Feral Pig (*Sus scrofa*) Soil Disturbance in Henry Coe State Park, California

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Abstract Exotic feral pigs (*Sus scrofa*) exist at increasing densities in California's oak woodlands, where their disturbance of the soil in the course of gathering roots and grubs constitutes a major change in disturbance regime and hence a management problem. In the summer and fall of 2003, I gathered data on feral pig soil disturbance and its associated habitat by walking a series of transects across Henry Coe State Park, a wilderness area in which a trapping program to control the feral pig population had recently begun. By comparing my data with data gathered in 1982 on the same transects, I determined: 1. That pig rooting has declined significantly between the two years of data-gathering; and 2. That this reduction was greater in the wetter of the two large watersheds of the study area. The implications for management are that, at least in this central California location, trapping feral pigs is an effective method of controlling their soil disturbance in the short term, and that it is evidently more effective where less precipitation is received. The ecological implication is that pigs may be concentrating in wetter areas, and thus estimates of pig population based on observation of those areas are likely to be faulty.

Introduction

Invasive species – organisms released into an environment to which they are not endemic, and in which their population is capable of expanding – are considered by many to be one of the most significant threats to global biodiversity. Invasive species may compete directly with native species whose numbers are often limited by predation. Invasives may also alter the environment, thereby transforming the habitat upon which native species depend (Ehrlich 1977). The feral pig, *Sus scrofa*, is a good example of an invasive organism, competing with native small mammals for acorns, grubs, and below-ground storage organs (Barrett 1987); reducing already-compromised oak recruitment by acorn predation; and producing a change in disturbance regime by their aggressive soil excavation in search of food.

The feral pig common in the west is descended from domestic pigs escaped since 1769 and European wild boar introduced for sport hunting since 1923 (Barrett 1987). The majority of feral pigs' active hours are spent rooting in the ground with their cartilaginous snouts for bulbs, worms and grubs, their main sources of protein (Krosniunas 1984, Van Vuren 1984). Soil disturbance is the most significant effect of feral pigs on their environment; pigs dig up areas of up to several hectares a day to a depth of 10 cm, turning over the soil and uprooting or burying all plant matter within the area. This "rototilling" impacts both plant communities and soil characteristics. Soil disturbance by feral pigs is regarded as a significant management problem in California as in many other places in the world.

The question, then, for managers, is how to control the numbers and behavior of these animals, which travel hundreds of km daily and bear two litters of six to 12 piglets each year (Barrett 1987). They are omnivores and thus difficult to target specifically with poison. Additionally, no reasonable method of excluding them from vast areas of backcountry is available. Trapping and killing appears to be the only realistic recourse. Given their vagility and fecundity, however, there is no guarantee that this method will work either, certainly no guarantee that it will prove cost-effective. Such a trapping program has recently been instituted in Henry W. Coe State Park, an oak woodland wilderness representative of feral pig habitat in California.

By recording data on a series of transects in Henry Coe State Park, and comparing them with similar data gathered in 1986, I endeavored to address several questions: Which habitat types at Coe State Park are most commonly disturbed by the pigs? What is the extent of this disturbance, by habitat type? What is the effectiveness of the Park's trapping program? And what is the longer-term trend in pig soil disturbance within the Park?

Methods

In the summer of 2003 I gathered data on feral pig (*Sus scrofa*) soil disturbance in Henry Coe State Park (Coe SP), an 80,000 acre area of oak and digger pine grassland in the Diablo Range of central California. The park consists of two large watersheds; there is a rainshadow effect, so the eastern watershed receives significantly less precipitation than the western watershed (fig. 1). In 2002 Coe SP instituted a trapping program to attempt to control pig densities, and thereby their soil disturbance.

