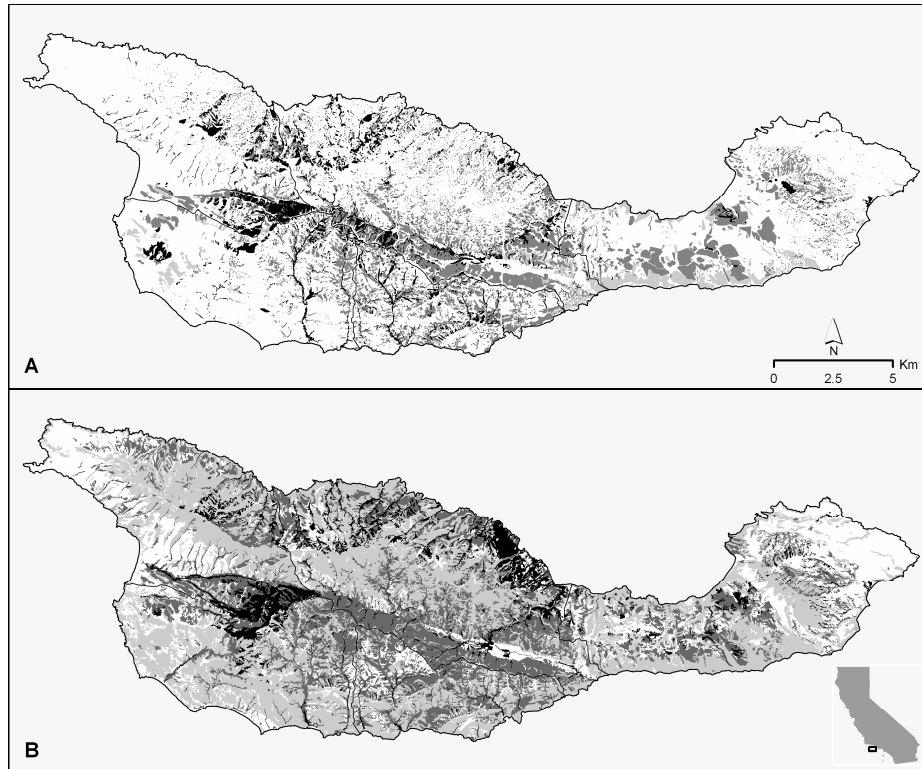
fewer sheep might have needed to be dispatched – and how much degradation of the island could have been averted – if the program had been more intensive and accelerated.

The desired effect of the removal of sheep was recovery of native vegetation, and that recovery has been dramatic (Figure 1). But in some areas there was also a concurrent proliferation of some non-native pest plants (Klinger et al. 1994). The degree to which the extent and severity of these weed infestations can be attributed to release from sheep grazing is not known, however, because in 1988-1989 another significant modifier of habitat was removed: approximately 2,000 head of domestic cattle (*Bos taurus*) were removed via round up and transport to the mainland, and vegetation response to cattle removal can be profound (see Wagner et al. 2004). Nevertheless, the release of both desired and undesired vegetation can be categorized as an "anticipated effect" of the sheep removal project. That same vegetation recovery, however, also set in motion an effect, described below, that was unanticipated and perverse, and that will take decades to manifest.

