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Too many hogs? A review of methods to mitigate impact by wild boar and feral hogs

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Abstract: Feral hogs (*Sus scrofa*) are among the most widely-distributed mammals in the world and have the highest reproductive output compared with other ungulates. Worldwide, feral hogs are increasing in range and numbers. Human–feral hog conflicts include impact on abundance and richness of plant and animal species, crop damage, predation on livestock, vehicle collisions, and disease transmission. We reviewed methods employed to mitigate the impact of feral hogs on human activities and discussed these methods in terms of effectiveness, feasibility, costs, and social acceptance. Traditional methods of control include trapping, angering, shooting, poisoning, and Judas hogs. Nonlethal methods of control include fertility control, fencing, repellents, diversionary feeding, and translocation.The review indicated that successful eradications of feral hogs from islands have been achieved by combining different control methods and by establishing post-eradication monitoring to ascertain that the eradication had been completed. Conversely, on the mainland and in countries where feral hogs have long been established, management of human–feral hog conflicts often relies on population size reduction through hunting and poisoning the animals or on exclusion fencing and diversionary feeding. In the majority of instances, population control is not based on previous knowledge of local densities or on predicted impact of control on population size. Based on these results, we propose a framework of criteria to guide decisions regarding the suitability of different options to manage human–feral hog conflicts in different contexts.

Key words: diversionary feeding, fencing, feral hogs, fertility control, human–wildlife conflicts, poisoning, population control, shooting, *Sus scrofa*, trapping, wild pigs

Wild boar and feral hogs (*Sus scrofa*, collectively (referred to as feral hogs unless otherwise specified) are among the most widely-distributed mammals in the world. Their natural range extends from western Europe and the Mediterranean basin to eastern Russia, Japan, and Southeast Asia (Sjarmidi and Gerard 1988). In the northern hemisphere, this species recently recolonized Sweden, Finland, and Estonia (Erkinaro et al. 1982) and was reintroduced in the United Kingdom (Wilson 2005). Feral hogs, which are derived from domestic hogs, were introduced to North and South America (Barrett 1978, Mayer and Brisbin 1991) Australia, and New Zealand (Choquenot et al. 1996).

Feral hogs are long-lived omnivores characterized by the highest reproductive rate among ungulates, with annual increases in population that may exceed 100% (Katahira et al. 1993, Bieber and Ruf 2005). The species occurs throughout a wide spectrum of habitat types, ranging from semiarid environments to tropical forests, mountains, and marshes. As monogastrics, hogs have a limited capacity for digesting cellulose, and their survival and reproductive output depend on the availability of high-energy food, such as acorns (Massei et al. 1996). Due to their habit of rooting for food, feral hogs cannot survive in areas where snow cover persists for several consecutive weeks or where droughts harden the soil.

Throughout the world, feral hog populations are increasing in numbers and range. For instance, in the late 1980s the number of wild boar shot annually in France was <100,000, but reached around 450,000 in 2002 (Pfaff and Saint Andrieux 2007). Similar trends were observed in many other European countries and in Australia, possibly due to a combination of socio-economic and ecological changes (Sáez-Royuela and Tellería 1986, Spencer and Hampton 2005). These changes include lack of predators, reforestation of rural areas, reintroductions, limited hunting, supplementary feeding, translocations, and mild winters, which improved their winter survival (Genov 1981, Erkinaro et al. 1982, Geisser and Reyer 2005, Spencer and Hampton 2005). In the United States, the number of states reporting the presence of feral hogs rose from 23 in 1988, to 30 in 2002, and 39 in 2004 (Hutton et al. 2006). Pimentel et al. (1999) estimated that 4 million feral hogs lived in the United States, while Muller et al. (2000) reported 3 million feral hogs in Texas alone. In Australia, the estimated number of feral hogs varies between

Figure 1. A group of trapped feral hogs. (*Photo courtesy C. Wyckoff*)

13 and 23 million (Spencer and Hampton 2005). In the United States and Australia, feral hog expansion was attributed to deliberate releases to create sport hunting opportunities, range expansion as population numbers increased, escapes from hog farms, habitat alteration due to human activities, milder winters, and increased forage availability associated with agricultural development (Waithman et al. 1999, Hutton et al. 2006). In Europe, wild boar recently colonized suburban areas of Berlin, Barcelona, and Genoa, all of which reported increasing numbers of sightings (Walker 2008).

Throughout their range, feral hogs have a substantial impact on human interests, including damage to crops and livestock, spread of diseases, and vehicle collisions (Engeman et al. 2004, Conover 2007, Conover and Vail 2007, Mayer and Johns 2007). Feral hogs may also cause reduction in plant and animal abundance and richness, particularly where they occur as non-natives; they are regarded to be among the worst 100 invasive species in the world (Hone 2002, Massei and Genov 2004, Seward et al. 2004, Engeman et al. 2007). Current trends of human and hog population growth and landscape development indicate that human–feral hog conflicts are likely to increase in the near future. However, feral hogs also are important as game, and in some parts of the world, they provide a valuable source of protein (Waithman et al. 1999, Milner-Gulland et al. 2002). Therefore, population control or eradication, which often are advocated by wildlife managers, veterinarians, farmers, and conservationists, can be opposed by local hunters and the tourist industry.

Publications on feral hog control are almost invariably focused on single case studies. Exceptions include Choquenot et al. (1996), the State of Hawaii (2007) and West et al. (2009), who listed methods to control feral hogs in Australia, Hawaii, and the United States, respectively, and Campbell and Long (2009*a*), who focused on options to manage the impact of feral hogs in forested ecosystems. However, a comprehensive assessment of the feasibility, humaneness, social acceptance, and costs of methods to control hog populations and hog impact has not been produced. We present a critical review of these methods and develop a framework of criteria and recommendations to guide decisions regarding the suitability of different options to mitigate human–feral hog conflicts.

Methods to mitigate human–feral hog conflicts

Although Hone (1995) showed that hog abundance is not necessarily related linearly to impact, a high level of impact is usually regarded as an indicator of overabundant population. Human–feral hog conflicts traditionally have been managed through culling and poisoning the animals. More recently, however, community opposition to lethal methods to manage wildlife has become widespread because of animal welfare issues, concerns about human safety in urban settings, and environmental impact of toxicants (Beringer et al. 2002, McCann and Garcelon 2008, Reidy et al. 2008). As a result, many state agencies and local authorities are under pressure to consider safe, effective, nonlethal options to resolve human–feral hog conflicts. Management efforts, thus, have been redirected toward protecting resources, such as valuable crops or livestock, by using methods, such as exclusion fencing and fertility control, to reduce population size. We summarize the advantages and disadvantages of lethal and

Table 1. Lethal methods to manage human–feral hog conflicts.