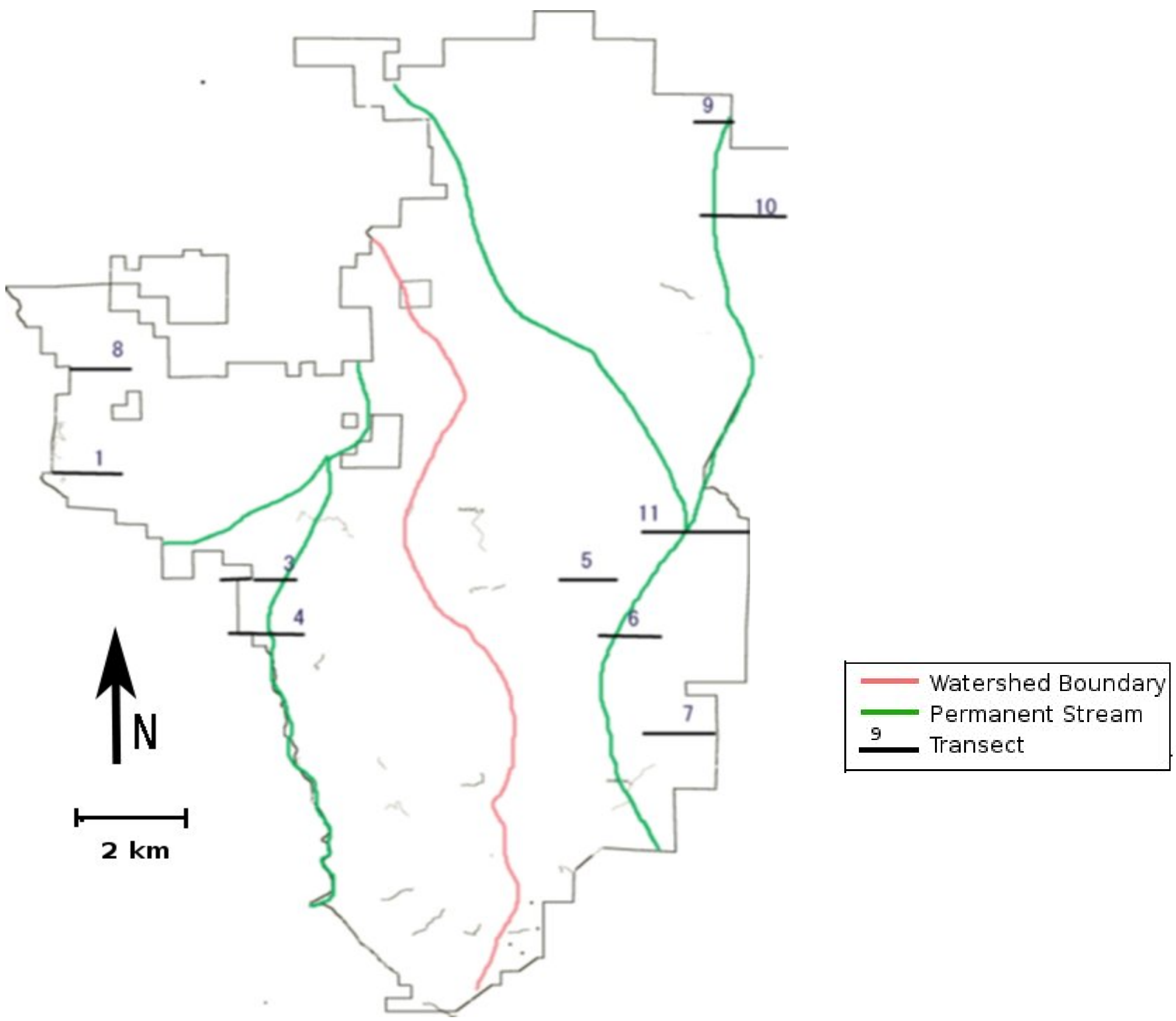

Figure 1. Henry W. Coe State Park

I walked 13 km of East/West transects due East/West across Henry Coe State Park, gathering data on successive 10-m square quadrats as I went, so as to ultimately survey a swath 10 m wide centered on each transect (Hone 1988; Anderson 1994). These transects duplicated, to within 50 m, those on which data, incorporated into my study, had been gathered in 1986 by Martha Schaub, a student in the lab of Reginald Barrett, UC Berkeley. I recorded habitat type (according to the California Wildlife Habitat Relationships System (CWHRS)) and area of soil disturbed by feral pigs for each quadrat. Soil disturbance was defined as an area of soil overturned to between 10 and 20 cm, with no new growth of grass or herbaceous groundcover showing, thus limiting my survey to areas disturbed within the previous year. Plots 10 m on a side were paced out or estimated visually; the percent of each quadrat's area disturbed was likewise estimated by eye.