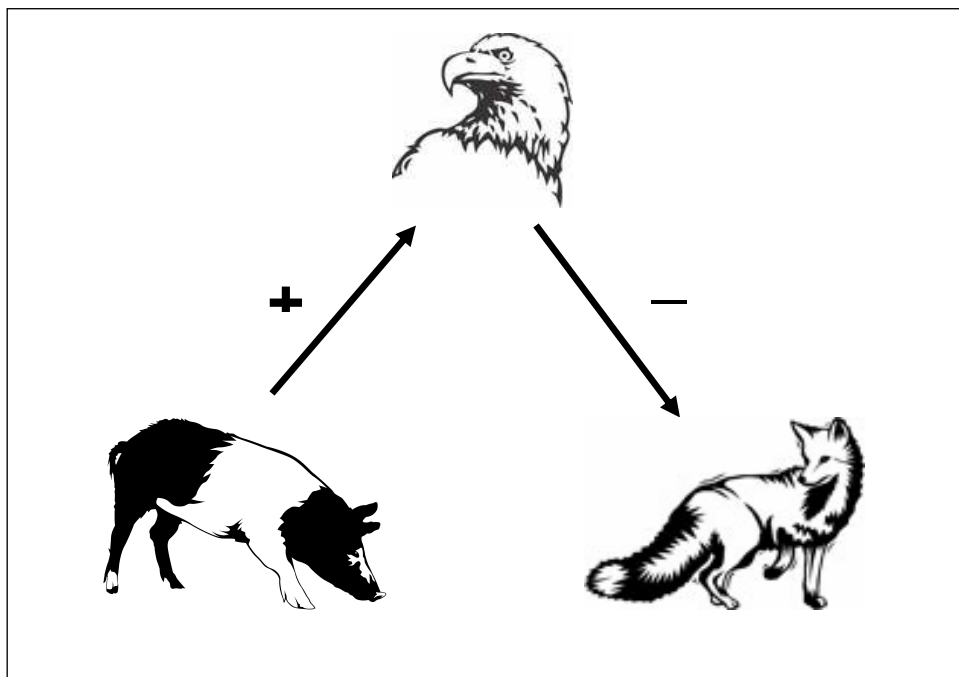
### Golden Eagle Removal

There is no evidence that golden eagles (*Aquila chrysaetos*) were breeding residents on Santa Cruz Island prior to the 1990s. By the end of that decade, however, multiple pairs had established territories on the island. With golden eagle populations in North America increasing in recent decades, immigrants had apparently arrived on the island, where they found not only an abundant food supply of feral pigs, but also the endemic island fox (*Urocyon littoralis santacruzae*), naïve to aerial predators and generally exposed by the slow recovery from devegetation caused by earlier overgrazing of sheep and cattle. A "hyperpredation" scenario ensued, whereby the non-native pigs sustained the non-native golden eagle population, and incidental predation led to a precipitous decline of native prey, the island fox (Roemer et al. 2002; Figure 2). In 2004, the island fox was federally listed as an endangered species.

In 1999, efforts were launched to live capture and translocate golden eagles from the northern Channel Islands to the mainland (Latta et al. 2005). At that time, it was assumed that a substantial and rapid reduction in the eagle population would suffice to allow for fox viability, and that not all of the eagles needed to be removed. Since then, 32 free-flying birds have been captured, mostly using concealed, baited, and manually-triggered bownets;



**Figure 1.** Vegetation change on Santa Cruz Island, 1985-2005. Maps depict vegetation coverage, pooled into general categories: bare ground and herbaceous vegetation, white; scrub and low stature vegetation, light gray; chaparral and medium canopy communities, dark gray; forest and woodland, black. (A) Vegetation map prior to/during the eradication of feral sheep (adapted from Jones et al. 1993 and Howarth et al. 2005) (B) Vegetation map classified from a 2005 image (adapted from TNC 2007). Inset shows the island location in the state of California.



**Figure 2.** Hyperpredation model for Santa Cruz Island fox. Feral pigs subsidized the establishment of a population of golden eagles, which through incidental predation drove the endemic fox to near extinction.

eggs and young were also removed from nests (Latta 2004, IWS 2006). Attempts to capture adult eagles at nest sites using nets and other methods have generally been unsuccessful. As the golden eagle population declined on the island so did capture efficiency. Between 1999-2001, \$265,000 was invested in capture efforts, netting 18 flighted birds, whereas between 2002-2004 eleven birds were captured at the expense of nearly \$506,000. In 2005, with an available budget of \$481,000, one eagle was captured.

It now appears that the presence of even a few eagles may slow or prevent recovery of the fox population. Between July 2005-June 2006, over 20 fox mortalities – approximately 10% of the subspecies' total estimated wild population at the time (Schmidt et al. 2007) – could be attributed to a single territorial pair of eagles. That pair was eventually captured, not by using our “traditional” methods but by employing an approach novel to the birds: a net-gun fired from a helicopter. That strategy was possible because we had a contractor on-island conducting an eradication of feral pigs, and we could couple its pilot experienced in wildlife management with a net-gun operator expert in interpreting and managing behavioral responses of helicopter-pursued eagles. That team safely captured both eagles in just two intensive half-day sessions, at a total cost of approximately \$10,000.