Method	Advantages	Disadvantages
Trapping and euthanasia	• Hogs are easy to trap • Humane, if frequently checked • Selective removal of age or sex classes • Species-specific removal • Low social disturbance • Fast-acting at population level • Hogs can be removed alive • Usable in residential areas • Can provide meat • Traps can be moved and re-used	• Trap shyness • Impractical on high slopes or very dense vegetation • Labor-intensive due to building, baiting, and checking traps • Requires euthanasia • Effective only when natural food availability is limited • Applicable on a small scale • Encourages animal translocation • Traps prone to human interference
Snares	• Effective if correctly set • May target localised problems • Can provide meat	• Often regarded as inhumane • May affect nontarget species • Remove relatively small numbers • Labor-intensive to set and check • Prone to human interference • Illegal in some countries
Ground shooting (with or without dogs)	• With several teams, cost-effective in areas of high densities • Selective removal of age or sex classes • Fast-acting at population level • Can provide meat and trophies • Useful for inaccessible or remote areas • Dogs can be used to flush hogs in dense vegetation	• May encourage hogs to avoid people • Changes in spatial and temporal behavior • May cause social perturbation and increased contact rate • Inhumane if shooters are inexperienced • Difficult to use or illegal in residential areas • Dogs may be injured or killed by hogs • Hunters may be shot • Untrained dogs may attack other species
Aerial shooting	• Cost-effective in areas of high densities • Selective removal of age or sex classes • Fast-acting at population level • Can provide meat and trophies • Useful for inaccessible or remote areas	• May encourage hogs to avoid helicopters • Changes in spatial and temporal behavior • Increase in unit costs as hog numbers decrease • May cause social perturbation and increased contact rate • Inhumane if shooters are inexperienced • Difficult to use or illegal in residential areas
Poisoning	• Cost-effective • Can be used on a large scale • Fast-acting at population level • Can be used to target trap-shy animals	• Often regarded as inhumane • Hogs might not eat poisonous baits • Can affect nontarget species • Bait shyness • May cause social perturbation in feral hogs • Unfeasible in residential areas • Toxicants are not approved in many countries • Requires banning on meat consumption
Judas hogs	• Can be effective for removal of remnant animals	• Used only with other control methods • Labour intensive due to trap and release • Expensive due radiotracking equipment

nonlethal methods to control the impact of feral hogs (Table 1). For each method, advantages and disadvantages should be regarded as relative to those of other control options.

Lethal methods of control

Trapping and euthanasia. Traps are widely-used to control feral hog populations (West et al. 2009). When the availability of natural food is low, feral hogs are relatively easy to trap, and trapping can effectively remove large numbers of animals in areas of high hog density (Figure 1; Table 1).

Many trap designs are available, ranging from those that can capture single hogs or small groups of them to corral types that can capture large groups (e.g., Saunders et al. 1993, Caley 1994, Choquenot et al. 1996, Sweitzer et al. 1997, West et al. 2009). The majority of traps are made of mesh frames with drop gates and side-hinges or top-hinged spring-gates that hogs must push to gain access to the food placed inside the trap. Corrals have similar gates but are larger and may have a funnelled entrance to guide animals toward box traps that are used to remove hogs. The food most frequently used to attract feral hogs to traps is maize, fermented wheat, vegetables, fruit, blood, fish, animal parts, or carcasses (Choquenot et al. 1996, Cruz et al. 2005, Twigg et al. 2005). Hog-specific baits are also commercially available, and attractants have been developed to increase trapping success (Cowled et al. 2006, Campbell and Long 2009*b*). If they can be checked at least once per day, traps are generally considered to be humane for feral hogs and for nontarget species, such as other wildlife and livestock that can be released. Large traps that allow the whole social group to be captured are likely to have little impact on social behavior. The latter is particularly important as social perturbation may lead to increased contact rates, with the potential risk of increasing disease transmission and may encourage long-distance movements, thus, extending the impact to neighboring areas (Sodeikat and Pohlmeyer 2002). Maintaining and regularly checking traps can be expensive in staff time and can be applied over only relatively small areas. However, traps can be moved and redeployed to other areas, and trapping can be fitted around other routine control activities.

Trapping success depends on a variety of factors, including topography, time of year, type of trap used, number and density of traps deployed, trap location, number of nights each trap is used, type of bait used, and duration of pre-feeding before the traps are set (Hone et al. 1980, Choquenot et al. 1996, West et al. 2009). For instance, in New South Wales, Australia, Saunders et al. (1993) found that season and trap location affected trapping success and that placing traps in areas with recent hog activity or along the treeline, rather than in the forest or in the clearings, increased trapping success.

Traps are difficult to transport and use on sloping or rough terrain; conversely, they can be easily deployed to remove hogs from residential areas. Compared to poisoning as a method of control, trapping has the advantage that the number of animals captured is known and carcasses can be safely removed. The fact that live traps may encourage translocation should be regarded as a disadvantage, as translocation of feral hogs should be discouraged (see below). In addition, traps can be easily damaged by people who are opposed to culling.

Trapping has been employed in many feral hog eradication projects. In the Pinnacles National Monument, California, trapping removed 70% of the hog population in the first 3 months, and the combination of trapping and opportunistic shooting increased the efficiency of hog eradication (McCann and Garcelon 2008). In Hawaii, trapping failed to remove feral hogs at low densities because these animals became trap wary (Reeser and Harry 2005). On Santiago Island, Ecuador, Coblentz and Baber (1987) found that trapping was ineffective, due to a combination of poor trapping success and lack of sufficient staff required to check traps. However, McIlroy (1983) and O'Brien et al. (1986) used trapping as the main method to eradicate feral hogs from study sites in California. On Santa Cruz Island, California, 16% of the 5,036 hogs removed to achieve eradication were caught in 102 traps that were set for 1,660 trap-nights (Parkes et al. 2010); by comparing hog home range size and trap distribution, researchers were able to predict the efficacy of each trap.

Snares. Snares consist of an anchored cable or a wire noose set to close around the neck or a foot of an animal. These devices may have stops that prevent them from closing and strangling animals of a certain size or break-away locks that allow larger animals to escape. The effectiveness of this method greatly depends on snare design, although snaring has been criticized as inhumane to both target and nontarget species (TWDMS, 1998).

The use of snares is regulated in many parts of the world and is illegal in most European countries. Snares have been used extensively in Hawaii to remove large numbers of feral hogs (Anderson and Stone1993). For instance, snares accounted for 55% of the feral hogs removed in Hawaii during 1983 to 1992 (Jeffery 1999). Snares were also used to complement shooting and achieve hog eradication on Sarigan Island, Western Pacific Ocean (Kessler 2002).

Snares are inexpensive and easy to set in large numbers. However, they can target only 1 animal at a time and should be checked at least once per day to monitor whether target and nontarget species have been caught. This clearly increases the cost of programs based on this method. In the Haleakala National Park, Hawaii, Anderson and Stone (1993) used approximately 2,000 snares, set at a density of 96 to 200 snares per km^2, for a feral hog control program. After 45 months, hog density was reduced from the initial 6 to 14 hogs per km^2 to an estimated 1 hog per km^2. However, snares were checked every 3 months, which meant that hogs caught in the snares were left to die for lack of water and food. At present, this approach would be deemed unacceptable due to its lack of humaneness.