Using contingency tables, I compared: 1) The proportion of quadrats in which soil had been disturbed in 2003 with that in 1986, 2) the 2003 with the 1986 data in the Western watershed of the park, which receives more precipitation, and 3) the 2003 with the 1986 data in the Eastern watershed of the park, which receives less.

Results

I compared observed frequency of feral pig soil disturbance in 1982 and 2003 on ten transects. The results are presented below (Fig. 2). These data show a significant decline in soil rooting between 1982 and 2003 (Fisher's Exact Statistic, $p<0.0001$; all contingency tables constructed and analyzed using JMP statistical software package).

Individual transects all fall wholly within one or the other of Coe's two watersheds: the Western, receiving an annual average of 66 cm of rainfall between 1974 and 1997 (Breckling 2003, pers. comm.), and the Eastern, receiving an annual average of 41 cm of rainfall between 1933 and 1988 (USGS 1988).

The observed changes in soil disturbance in each watershed are seen below (Fig. 3). Both watersheds experienced significant change (Fisher's exact statistic, $p<0.0001$), however, the percent change experienced is significantly different between them (continuity-corrected normal deviate = 360.4, $p<0.001$; calculated as per Zar 1999, pp. 556-557). This is to say that the

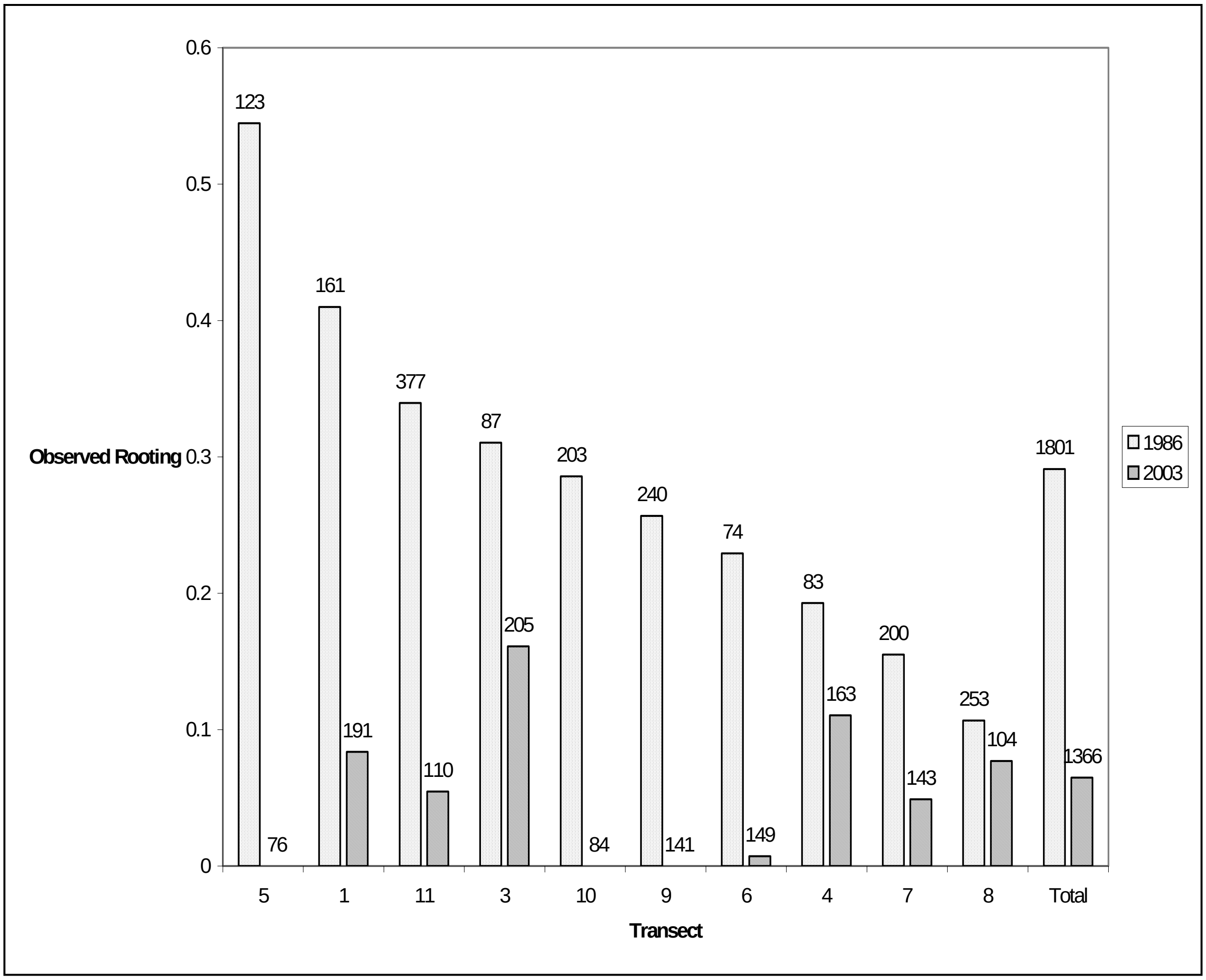

Figure 2. Proportion of Quadrats Disturbed. Transects are numbered as in figure 1. Total number of quadrats per transect above bars.

reduction in pig soil disturbance over the course of my study was significantly greater in areas of lower precipitation (27.4%) than in areas of higher precipitation (12.0%).

In 2002, 749 feral pigs were trapped and killed in Coe SP, at a total cost of $52,800 (Hartman 2003, pers. comm.). This is the most obvious explanation of the reduction in pig soil disturbance I observed. It appears that trapping has been effective in Henry Coe State Park as a means of controlling soil disturbance, and in addition that it has been more effective in the Eastern portion of the park where there is about 40% less rainfall.

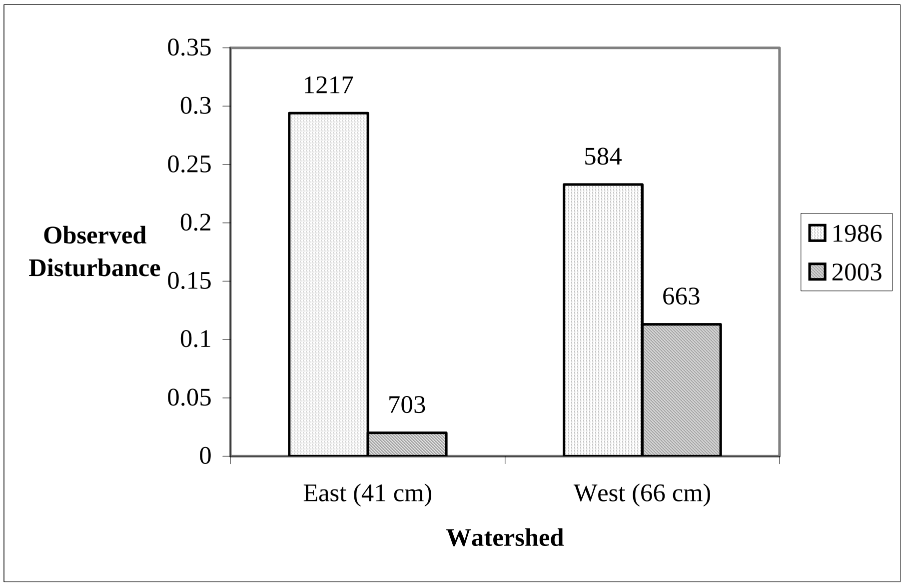

Figure 3: Proportion of Quadrats Disturbed, by Watershed. Mean annual rainfall indicated. Total number of quadrats in each watershed above bars.