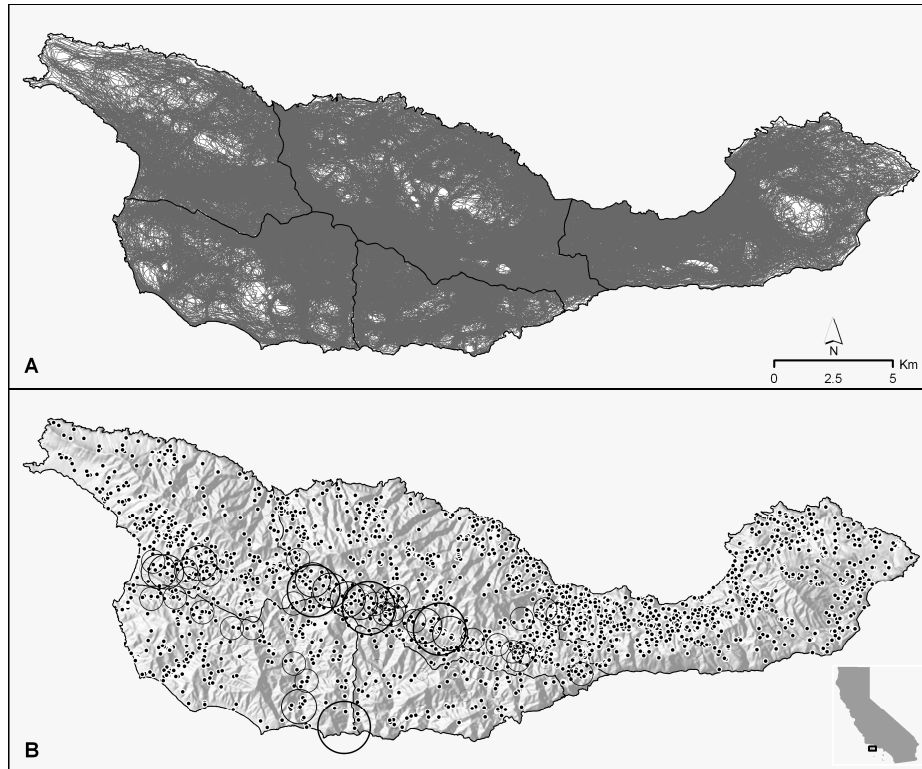
We do not know how many golden eagles remain on the island. Sightings of eagles have become exceedingly infrequent and unpredictable. In the past year, we have had only two golden eagle observations. The mortality of radio-collared foxes has become our only indicator of continued eagle presence, and between July 2006-July 2007, we recorded 23 eagle-related fox mortalities. Ground-based and aerial surveys continue to be unsuccessful.

### **Pig Removal**

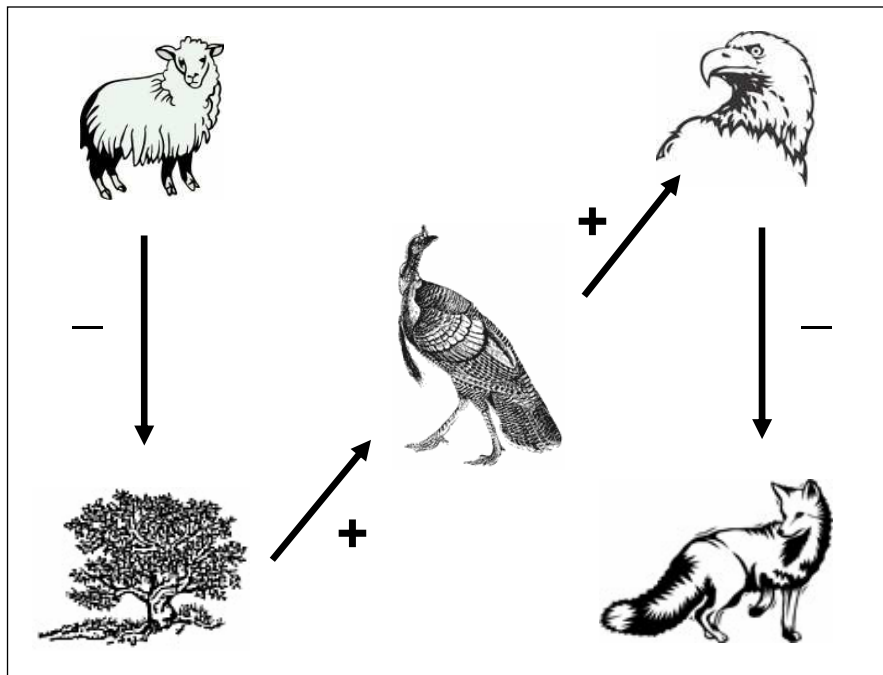
Pigs (*Sus scrofa*), also introduced to the island in the 1850s, have contributed to the imperilment of nine listed plant species on Santa Cruz Island, and the endangerment of three subspecies of island fox (NPS 2002). In 2005, TNC and NPS launched an eradication effort. In contrast to the feral sheep eradication on the island, the pig eradication project was conducted by a professional vertebrate eradication contractor. The defining strategic characteristic of this effort was the eradication team's singular focus on preventing the remaining pigs from being educated to avoid hunters even as the population was steadily reduced (Morrison et al.