Ground shooting. Shooting has long been established as a control method for feral hogs (West et al. 2009). In many parts of the world, recreational hunting is carried out by shooting from the ground or from high seats at bait stations. Hunters may hunt alone, in small teams, or in large groups to carry out drive hunts, in which animals are driven toward a line of hunters by people walking along a front to flush hogs from cover; often they use dogs trained to flush hogs. In Europe, the use of hunting dogs is widespread, particularly in areas with dense vegetation (Geysser and Reyer 2004). Dogs are also used by hunters in Australia, New Zealand, and the United States (McIlroy and Saillard 1989, Campbell and Long 2009*a*).

Hunting is effective in areas with high densities of hogs, as many animals can be culled in relatively short periods (Table 1). Hunting may allow selective removal of specific age or sex classes and provide hunters with the additional incentive of meat and trophies. Feral hogs can learn to avoid hunters by becoming more active during the night and by avoiding areas where hunting occurs. However, the effects of hunting on the spatial behavior of feral hogs are still unclear. For instance, in France, hunting with dogs caused wild boar to increase home range sizes (Calenge et al. 2003). In Germany the home range of 6 wild boar groups out of the 9 groups monitored increased from 183 ha (pre-hunt) to 299 ha after a drive hunt, and 3 groups also moved up to 6 km outside their previous range (Sodeikat and Polheimer 2002). However, 2 other studies, in Germany and Australia (McIlroy and Saillard 1989, Keuling et al. 2008), found no effect of hunting on spatial behavior of feral hogs. During a study carried out in the Namadgi National Park, Australia, hunters with dogs on 19 occasions passed within 100 m from hogs that carried radiotransmitters, and they found and killed a hog only once (McIlroy and Saillard 1989). Although hogs were active when the hunt started, they became stationary when the hunters moved closer, and most animals did not leave their home range. Dexter (1996) suggested that the impact of shooting on feral hogs' behavior might depend on the level of human disturbance that animals have experienced. Where hunting pressure is constant and high, hogs may learn to cope with the disturbance by hiding or lying still until the hunters have moved away.

Poorly-trained dogs may pursue and kill other animals, thus, causing serious disturbance to local wildlife and increasing the staff effort to achieve eradication. (Massei and Toso 1993, Cruz et al. 2005). Other disadvantages of hunting include potential social disturbance and animal welfare issues. If hogs leave their normal home range, they can potentially increase their contact rate with other hogs and, thus, extend their impact to other areas. Animal welfare issues concern hogs that are injured but not killed and dogs that can be severely injured by hogs. Controlled shooting by experienced staff can overcome this problem, and dogs trained in flushing but not attacking feral hogs are less likely to be injured.

Ground shooting has been employed in a large number of projects aimed at eradicating or controlling feral hog populations. For instance, on Santiago Island (Ecuador) Coblentz and Baber (1987) found ground shooting effective, but time consuming. On the same island, Cruz et al. (2005) found a rapid increase in effort required to remove hogs in the final stages of the eradication campaig; in 2000, the effort required to remove each hog was 450 times greater than it was in 1998. However, the authors mentioned that opportunistic hunting over bait sites was particularly useful as a secondary technique to reduce feral hog numbers after trapping. In Switzerland, Geisser and Reyer (2004) showed that hunting was more effective in reducing damage to crops than fencing or supplementary feeding, although shooting was also regarded as time consuming. In California, Barrett (1978) found that hunting with dogs throughout the year removed approximately 20% of the feral hog population. In Australia, McIlroy and Saillard (1989) reported that sustained hunting throughout the year reduced the population density to 3 to 8 hogs/km^2 compared to 43 hogs/km^2 in a nearby area with low hunting pressure. Similarly, in Hawaii, shooting by hunters with dogs that varied the routes hunted, the time of the day when the hunt started, and the interval between hunts led to eradication of hogs from large, fenced compartments or reduced densities to less than 1 hog/km^2 (Stone and Keith 1987).

Ground shooting also was used as the main technique to eradicate hogs from the 5 km^2 Sarigan Island, Pacific Ocean; circa 2,000 man hours were required to remove 68 feral hogs and 904 feral goats in 2 months and achieve eradication of both species (Kessler 2002). About 50% of this effort was taken by follow-up surveys to ascertain complete eradication.

Recent studies suggested that targeting a particular sex or age class could improve hunting efficiency. For instance, reducing juvenile survival has the largest effect on population growth rate, and increasing hunting pressure on adult females, particularly in years of low food availability, appears to be the most effective approach to population control (Sweitzer et al. 2000, Bieber and Ruf 2005). However, compensatory responses to culling, such as increased immigration and reproduction, can limit the success of hunting (Hanson et al. 2009).

Ground shooting has been employed to control disease outbreaks, such as classic swine fever. In this context, the hunting rate is usually assumed to be constant over time. However, a recent cost analysis model showed that, by implementing flexible hunting strategies that vary according to the density of hogs and disease prevalence, managers can minimize the cost of hunting and the sanitary costs associated with the infection over a specific period of time (Bolzoni and De Leo 2007). These results can be used to design cost-effective contingency plans to control feral hog populations in case of disease outbreak.

Intensive, sustained hunting can eradicate feral hogs from vast areas. In many European countries, wild boar went extinct due to hunting pressure when wild game was regarded as one of the few sources of protein (Saez-Royuela and Telleria 1986). Nowadays, recreational hunting appears unable to control feral hog densities, as evidenced from current trends in feral hog numbers in Europe, Australia, and the United States (Choquenot et al. 1996, Hutton et al. 2006). In Hawaii, Reeser and Harry (2005) showed that volunteer hunting or public hunting failed to remove feral hogs at the required rate, while professional hunters were more successful. In France, Toigo et al. (2008) found that between 1984 and 2004 the number of wild boar culled in the study area by recreational hunters rose from 200 to 1,000 and that the propensity of hunters to target adult males instead of females and hoglets reduced the effectiveness of population control. Conversely, recreational hunting offers the opportunity for hunters to be directly involved in participatory management of a sustainable resource. In this capacity, hunters may also volunteer precious skills and free labor that can benefit the often tight budgets of projects aimed at mitigating feral hog impact.

Aerial shooting. Shooting from helicopters is relatively common in countries such as the United States and Australia, which have vast, uninhabited areas of sparse vegetation where it is relatively easy to locate groups of animals. This method can achieve quick decreases in hog abundance over large areas. Thus, one of its greatest advantages is that it allows large-scale coordination of effort among several landowners (Table 1).

Aerial shooting in areas of high hog densities has a relatively low cost per hog killed and allows population control in inaccessible areas. Besides having similar advantages and disadvantages of shooting from the ground, however, aerial shooting can disperse animals, is ineffective in areas with dense vegetation, and, as hog numbers decline, the cost of aerial shooting increases relatively more than the cost of ground shooting (Choquenot et al. 1999). For instance, in Australia, Choquenot et al. (1999) demonstrated that, as aerial shooting reduced hog populations below threshold densities of circa 2 to 6 hog/km^2, the number of hours to cull individual hogs increased exponentially. In another area of New South Wales, Australia, aerial shooting did not affect the home range size and movements by feral hogs, possibly due to the dense vegetation where hogs could hide as the helicopter approached (Dexter 1996). The availability of shelter could explain differences in hog behavior among studies carried out in different environments, and this should be taken into account when planning hog population control.