Discussion

The Henry Coe State Park General Plan of October 1985 states (Van Vleck et al. 1985, 94):

"Policy: The district superintendent will take steps to initiate studies and carry out plans to remove exotic species.... The highest priority will be given to feral pigs because of the significant impact they cause."

However, the effects of pig soil disturbance in California are not clearcut. The three main hypothesised impacts of their rooting are on oak (*Quercus* sp.) recruitment, grass and forb population mosaics, and soil chemistry or structure; I will discuss each in turn.

Oak recruitment There is little doubt that pig consumption of acorns can suppress oak regeneration. During acorn season pigs can consume upwards of 3 kg dry weight of acorns per day, if such quantities are available that year, in the process gaining 0.5 – 1 kg per day of body weight (Barrett 1978). The impact on oak populations has been clearly demonstrated by several researchers (Kotanen 1995, Peart and Patten 1993, Moody and Jones 2000), with pig exclosures averaging 6 times more oak seedlings than open ground. Feral pig feeding is likely impacting oak regeneration in California. The water is muddied somewhat by uncertainties regarding oak recruitment. Oaks exhibit very low rates of regeneration in natural communities, and deciduous oaks such as *Q. lobata*, *Q. Douglasiana* and *Q. Kelloggii* have not been observed to produce any new adults of reproductive age in many parts of California as long as observations have been made. The reasons for this are obscure, but may include acorn predation and seedling browsing (Borchert et al. 1989), slope and aspect (Brooks and Merenlander 2001), facilitative shrub interactions (Callaway 1992), soil water competition with annual grasses (Gordon and Rice 1993), and fire suppression (McClaren and Bartolome 1989). While removing feral pigs from California's backcountry ought to increase acorn germination, even in the presence of possibly greater predation by former competitors such as ground squirrels (*Spermophilus beecheyi*) and mule deer *(Odocoilius hemionus*), it is not clear that increased germination would lead automatically to increased recruitment of replacement oaks. It may be that the after-effects of cattle ranching, with its large-scale tree clearing and introduction of exotic annual grasses, has created an alternative stable state, in which exotic grasses competitively exclude oak seedlings by more efficiently uptaking soil water (Gordon and Rice 1993). This may be especially problematic where tree densities are insufficient to provide adequate microhabitat (cover, soil moisture, and nutrients), to allow oak seedlings to survive past 90 days[1] (Moody and Jones 2000). Also, while fire suppression keeps chapparal communities from regenerating (McClaren and Bartolome 1989) "nurse shrub" densities may be insufficient to protect seedlings from browsing (Callaway 1992). On the other hand, it is also possible, and to be hoped, that this cocktail of interactions are acting in concert and the removal of one important inhibitor, such as feral pigs, might allow California oaks to begin to recover their numbers.

Plant communities Studies designed to test the effect of soil disturbance by feral pigs on California plant communities have proven surprisingly equivocal. Peart and Patten (1993) found plant communities within exclosures on Santa Cruz Island to differ from those outside, with total plant cover less inside exclosures; this suggests that, at least on Santa Cruz Island, pigs may be helping to maintain a (more dense) grassland state by their rooting. Kotanen (1995) found plant diversity within exclosures to increase the first year of observation, and to decrease thereafter, relative to the outside. He also found no significant differences in relative quantities of native and exotic plants owing to pig soil disturbance. Cushman (2003, pers. comm.) found an overall decrease in plant diversity after rooting, and a complex pattern of plant biomass changes, which could be interpreted as suggesting that pigs preferentially root in areas already grown over with soft annual grasses, avoiding areas of tough perennial natives. In addition, it must be

[1] Acorns come "packed" with enough nutrient to last them this long.

remembered that as pigs have been released into California they have effectively replaced two former soil disturbers: humans and, especially, grizzly bears. I would suggest that feral pig soil disturbance is thus more a continuation of a long-term disturbance regime in California than a new and potentially destructive influence, and that its impacts over time will stem more from its increased range than its intrinsic properties; pigs will soon outnumber preconquest humans and grizzlies taken together, and are more aggressive rooters than either. I suggest that pig rooting helps to maintain a grassland state over more of California than it would otherwise cover, inhibiting processes of facilitative succession that would otherwise help to regenerate native oaks.