2007). Perhaps the most significant tactical advantage was the full integration of aerial, GIS, GPS, and telemetry technologies in the effort. A helicopter, for example, serviced almost all daily activities, which greatly enhanced efficiency on this large and rugged island (Figure 3). Nearly 80% of the 5,036 total pig dispatches were from the helicopter. With this strategic and tactical advantage the interval between the dispatch of the first and what appears to be the last pig was only 15 months.

An eradication approach of this intensity may appear cost-prohibitive to have general application. To evaluate the relative cost-effectiveness of this more intensive approach, I compared the costs of the project on Santa Cruz Island with that of an effort to eradicate pigs from neighboring Santa Catalina Island (Garcelon et al. 2005). That program began in 1990; the few pigs known to remain continue to be pursued (P. Schuyler, personal communication). A key difference between the projects on the two islands was the integral use of helicopter support on Santa Cruz. Schuyler et al. (2002) estimated the direct cost of the Catalina Island project from 1990-2001 to be \$1,873,558, unadjusted for inflation and not including costs associated with fencing, fuel, and administration/support by the sponsor (Santa Catalina Island Conservancy). At the time, the authors estimated that an additional \$825,000 would be needed to complete the project. From that amount I subtracted the proportion of the 1990-2001 costs that covered fuel and administration, i.e. ~11%, and added the difference to the direct costs to date, to calculate a total unadjusted direct cost of \$2,604,955. For the purposes of this analysis, I assumed the Catalina Island eradication had a duration of 15 years, and divided the total direct cost by 15 to generate an average annual expenditure of \$173,664 between 1990 and 2005. If each annual expenditure is adjusted to 2005 dollars (FRB 2007), the direct cost of the Catalina Island project to date has been \$3,216,511. The Santa Cruz feral pig eradication “fixed price” contract value was \$3,900,000, which also did not include fencing, fuel, or sponsor (TNC and NPS) administration costs. In other words, the direct cost of the Catalina Island eradication, with operations underway for approximately 15 years, is 82% the cost of the Santa Cruz Island eradication which has taken approximately two years. Interestingly, Catalina Island, at 194 km<sup>2</sup>, is 80% the area of Santa Cruz Island.



**Figure 3.** Cumulative effort and outcomes from the feral pig eradication project on Santa Cruz Island, 2005-2007. (A) Black lines indicate the fence that divides the island into five pig management zones. NPS owns the easternmost zone; TNC owns the remainder of the island. Gray lines depict helicopter GPS flight paths during the hunting and monitoring phases of the project. (B) Pig dispatch locations; circles center upon trap locations with size representing the relative number of pigs dispatched in that trap. Inset shows the island location in the state of California.



**Figure 4.** Hypothesized hyperpredation cascade for Santa Cruz Island fox. Subsequent to the removal of feral sheep, vegetation recovery improved habitat quality and quantity for introduced turkey. As the turkey population grew, it could substitute for recently-removed feral pigs as a food source for golden eagles, leading to continued imperilment for incidental prey, the island fox.

The analysis above is admittedly simplified. Costs, for example, were not distributed equally among years, and there are other differences than helicopter use between the Santa Cruz and Santa Catalina efforts (Schuyler et al. 2002). Importantly, the Catalina Island effort did not begin as an eradication project but transitioned to one after pig population control failed to produce desired and sustainable results. An earlier control phase can complicate the attainment of an eradication goal (Morrison et al. 2007). Also, unlike on Santa Cruz Island, managers on Catalina Island needed to contend with a small on-island city (Avalon, CA) that surely constrained some hunting activities. Nevertheless, the point of emphasis with the comparison is that the costs of the two projects are comparable. In the end, a less intensive approach may not necessarily be less expensive – it may just result in a different payment schedule.