Aerial shooting has been used as the main method to eradicate feral hogs; for instance, 77% of the 5,036 hogs in Santa Cruz Island, California, were shot from helicopters in 15 months (Parkes et al. 2010). Shooting from helicopters can be a valuable tool to control disease outbreaks because it provides a quick reduction of hog density. During a simulated exotic disease outbreak in New South Wales, Saunders and Bryant (1988) used this method to evaluate the effectiveness of plans to eradicate feral hogs. The results indicated that, although 80% of the hogs were removed in 5 days of aerial shooting, some hogs modified their behavior to avoid detection. One year later, due to reproduction and immigration, the population had recovered to 77% of the pre-control population; Saunders (1993) concluded that, at least in the local conditions, eradication of hogs was an unrealistic goal and that efforts would be better directed toward eradicating the disease rather than the host population.

Poisoning. Poisoning can achieve rapid reduction in the number of feral hogs on a large scale and at moderate costs and has been used extensively to control feral hogs (Table 1). For instance, on Santiago Island, Ecuador, Coblentz and Baber (1987) found that poisoning was far more efficient than shooting or trapping to reduce the hog population size. On the same island, Cruz et al. (2005) used spot-poisoning to complement ground shooting in the final stages of the eradication campaign when shooting had become too inefficient due to the low density of hogs. Spot-poisoning consisted of leaving meat chunks or entire goat carcasses laced with a poison where signs of fresh hog activity had been observed and where hunters had failed to cull the hogs. In this study, the effectiveness of using toxicants as a supplementary method was demonstrated as the last hog was poisoned 6 months after the last hog was shot (Cruz et al. 2005). In New South Wales, Hone (1983) demonstrated that 9 days of pre-baiting, followed by 3 days of poisoning over a 50-km^2 area, killed 73% of the feral hogs. Aerial hunting was then used to kill 95 of the 98 feral hogs in the area. The study suggested that, if eradication is attempted, poisoning should be combined with at least 1 other population control method.

The success of a poisoning campaign depends on many factors, including time of the year, bait composition, adequate distribution and abundance of baits, type of toxicant, and hog density. In the Namadgi National Park, Australia, McIlroy and Saillard (1989) found that the success of poisoning depends on adequate distribution and abundance of baits and on timing, as bait consumption by hogs varied greatly throughout the year. In the same area, the use of poisoned baits in autumn, when hogs were attracted to baits because of limited natural food supply, reduced hog numbers by 91% and 100% in 2 study sites (McIlroy et al. 1989).

The humaneness of toxicants used in hog control is increasingly being questioned, and the possibility of affecting nontarget species, and the environmental fate of toxicants can pose serious constraints on the application of this technique. At present, poisoning is carried out in Australia and New Zealand, but there are no toxicants registered for use on feral hogs in either the United States or Europe (Cruz et al. 2005, Campbell and Long 2009*a*, West et al. 2009). In Australia, sodium monofluoroacetate (1080) is incorporated into baits and is considered to be one of the most effective toxicants for quickly reducing feral hog numbers (Hone 1983, Twigg et al. 2005). The relatively large doses required to kill feral hogs implies that the use of 1080 carries a high risk of poisoning nontarget species (Kavanaugh and Linhart 2000). However, 1080 has been employed mainly in areas where nontarget species were absent or where bait uptake by nontarget animals, such as livestock, were prevented by building hog-specific bait stations. In northwestern Australia, 1080 poisoning for 8 to 9 days caused a 89% decrease in the numbers of feral hogs (Twigg et al. 2005). Twigg et al. (2005) recommends this method to meet the requirements of disease-containment strategies based on significant density reduction within a few weeks from a disease outbreak.

The anticoagulant warfarin also is used to poison feral hogs in Australia. Warfarin and 1080 have been employed to eradicate feral hogs from Santiago Island in the Galapagos (Cruz et al. 2005) and to reduce the feral hog populations in Australia by 73 to 96% (Saunders et al. 1990). Besides their environmental impact, toxicants, such as 1080, have also the potential to induce bait shyness because hogs that ingest sublethal doses are less inclined to feed again on the same bait (Hone and Kleba 1984). In contrast to 1080, warfarin is slow-acting and symptoms of intoxication appear long after a lethal dose is ingested, thus, reducing the chance of hogs acquiring bait-shyness (Cruz et al. 2005). Using warfarin in eastern Australia, Saunders et al. (1990) reduced the local feral hog population by 99% in 3 months. However, one of the 2 sows that survived produced 2 litters, which highlighted the importance of maintaining a control program in years following the initial density reduction.

Studies are currently being carried out in Australia to identify more humane, fast-acting toxicants that can be used to control populations of feral hogs (Cowled et al. 2008). However, Fagertsone et al. (2008) reported that, in the United States, companies average 11 years and spend approximately $22 million to develop and bring new animal drugs to the market. Registration costs and growing public concerns toward use of toxicants on wildlife suggest that, at least in Europe and in the United States, it is unlikely that poisoning will be used to manage feral hog populations.

Judas hogs. Judas hogs are animals that are trapped, equipped with a radio-collar, and released so that they rejoin conspecifics. The whole group can then be located and culled by hunters. This technique was tested in Australia and indicated that the best results were achieved by releasing sows captured in the same area where they had been trapped (McIlroy and Gifford 1997). Out of the 15 Judas hogs released, 12 established contact with ≤12 other animals; hogs released in the same site of capture rejoined their group within 1 week.

This method can be employed to locate the last few trap-shy or poison-shy hogs once the population density has been drastically reduced through trapping or shooting (Table 1). The main advantage of using Judas hogs is quick detection of animals; using this technique, Wilcox et al. (2004) showed that hogs were detected within 1 hour compared to 4.1 hours to locate hogs without telemetry when the population was at its maximum density, and almost 60 hours when the density was very low. On Santa Cruz Island, only 9% of the 5,036 hogs removed to achieve eradication were dispatched as a result of their association with Judas hogs (Parkes et al. in press). However, once all hunting had ceased, hogs equipped with radio collars found 3 out of 7 of the remaining hogs and were responsible for the dispatch of the last hogs in 2 compartments (Parkes et al. 2010).

Judas hogs can also be employed to identify areas frequently used by the hogs so that baiting with toxicants or hunting can be redirected toward these sites. McIlroy and Gifford (1997) suggested that, to decrease the cost and time required to trap the last few animals, hogs captured and kept in captivity at the beginning of a population control program could be used as Judas hogs. To improve the efficiency of this method to achieve eradication, McCann and Garcelon (2008) suggested that all Judas hogs should be surgically sterilised before release. When using Judas hogs, Parkes et al. (2010) sterilized all males prior to release, and induced females into estrus to enhance their attractiveness to males, showing that these females were significantly better than the males at attracting other hogs.