Soil Finally, Moody and Jones (2000) searched for effects of pig rooting on soil characteristics such as moisture, pH, and nutrient dynamics and found none that could not be attributed to effects of spatial position relative to live oak (*Q. agrifolia*) canopies. Thus, other than changes in soil structure leading to increased danger of erosion, physiochemical impacts of pig soil disturbance appear to be insignificant.

While my data offer little direct insight into these questions, I feel it is important to situate management efforts in a rigorous context. Taxpayer dollars (at Coe S.P., for instance) are being spent to kill feral pigs as a method of controlling their soil disturbance, and my research suggests that, at least in this instance, it is successful. However, so long as the urgency of the problem and even its nature are not being clearly articulated, estimating the benefits derived will remain difficult.

My data show that the prevalence of feral pig soil disturbance decreased dramatically between 1986 and 2003, contrary to anecdotal evidence (e.g. Breckling 2003, pers. comm.). In addition, the decrease was significantly more pronounced in an area of relatively low precipitation. One interpretation of these results is that the trapping program undertaken in my study area has been effective, especially in the Eastern half of the park where rainfall is low. Either pig biology or soil physics might help explain this; pigs lack sweat glands and consequently must immerse themselves in water to control their temperature in hot weather (Barrett 1987), thus their sojourns in dryer areas might be expected to be briefer. Also, because California's clay soils are much more difficult to disturb when well-dried than when moist, pigs might be expected to prefer moister habitat. Whatever the reason, my data indicate that feral pigs are concentrating their soil disturbance in the moister Western area of Coe S.P. Since higher-rainfall areas of Coe S.P. are, not coincidentally, also much more popular with park visitors, this suggests a mechanism by which informal observation of pig soil disturbance is likely to systematically underestimate its true extent. Pig populations may expand into dryer areas on reaching their carrying capacity in more preferable habitat, and abandon them as populations decline; if observations are only made in preferable habitat (for humans and swine), observed concentrations will appear constant across these population fluctuations.

Several potential confounding factors must be considered. First, in the absence of data from nearby land on which pigs have been left unmolested, the supposition of effectiveness of pig trapping in reducing soil disturbance rests on nothing stronger than logic. This would be a fruitful direction for future research; I predict that soil disturbance by feral pigs in unmanaged areas will be significantly unchanged relative to the area of my study, over a similar time period. Second, climate change appears to be a reality in California as elsewhere, and it is entirely possible that steadily decreasing rainfall or other climatic effects are affecting pig behaviors and locations. The precipitation data to which I have access are insufficient to address this possibility. A final possible causal factor is the acorn mast in the years immediately prior to the years of study. While pigs cause little soil disturbance in gathering acorns, the bulk of their diets, they more energetically seek out high-protein foods such as earthworms when sufficient acorn crops are available (Barrett 2003, pers. comm.). As it happens, however, neither 1981, 1982, 2003 or 2004 showed unusual acorn crops at Hastings Reservation, which is close enough to Henry Coe SP to serve as a proxy (Koenig 2003, pers. comm.).

Conclusion

Pig rooting has declined significantly between 1986 and 2003 in Henry Coe State Park, probably owing to a pig trapping program begun in 2002. This reduction was greater in the wetter of the two large watersheds of the study area. The implications for management are that, at least in this central California location, trapping feral pigs is an effective method of controlling their soil disturbance in the short term, and that it is evidently more effective where less precipitation is received. Further data, from a comparable area where pigs are not being trapped and killed, would provide more evidence for this. The ecological implications are that reduction in population owing to trapping, possibly combined with climatic pressures, may be causing the pigs to concentrate in wetter areas, and thus anecdotal estimates of pig population are likely to be faulty.

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