While per acre direct costs may have been similar between the two islands, other associated costs were likely not. On Santa Cruz Island, *not* conducting an accelerated eradication program would have resulted in significant financial, opportunity, and ecological costs. The indirect costs (administration, operations, and other support) of maintaining an eradication team on-island would have been substantial; the sooner the project ended the sooner that capacity could be invested elsewhere. Meanwhile, the viability of many species on the island was dependent upon eradication of the pigs, so resource-intensive species-specific management efforts (e.g., island fox captive breeding, golden eagle relocation, rare plant protection) would have likely needed to be sustained as long as pigs remained. Critical restoration needs like weed control could not be addressed, not only because pigs would have likely set back any progress made, but also because species-specific crisis management left little surplus capacity to do so. With a less intensive program, investment risks also would have compounded. The longer a project takes the more vulnerable it may be to disruption by weather, waning institutional will, legal challenges, and so on. And, the longer a project takes, the more replacement and perhaps selection of the target population will occur, which can undermine the likelihood of success (Morrison et al. 2007). Simply put, the faster the eradication program, the fewer animals need to be dispatched, the lesser the myriad costs and risks, and the sooner the degradation can be halted and the restoration begun. For some imperiled species, the difference

of those few years can be fateful. Thus, the question of concerning affordability of the more intensive approach should be whether the conservation community can afford *not* to use a more intensive approach.

### Turkey Removal

In 1975, seven wild turkey (*Meleagris gallopavo*) were introduced to the island for recreational hunting. Over the following decades, the population remained localized in the center of the island and numbered approximately 40-50 (P. Schuyler, personal communication). In the early 2000s, the population began to irrupt, growing from a single overwintering flock of 46 in 1999 to a population of 276 birds in 2006, dispersed over three distinct areas (L. Laughrin, unpublished data).

What might explain the turkey population's sudden irruption? The turkey increase did correspond with a low fox population, so perhaps prior to the fox population crash, foxes provided "top-down" control of the turkey through nest and poult predation. Yet, the feral pig population was not observed to be in decline during this period, and pigs would likely depredate the nest contents of turkeys as well. A different hypothesis to explain the increase is more "bottom-up" than release from top-down control. Following the feral sheep removal, vegetation recovery on the island was extensive (Figure 1). Thus, the removal of sheep may have effectively transformed the island from poor quality turkey habitat to high quality turkey habitat. The lag between the decrease in sheep and the increase in turkeys may simply be the period of recruitment and fruiting of native vegetation, like oak (*Quercus*) species whose acorns may be an important food for turkeys.

In assessing the increase in turkey numbers, TNC evaluated the risks that turkeys posed to island biota. Of principal concern was that turkey might replace the recently eradicated pigs as a food source for golden eagles (Figure 4). Given that golden eagles do depredate turkeys (Eaton 1992), the rapid population growth and geographic expansion was alarming. Barring some rapid intervention, the turkey population would likely continue to grow, freed as it was from habitat limitation (Figure 1) and from the nest predation and food resource competition it likely faced with pigs. TNC decided that especially after such substantial investment had been made to remove pigs, it was precautionary and prudent to attempt to remove the turkeys before their population increased further. With an exponential population

growth trajectory, waiting even another breeding season could have allowed the population to increase and expand to a point that management would be significantly more difficult and expensive.

Fortuitous for TNC was that the upcoming winter – when turkeys tend to aggregate in flocks that would be amenable for trapping – was to coincide with a waning of pig hunting activity by the on-island pig eradication team. Having available much of the expertise, capacity, and equipment necessary to mobilize a turkey removal effort helped make possible the needed rapid intervention. The turkey removal was conducted with the same attributes as the pig eradication, i.e., with a focus on humane dispatch and on not educating individual turkeys as the hunt proceeded (Morrison et al. 2007). Using strategic and disciplined deployment of drop nets, the population was reduced substantially in December 2006. Some captured birds were surgically sterilized by licensed veterinarians, affixed with radio-telemetry harnesses, and released to help assess the distribution, abundance, and activity patterns of the residual population. Although it is difficult to assess progress in advance of the next overwintering season, it does appear that the program has reduced the population to a very few individuals. Cost of this program has been approximately \$55,000.

## SYNTHESIS

Population removal efforts on Santa Cruz Island over the past three decades provide a unique vantage to assess risks and efficiencies in vertebrate eradication programs which may have application to efforts on other islands.