Nonlethal methods

Fertility control. Chemical sterilization to reduce overabundant wildlife has been discussed for at least 2 decades (Fagerstone et al. 2002). For many years the lack of long-acting, safe contraceptives, the practicality of delivering oral contraceptives in baits, and the potential effects on nontarget species prevented the use of this method. Recently developed immunocontraceptives have reawakened interest in this technique to control feral hogs. Immunocontraceptives act by causing the production of antibodies against hormones or proteins essential for reproduction (Miller et al. 2008). These compounds recently have been formulated as single-shot vaccines, capable of inducing long-term infertility after a single injection. For instance, the Gonadotropin-Releasing-Hormone (GnRH) vaccine stimulates the production of antibodies against GnRH, which is, in turn, responsible for the production of sex hormones that lead to ovulation and spermatogenesis. Animals injected with this vaccine can be rendered infertile for 1 to 5 years

Table 2. Nonlethal methods to manage human–feral hog conflicts.

Method	Advantages	Disadvantages
Fertility control (injectable contraceptives)	• Humane • Long-term effectiveness • No social disruption • Usable in residential areas • Species-specific • Can decrease disease transmission	• Slow-acting at population level • Requires trap-inject-and-release • Applicable to small scale • Expensive due to trapping effort
Fencing	• Very effective when well-constructed • Humane • Short-term protection of vulnerable crops • Long-term protection of livestock or areas • Useful to partition areas and facilitate eradication • May be fitted with one-way gates to allow animals to exit • Fences can be moved and reused	• High initial set-up costs • High maintenance costs, including replacement • May interfere with public access • May increase damage in adjacent areas
Repellents	• Humane • No social disruption • Usable in residential areas	• Short-term duration • May concentrate damage in adjacent areas • No repellents registered for hogs
Diversionary feeding	• Humane • May concentrate hogs for a short time • Fast-acting to alleviate damage to crops or areas	• Efficacy depends on availability of diversionary food • Labor-intensive if diversionary food is provided continuously • May increase reproductive output and thus population size • May attract and affect nontarget species
Translocation	• Perceived as humane • Fast-acting at population level • Usable in residential areas	• Labor-intensive due to building, baiting, checking traps, and transporting hogs to new area • Effective only when natural food availability is limited • May translocate pathogens and diseases • Animals may suffer during trapping, translocation and post-release • May encourage illegal or irresponsible introduction of hogs

(Killian et al. 2008, Miller et al. 2008). GnRH vaccines have been tested extensively on many wildlife species, including feral hogs. In most species, these contraceptives have been found to be safe and effective for many years without side effects on the animals' behavior, welfare, or physiology (Killian et al., 2006, Massei et al. 2008, Table 2). Immunocontraceptives also have been proposed as a possible means of decreasing transmission of several wildlife diseases by reducing the abundance of newborn, susceptible animals within the population (Killian et al. 2007).

Fertility control has a high level of public acceptance and could be used to decrease numbers of feral hogs, particularly for isolated populations where immigration and emigration do not affect the population dynamics. However, managing feral hog populations by using injectable contraceptives could be more expensive than trapping, as the costs of contraceptives will add to that of trapping, and, thus, will more likely to be confined to small-scale, specific contexts where lethal control is not feasible or desirable. Examples of the latter are urban areas or national parks where hunting is not allowed (C. Gortazar, National Research Institute on Game Biology, personal communication) or where lethal control could affect contact rates and spread of diseases.

Compared to trapping or shooting, fertility control is relatively slow in decreasing local abundance because the benefits of this method can be accrued only after several years or if fertility control is applied in conjunction with other population control option. For instance, fertility control could be used to keep the density of feral hogs at a set level once lethal control has been applied (Cowan and Massei 2008). More research is ongoing to develop oral contraceptives to widen the spectrum of contexts where fertility control could be applied. If oral, nonspecies-specific contraceptives become available, the possibility of affecting nontarget species must be addressed. Hog-specific feeders have been designed and evaluated for bait uptake by target and nontarget species. For instance, the Boar Operated System (BOS™) is an effective, species-specific device developed to deliver contraceptives and other pharmaceuticals to feral hogs (Massei et al. 2010). In Europe and the United States, BOS has been used successfully to deliver baits to feral hogs only, unless bears (*Ursus americanus*), which also can feed from the BOS, are present (Long et al. 2010; M. Avery, National Wildlife Research Center, personal communication).

Mathematical models designed to evaluate the effect of fertility control on population dynamics of feral hogs, indicate that a relatively small proportion of females in a population must be rendered infertile to reduce population size (Cowan and Massei 2008). According to these models, treating 30% of the adult females every year with contraceptives that induce permanent infertility, would lead to halving the female population in 5 years. Although more research is required to test these predictions in field trials, these results confirm the potential of fertility control to play an important role in feral hog population management.

Fencing. Fencing has been used in 3 different scenarios: (1) as a preventive measure, to reduce feral hog impact into economically or conservation sensitive areas, such as nesting grounds, threatened habitats, wildlife refuges, farms and agricultural fields; (2) as a reactive measure to protect an area from feral hog impact once local eradication has been achieved; and (3) to partition an area, typically a large island, into smaller units and to facilitate eradication from each unit (Table 2).

Many types of fencing, simple or electrified, are available and often consist of woven wire mesh 65- to 80-cm-high with strands of barbed wire strung along the top, bottom, and above the woven wire to create a fence of 110 to 120 cm in height; the fence also often is buried to a depth of 40 to 60 cm to prevent hogs from forcing their way through it (Hone and Atkinson 1983, State of Hawaii 2007, McCann and Garcelon 2008). Fences also can be fitted with one-way gates to allow animals to exit an area but not to reenter it. Several electric fencing designs also have been developed and tested to exclude feral hogs; these usually consist of 2 to 3 strands of electrified fencing spaced 15-30cm apart.

In Australia, different fence designs have been tested to protect crops and lambing paddocks (reviewed in Hone and Atkinson 1983). In California, electric fencing had been used to prevent feral hogs from entering irrigated summer pastures (Barrett 1978). In France, steel-wire electric fencing was used extensively to prevent damage to valuable crops over relatively small areas (Vassant and Boisaubert 1984, Vassant 1994), although Geisser and Reyer (2004) noted that it may cause a shift in damage to adjacent, nonfenced fields. The general conclusions from many studies are that fence design affects the effectiveness of the method and that electrification significantly reduces the number of feral hogs crossing the fences, although the cost of maintenance is higher for the electric fencing (Hone and Atkinson 1983, Reidy et al. 2008). To prevent overgrown vegetation from damaging the fence or interrupting the circuits and to maintain the functionality of the fence, herbicides or manual clearance of vegetation must be used regularly (Littauer 1993).

Recently developed polywire electric fencing that uses conductive wires incorporated into ribbons or ropes is now available. Compared to fixed-steel wire electric fencing, the newer designs have the advantage that they can be easily set up, removed, and reused so that they can be employed temporarily. Using portable polywire, electric fencing, Reidy et al. (2008) found that 2 strands at 20 and 45 cm from the ground excluded 75% of hogs that visited bait stations in Texas. As most of the hogs that crossed this fence were juveniles that slipped under it, the authors concluded that the fence was more effective in preventing access by adult hogs. In Switzerland, Geisser and Reyer (2004) found that the 2-strand electric fencing locally used to protect crops was not as effective as shooting the feral hogs to decrease damage to crops. However, in Slovenia, a combination of polywire-polytape electric fencing reduced damage to maize fields by 100%; but, the researchers observed an increase in damage to neighbouring arable fields (Vidrih and Trdan 2008).