### The High Price of Education

The risk of failure in eradication programs is real and managers must explicitly focus on reducing that risk when planning and implementing their program. Not educating the remaining animals as the population is reduced is perhaps the most important means of reducing the risk of failure. That requires a focus on how the last individual will be captured – well before the first is even approached. Perhaps the greatest illustration of this principle from Santa Cruz Island comes from the golden eagle removal program. That program was initiated without an awareness that we might indeed need to capture all of the eagles. Had we that orientation early in the project, we might have been

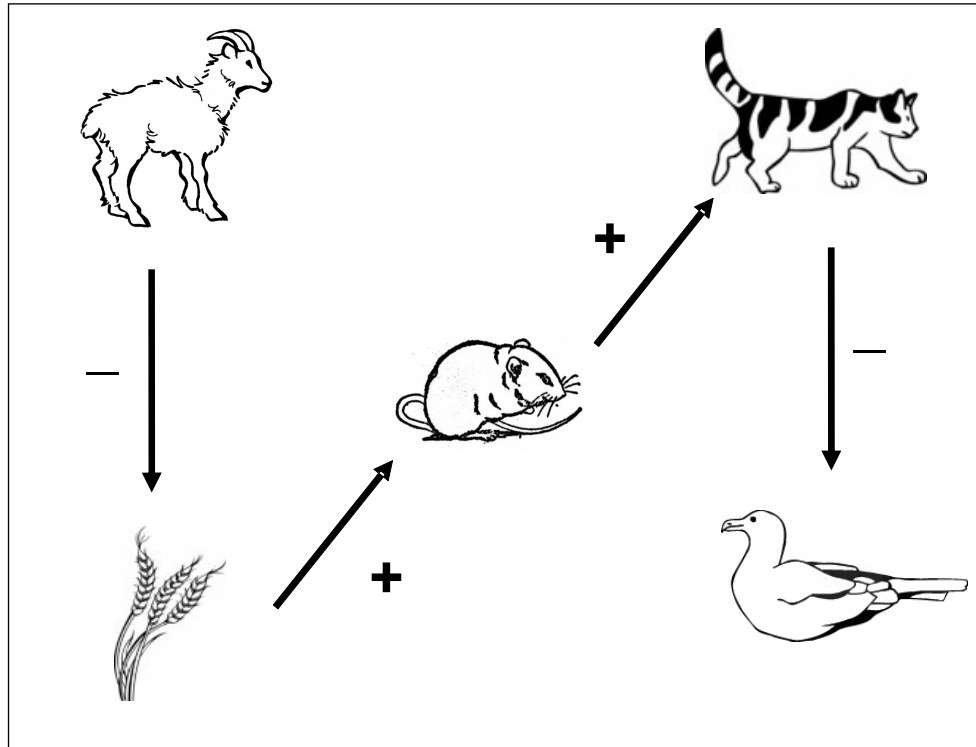
that much more cautious not to allow eagles to witness other birds being captured, or see us in the vicinity of their nest, and so on. This is not to say that the eagle teams working on the project were careless on this count. But eradication differs in a fundamental way from control: with eradication, *every* engagement with an individual matters, because ultimately every individual will need to be removed. The efficiency of the feral pig eradication is a testament to the benefit of having this strategic approach from the start. That the feral pig eradication project on Santa Catalina Island began as a population control program may to a large degree explain why it is still underway.

### Monitoring for Success

Removal of a target species may trigger ecological cascades leading to undesired or unanticipated effects on native biota. An example of an undesired but *anticipated* potential effect on Santa Cruz Island was the risk that the removal of pigs might actually increase the predation of foxes by golden eagle and so speed their extinction (Courchamp et al. 2003). We addressed this hypothesized perverse effect prior to the launch of the pig eradication by radio-collaring and monitoring a large proportion of the wild fox population, so that if the mortality rate did increase during or after the pig removal it could be detected and managed. In contrast, the turkey population increase in the wake of the vegetation recovery following sheep removal (Figure 1), and the hypothesized threat it posed for foxes (Figure 4), was for the managers on Santa Cruz Island an “unanticipated” effect. At the time of the sheep removal, golden eagles were not even considered a factor in the island’s community dynamic.

Although the trophic dynamic depicted in Figure 4 may seem idiosyncratic to Santa Cruz Island, a simple substitution of species with others occupying the same trophic position (Figure 5) reveals how this potential scenario may be rather common on invaded islands of the world. What might be anticipated with the removal of a habitat modifying herbivore is an increase in food resources for smaller herbivores which may lead to an increase in their abundance and a consequent release of mesopredators from food limitation, with an adverse effect on other prey. This mechanism differs from the top-down release of mesopredators from apex predators, as described in Crooks and Soulé (1999). Indeed, most attention on food web effects of eradication on islands has focused on direct and indirect top-down effects of removal of





**Figure 5.** Hypothesized bottom-up release of non-native mesopredators on islands. Vegetation recovery following removal of non-native herbivores could increase the food supply (e.g., perhaps nonnative grasses) for rodents (perhaps also non-native), and that could subsidize an increase in non-native mesopredators, with a cascading adverse effect on native biota.

species (e.g., Courchamp et al. 1999, Zavaleta et al. 2001). How bottom-up processes and anthropogenic habitat change influence mesopredator release effects has not been well studied (Elmhagen and Rushton 2007). Understanding these and other ecological relationships (Courchamp and Caut 2005) is critical for managers of restoration efforts on highly degraded and invaded islands.

Managers should not be daunted by the risks of undesired and unanticipated effects, but rather be committed to lessening their number and magnitude. Above all, the examples presented here underscore the necessity of science-based planning, and the importance of ecological monitoring and responsive management – before, during, and perhaps long-after an eradication. While the dynamics depicted on Figure 5 could conceivably manifest relatively rapidly in response to herbivore eradication, it is noteworthy that the dynamics of concern with turkeys on Santa Cruz Island were taking decades to unfold.

### The Value of Trophically-Strategic Sequencing

For islands with multiple invaders that include habitat modifying species like sheep there may be strategic advantages in eradicating other problem species first, since the removal of the grazer may trigger a vegetation recovery that could benefit the other undesired species and frustrate the removal of them. Perhaps, for example, pigs would have been easier to eradicate prior to or simultaneously with the sheep, because the devegetation wrought by sheep may have suppressed pig habitat and so pig numbers, and rendered pigs and pig sign easier to detect. Another neighboring island's feral pig eradication project may illustrate this point. Santa Rosa Island, at 215 km<sup>2</sup>, was cleared of pigs between 1990-1993 using mostly ground-based hunting techniques and without the benefit of fencing (Lombardo and Faulkner 2000). At the time, Santa Rosa was largely devegetated by overgrazing of non-native herbivores; over 70% of the island was grassland or non-vegetated (Lombardo and Faulkner 2000), which is a proportion similar to the area of grassland and bare

ground on Santa Cruz Island when sheep were present, i.e., ~74% (Figure 1A). A total of 1,175 pigs were removed from Santa Rosa Island. By the time the pig eradication was underway on Santa Cruz Island, however, the proportion of open habitat (grassland and bare ground) had been very much reduced, to ~24% (Figure 1B), and a total of 5,036 pigs were ultimately removed. The direct cost of the Santa Rosa Island pig eradication (K. Faulkner, personal communication), assuming equal allocation over three years beginning in 1990 and adjusted to 2005 dollars (FRB 2007), was \$1,080,050 – approximately a quarter of the direct cost of the Santa Cruz Island project.

If one species effectively limits the population size of other undesired species, managers should consider leveraging that effect to their strategic advantage. For example, in a community that has the potential to undergo a bottom-up release of predators, such as that depicted on Figure 5, there may be great benefit to first remove the invasive plant, and or the invasive rodent, and or the invasive predator before removing the species that is directly or indirectly suppressing the size of their populations and, hence, their adverse impacts. Unfortunately, trophically-strategic sequencing cannot always be implemented due to political, social or other reasons (that was the case with pigs on Santa Cruz Island; it was not our prerogative to remove them prior to sheep and cattle.) Yet, if the reasons to not optimally sequence are based more on cost and logistical considerations, those rationales should be scrutinized closely given that there may be great efficiency and economy of scale not only in optimal sequencing but also in the synchronizing of restoration efforts.

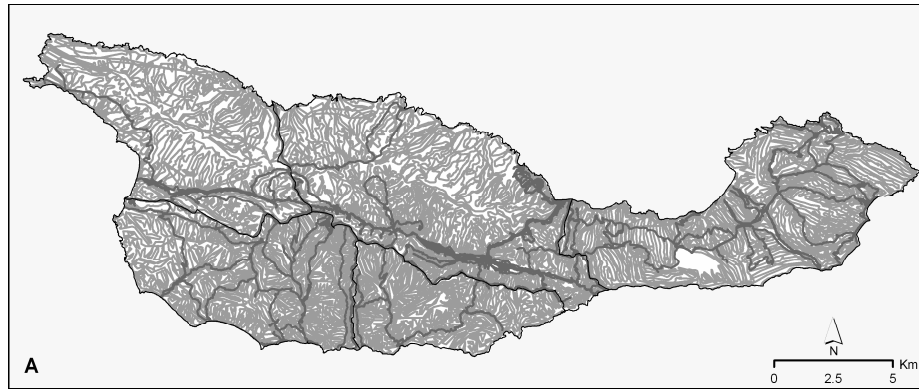
### **Maximizing Restoration Return on Investment**