When permanent fencing is used after eradication to keep an area free of feral hogs, its efficiency depends on both the type of fencing and the perimeter (size of patches and length of fencing) ratio (Hone 1995). The main disadvantage of permanent fencing is the initial setup costs and subsequent maintenance costs. In some areas, such as the Hawaiian rainforest, wire fences erected to exclude hogs from sensitive area required monthly inspections and had to be replaced every 5 to 15 years (Katahira et al. 1983). In addition, fences also had to be repaired following storms or earthquakes. However, fencing can be employed successfully to control impact by feral hogs. For instance, 42 km of fence were used in the Pinnacle National Monument, California, to surround an area of 57 km^2 and eradicate hogs (McCann and Garcelon 2008).

Repellents. A large number of olfactory, acoustic, and gustatory repellents has been developed to decrease the impact of wildlife on human activities (Conover 2002; Table 2). In a study aimed at identifying deterrents for wild boar, Vassant and Boisaubert (1984) tested 25 potential chemical repellents and acoustic scarers, such as cannons firing at random, electronic sound generators, and wild boar alarm calls. The results showed that wild boar became habituated to all repellents within a few days. In China, Cai et al. (2008) found similar results with several repellents used by local farmers to protect crops against wild boar and concluded that the only effective measure was the presence of humans in the field. In France, Vilardell er al. (2008) tested 2 potential repellents to protect tortoise nests from predation by wild boar and found both compounds ineffective. Thus, the evidence so far suggests that repellents are unlikely to be effective in reducing the impact of feral hogs.

Diversionary feeding. Diversionary feeding, also referred to as supplementary feeding, often is carried out by hunters to concentrate densities of feral hogs in the forest and optimize culling effort and to decrease crop damage (Geisser and Reyer 2004; Table 2). To remain effective, supplementary food must be available continuously, which makes this method expensive in terms of staff and resources, however, these costs can be absorbed by hunter groups and volunteers (Vassant et al. 1987).

The effectiveness of this technique in reducing crop damage is controversial. While some studies reported that diversionary feeding was successful (Andrzejewski and Jezierski 1978, Vassant 1994, Calenge et al. 2004), others found limited or no effect on crop damage (Hahn and Eisfeld 1998, Geisser and Reyer 2004). For instance, in France, Vassant et al. (1987) used maize, distributed daily along transects in the forest from late June till early August and concluded that, although this method was effective to reduce crop damage by wild boar, its actual cost was similar to that of replacing crop losses. In Switzerland, Geisser and Reyer (2004) found that in September and October, when maize and wheat are ready to harvest and particularly vulnerable to damage, wild boar hardly visited the feeding stations where supplementary food was provided, irrespective of the type of food these stations offered. In another French site, Calenge et al. (2004) used corn as dissuasive feeding to protect valuable vineyards and reported a 60% reduction in both the proportion of damaged vineyards and the level of damage, with a net financial benefit for the farmers. In many European countries, practitioners spread corn throughout the year to attract boar to their hunting grounds. However, several authors (Andrzejewski and Jezierski 1978, Geisser and Reyer 2004, Schley et al. 2008) warned that this practice could enhance reproductive success and survival of feral hogs and, thus, contribute to long-term increase in damage to crops.

Even when it is cost-effective, diversionary feeding should be regarded only as a short-term solution to protect crops (Conover 2002). When used as a deterrent, diversionary feeding might be employed to decrease damage to localized, valuable crops, such as vineyards, for very short periods. If the amount of diversionary feeding provided is small compared to the availability of natural food (5 metric tons of corn versus 900 to 1,500 metric tons of naturally available acorns [Calenge et al. 1994]), and the feeding is localized in time and space, the effect of this method on feral hog population dynamics would be negligible.

Translocation. Translocation of problem animals is increasingly advocated to mitigate human–wildlife conflicts, even if the choice of using this method over other management options often is dictated by public pressure rather than by scientific or economic reasons (Beringer et al. 2002, Conover 2002). Translocations may encourage irresponsible introductions, and in many countries translocating feral hogs is illegal, particularly where the species is non-native (Hutton et al. 2006). Several authors (e.g., Gipson et al. 1998, Spencer and Hampton 2005) indicated that transport and release of feral hogs by hunting clubs was the most important factor explaining the marked increase in distribution of this species throughout the United States and Australia.

A recent review of translocation of problem animals found that, despite their perceived humaneness, translocations may have a detrimental impact on survival rates and lead to extreme dispersal movements (Massei et al. 2010). In some species, individuals that survive a translocation may suffer from malnutrition, dehydration, decreased immunocompetence, and predation. In addition, some animals resume the nuisance behavior at the release site. More importantly, in the context of feral hogs, translocations have the potential to spread diseases to conspecifics, humans, domestic animals, and livestock. Very few studies reporting the costs of translocations neither address which stakeholders are expected to pay for translocating problem animals nor mention whether and for how long the conflict lasted before it was resolved following the translocations of problem animals. If public interest in translocation to resolve human–feral hog conflicts increases, stakeholders advocating this method should be informed of the costs (including welfare costs), risks, and consequences of carrying out this type of control. However, as illegal translocations are regarded as one of the main causes of the increase of feral hog range, it is unlikely that this method is proposed to mitigate human–feral hog conflicts.

Monitoring effects of population control

Sustained monitoring is critical to determine the effectiveness of the methods used to decrease feral hog population size or impact. The greatest challenge for managers of eradication programs is deciding whether the inability to detect hogs indicates that the species has been eliminated. Cessation of monitoring too soon risks declaring eradication incorrectly, but monitoring for too long wastes resources if the eradication is complete (Morrison et al. 2007, Ramsey et al. 2008). The majority of eradications of non-native mammals from islands remains unpublished, and many of these data have not been collected (Simberloff 2003). This makes it impossible to evaluate the efficiency of these eradication programs and to learn lessons for future control options.

Several methods are available to monitor the effects of population control on feral hog numbers. Because feral hog absolute numbers are notoriously difficult to assess (Sweitzer et al. 2000), many estimates rely on indices of abundance, such as passive tracking indexes derived from activity signs, such as tracks, pellet groups, and rooting (Engemann et al. 2001). Other methods are based on monitoring bait uptake at baiting stations or on aerial and ground surveys. For instance, using bait uptake to monitor reduction in hog abundance achieved by trapping, Choquenot et al. (1993) found that trapping had reduced the numbers of feral hogs in 2 areas by 93 to 100%. However, an alternative monitoring method based on spotlight counts suggested an 81% and 83% reduction, respectively, indicating that the different monitoring method may lead to different conclusions. Indices of abundance based on bait consumption tend to overestimate population reduction because they do not include animals that do not feed on the bait. Cruz et al. (2005) established an extensive post-eradication monitoring program on Santiago Island (Ecuador) by distributing goat carcasses over the entire island and by monitoring for hog disturbance 4 times, at 10- to 40-day intervals. Mc Cann and Garcelon (2008) suggested that post-population control monitoring should be used also to direct removal activities toward areas where signs of hog activity have been observed.

Besides quantifying the impact of population control, monitoring also has the advantage that managers can see the long- and short-term consequences of control, for instance the decrease in activity signs, such as soil disturbance, or the increase in species previously affected by the presence of feral hogs.

Ramsey et al. (2008) developed models to estimate the degree of confidence in the success of eradication program when monitoring failed to detect any more hogs. These models allow researchers to determine the relationship between detection probability and searching effort through aerial or ground hunting and could be used to explain to managers the risk inherent in decisions that must be taken before declaring an eradication completed. Using a similar approach, Morrison et al. (2007) were able to reduce the time for eradication and post-eradication monitoring of hogs in Santa Cruz Island from an initial estimate of 6 to 11 years to approximately 2 years.

Cost of mitigation

The costs of different control methods depend on density of animals, topography, vegetation cover, local capacity (including volunteers), resources, bureaucracy, and required environmental compliance. Stakeholders' expectations concerning the time to resolve a particular conflict also affect the choice of methods, the intensity of application (such as number of traps and trap nights, number of staff employed, etc.), and, ultimately, the cost, particularly if the mitigation of the conflict requires a quick solution. If short-term reduction of numbers is required, for instance following a disease outbreak, the choice between population control methods depends on which technique is more likely to provide quick reduction (Saunders 1993).

Costs of feral hog population control are difficult to compare among studies, even when the same method is applied, because they can be expressed in different units, such as number of hogs removed per hour, per trap night, or per area, and often they refer to combined costs of different methods. In addition, other costs, such as travel, administration, data analysis, and report writing are seldom reported. In a review of feral hog eradication projects, McCann and Garcelon (2008) found that costs varied from \$165,000 to remove 144 hogs in 2 years from a 20 km^2 area in California to \$3.4 million over 15 years to remove >12,000 hogs from a 194 km^2 island.

Comparisons of costs of different methods are valid when these can be applied to the same location. For instance, on Santiago Island (Ecuador), Coblentz and Baber (1987) employed a variety of methods aimed at feral hog eradication and concluded that trapping and snaring were ineffective and costly, due to a combination of poor trapping and snaring success, costs of building, deploying and checking traps, and to the malfunctioning of snares. Ground shooting was effective, but time-consuming, and poisoning was comparatively the most cost-effective as the cost of individual hog removal by poisoning was estimated to be 11 times cheaper than shooting and 80 times cheaper than trapping.

In the Pinnacles National Monument, erecting a 42-km-long fence to enclose a 57-km^2 area cost \$2 million (McCann and Garcelon 2008). Once fencing was completed, the eradication of hogs through hunting, trapping, and Judas hogs cost \$632,601 and 13,489 man hours, with an estimated effort of 24.2 hours per hog removed, across all the techniques. When the researchers added the total number of hours spent on all aspects of the project, such as field work, travel, and administration, the effort rose to 67.5 hours per hog removed.

In Hawaii Volcanoes National Park, the cost of wire fencing with single-strand barbed wire at ground level was \$18,000 to \$26,700/km (Katahira et al. 1993). In the same area, the cost of fencing in 2007 was estimated at \$50,000 to \$140,000/km when the cost of helicopter required to transport material and personnel to otherwise inaccessible areas was included (State of Hawaii 2007). In a different context, using helicopters in New South Wales to shoot feral hogs reduced the local population by 95% in only 5 days at a modest cost of \$11.35 per hog (Saunders and Bryant 1988).

In the United States, the cost of fixed hog exclusion fencing was $8,200 to $21,300/km, and electric fencing, often used to control impact by deer, cost about $2,000/km (Reidy et al. 2008). In the United Kingdom the cost of permanent deer fencing was $4,800 to $8,800/km (Rural Development Service 2006). The cost of polywire-polytape electric fencing successfully used to control feral hogs in Slovenia was $310 to $380/km (Vidrih and Trdan 2008).

When evaluating different options for a feral hog control program, managers must also acknowledge that the cost of hog removal increases substantially with time. For instance, the cost of hunting hogs in the Namadgi National Park, Australia, increased 5-fold from the first 6 months to the third year (Hone and Stone 1989). However, as lessons from previous eradication programs are learned, recent eradications have been become substantially more cost-effective. For instance, the time taken to eradicate hogs from Santa Cruz Island was half of that required on a neighbouring island (Santa Rosa Island) of similar size and 12 times faster than that on Santiago Island, Ecuador (Parkes et al. 2010). The success of the Santa Cruz Island eradication program was due to a combination of reasons: (1) extensive stakeholder consultations prior to agreeing to fund and proceed with the eradication; (2) a fixed-price funding model, where professional contractors were paid for completion of eradication, regardless how long it took or of how much it cost them; and (3) use of modern technologies, such as GIS mapping of animals removed in different areas, to coordinate efforts and optimize control (Parkes et al. in 2010). When feral hog density becomes very low, motivating staff is often a major challenge, and financial incentives might help to boost staff morale. Cruz et al. (2005) mentioned that social, moral, and financial incentives were crucial in maintaining the motivation of hunters in the last phase of hog eradication.

A decisional framework to manage feral hogs

Current patterns in feral hog expansion of range and numbers suggest that these trends will persist, and conflicts with human activities will increase if long-term, effective population control is not undertaken. Based on the results of this review, we propose a framework to guide decisions regarding control options to mitigate the impact of feral hogs (Figure 2).

In many parts of the world where feral hogs are non-native, ecologists believe that the ultimate aim of control should be eradication. This view, however, is not shared by all stakeholders (e.g., recreational hunters). Complete eradication of feral hogs is difficult and expensive, but it has been achieved, largely on small islands. Feral hogs have now been eradicated from at least 25 islands with areas from 5 to 600 km^2 (Kessler 2002, McCann and Garcelon 2005). Sites with newly established, geographically isolated populations can be regarded as ecological islands. In these areas, efforts should be focused toward eradication before the population range and numbers increase, although disturbance could cause hogs to move considerable distances (Leaper et al. 1999) and may ultimately affect the success of a local eradication. For islands and geographically isolated populations, McCann and Garcelon (2008) suggested that an intensive eradication program should be preferred to sustained control for the following reasons: (1) only a high-intensity program can achieve eradication in a short period; (2) fewer hogs need to be culled because populations are not given the time to reproduce or to learn to avoid control; (3) the high cost of an intensive eradication program is likely to be less than that of sustained control over a period of several years; and (4) a short, well-managed program is likely to receive less public scrutiny and opposition. In addition, the longer an eradication project runs, the more it is exposed to factors that can undermine its success (Morrison 2007, Parker et al. in press). These factors include reinvasion of areas already cleared of feral hogs, reproduction that causes the hog population to increase, public opposition, legal challenges arising in the course of the project, increased lack of staff motivation, and funders' fatigue which may result in lack of sustained funding to complete the program. Post-eradication monitoring also should be included in any eradication program to confirm achievement of the objectives (Figure 2).