As was illustrated in the direct, indirect, and opportunity cost comparison between the Santa Cruz and Santa Catalina island pig eradications, projects designed for intensity and, therefore, efficiency can offer great benefit. The return on investment can be further enhanced by planning to tackle multiple issues simultaneously or in immediate succession, thus leveraging the often substantial “start-up costs” of a project. Once the pig eradication team and equipment were on Santa Cruz Island, for example, it became clear that other restoration needs could then also be met, and much more cost-effectively and efficiently than if they each required independent mobilization to the

island. The golden eagle net-gunning and the turkey removal are examples of projects that had the incidental effect of maximizing the return on that initial investment in the pig eradication. By spreading costs over a variety of projects – whether by purposefully planning for and addressing multiple taxa on a single island, or the restoration needs of multiple neighboring islands – management becomes increasingly affordable. Such economies of scale can, of course, extend beyond vertebrates. Late in the feral pig eradication project, for example, TNC contracted with the provider to map weeds on the island and implement weed control on remote infestations. Use of the helicopter expedited the mapping and circumvented the risk of weed transmission by walking; it also provided additional island-wide surveillance for residual pigs (Figure 6). So a product from the weed mapping project was “free” additional monitoring for pigs. Regrettably, it was not until late in the pig eradication project that TNC began to contemplate such opportunities for efficiencies and economies of scale. It would behoove managers of future projects to proactively identify ways to leverage their investment in one aspect of restoration to benefit others.

### **Efficiency as a Risk Reduction Strategy**

The longer a project takes the more it is exposed to factors that can undermine its success. The eight year lag between Phases I and II of the sheep eradication on Santa Cruz Island put the investment and accomplishment in Phase I in continuing jeopardy. The risk that sheep would reinvade the area already cleared increased with each passing year, as the contrast between vegetation conditions across the fenceline – and so the incentive to cross – increased. The feral pig eradication on Santa Cruz Island has been subject to ongoing legal challenge aimed at stopping the project. Although the plaintiffs in this case have thus far not been successful in their efforts, the potential that a program would be halted prior to its completion is real. Accelerated implementation reduces investment risk in eradication. But perhaps most importantly, efficiency can help reduce the risk of extinction of native species on islands. The demonstrated efficiency of the feral pig eradication project could be a model to help increase the pace and scale of effective biodiversity conservation on the world’s islands.



**Figure 6.** GPS tracks of helicopter surveys of 2007 weed mapping project. At the end of the feral pig eradication project on Santa Cruz Island, the contractor that had conducted the feral pig eradication won a competitive bid for an island-wide weed mapping project. Much of that work was conducted using low altitude helicopter-based surveying. The weed surveys also provided supplemental monitoring for residual pigs. The gap in coverage on the isthmus represents the no-fly zone around an island fox captive breeding facility.

## CONCLUSION

Ameliorating the extreme imperilment of island biodiversity often demands the removal of destructive non-native species. Given the scarcity of conservation resources, it is imperative that those efforts be conducted in ways that reduce their inherent investment and ecological risks, and that maximize the restoration return on those investments.

Santa Cruz Island is relatively large among the islands that have been the focus of eradication efforts (Campbell and Donlan 2005, Morrison et al. 2007), and the year 2007 marks the first in over 150 that there are no unmanaged non-native mainland vertebrates on the island. It took a quarter of a century to achieve this milestone. Over that same time period, great advances in the science and practice of eradication – theoretical, statistical, and technological advances, as well as practical experience from efforts worldwide – make it possible for work that once took decades to now take but years. These advances, and those surely to come, enable managers to now set their sites beyond incremental gains to the entirety of their island restoration goals, and implement a comprehensive restoration strategy that maximizes return on investment and minimizes the myriad risks in that investment. Restoration goals for the world's islands should, accordingly, be all the more ambitious.

## ACKNOWLEDGMENTS

The accomplishments described in this paper are a testament to the vision and dedication of individuals and partners far too numerous to name. I would, however, like to acknowledge helpful discussions with N. Macdonald and K. Walker (Prohunt Inc.), A. DeNicola (White Buffalo Inc.), K. Faulkner, W. Livingston, and P. Schuyler. I thank P. Schuyler, D. Garcelon, and S. Escover for reporting economic data on the Santa Catalina Island feral pig eradication; such information is invaluable for advancing eradication science and practice, and too often it goes unreported. I am also grateful for B. Cohen's map figures, and the helpful comments of P. Kareiva, J. Randall, and R. Shaw.

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