If the hog population is on the mainland and is surrounded by others, eradication might be very difficult to achieve because, even if the area is fenced, the risk of reinvasion persists. If

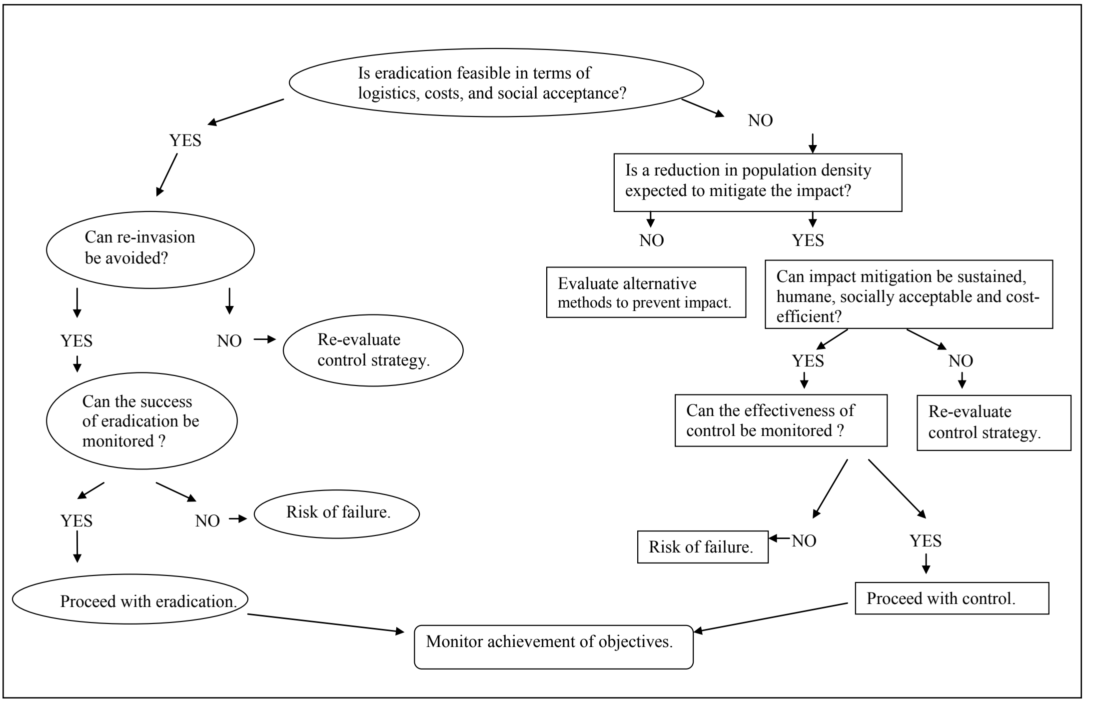

Figure 2. Decision tree to evaluate control options to decrease the impact of overabundant populations of feral hogs on human interests.

reinvasion cannot be avoided, managers should reevaluate the control strategy to determine whether the benefits of achieving temporary eradication justify the costs and whether other options, such as temporary fencing to protect valuable crops, rather than control of feral hog numbers could be successfully employed to reduce the conflict.

Where feral hogs have long been established, and particularly where the species is native, their distribution and numbers make eradication very unlikely. Invariably, these areas have long-established hunting traditions and recreational hunters that oppose eradication. In some instances, the meat derived from hunting can indeed contribute to the local supply of protein or generate income from hunting tourism and the meat export (Ramsay 1994, Milner-Gulland et al. 2002). Although intuitively perpetual freedom from a pest species has a very high value, in some instances the benefits of retaining this species could partly offset the costs. This is because future benefits may have lower economic value than those achieved immediately (Bomford and O'Brien 1995).

Where eradication is unfeasible or is opposed by local groups, sustained control must be employed to keep feral hog populations at densities that minimize human–feral hog conflicts. Sustained control includes methods to provide short-term solutions (e.g., to reduce crop damage or disease outbreak) and long-term management to mitigate or prevent the occurrence of conflicts for several years. If a reduction of feral-hog density is expected to mitigate the conflict, different control methods should be evaluated to determine their feasibility, sustainability, costs, humaneness and social acceptance (Figure 2). In case any of these issues is expected to be controversial, for instance if a strong public opposition arises toward some of the proposed methods or if adequate funding is not available to implement a population reduction program, the control strategy should be reevaluated.

The review indicated that only poisoning and shooting can quickly reduce the size of a population. However, poisoning is illegal in many countries and is unlikely to become a common practice, at least in Europe and in the United States. On the large scale, shooting that is carried out by recreational hunters does not appear to control feral hog numbers, probably because (1) a conflict of interests due to hunters being more likely to support sustainable harvest than drastic reductions in feral hog numbers, and (2) poor planning, based on inaccurate estimates of local densities and lack of knowledge of the effects of different levels of hunting pressure on population size. Conversely, when professional hunters are involved or when feral hog meat derived from hunting provides a significant part of people's diet, shooting may substantially reduce feral hog numbers (Geisser and Reyer 2004, Parker et al. in press). Based on these considerations, Geisser and Reyer (2004) recommended the development and introduction of new harvest models among local hunting teams to maximize population control. We suggest these models could include: (1) integrating hunting with other methods, such as trapping or fencing; (2) use of reliable methods to estimate feral hog density before and after control; (3) monitoring of the impact of different hunting pressures on population size and impact; and (4) coordinating efforts with other hunting groups and other stakeholders to agree to participatory management of feral hog populations.

Hogs that survive control campaigns may play a crucial role in rebuilding the population or maintaining diseases. Thus, it is important in such instances that alternative methods of control are also applied to target survivors. For instance, Choquenot et al. (1993) observed that poisoning and trapping preferentially removed sows, so males had to be targeted in residual populations. Control of feral hogs also requires managers to alter techniques in response to changing animal densities, animal behavior, and environmental conditions. For instance, trapping does not always remove older, more experienced hogs, ground shooting may preferentially remove solitary boars, and trapping may preferentially remove females (Choquenot et al. 1993, Saunders et al 1993, Mitchell 1998).

The vast majority of successful eradication programs employed an integrated management approach where several control options were carried out at the same time or in sequence. This ensured that animals that could not be targeted by 1 technique could still be removed by adopting complementary control methods. Conversely, current approaches to feral hog population control across Europe and the United States typically involve only shooting, occasionally coupled with diversionary feeding and fencing. In Australia and New Zealand shooting from helicopters often is integrated with poisoning to provide immediate solutions to human–feral hogs conflicts.

If methods to reduce immigration are not available or practical to implement, control should be directed toward both decreasing reproduction and increasing mortality. As oral contraceptives are not available for hogs, the most cost-effective methods are shooting, trapping, or using toxicants. For isolated populations or in suburban areas where these methods might be illegal or simply impossible to carry out due to concerns about human safety or the impact on nontarget species, fertility control could offer a valid alternative to lethal control options.

With few exceptions, very little research has been conducted to determine what proportion of a feral hog population should be targeted to decrease population size, despite the requirement in several countries for management plans to be submitted to the authorities before hunting can commence. Clearly, this is an area that warrants further research, in particular to quantify the effects of different control methods on population size and to identify optimal integrated management approaches.

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