Free-Roaming Dogs in Developing Countries: The Benefits of Capture, Neuter, and Return Programs

3 CHAPTER

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Introduction

As a result of human population growth, poor waste disposal management, the absence of responsible dog ownership policies, and heightened awareness of animal welfare and disease issues, increased attention is being given to the problem of free-roaming dogs. The population of dogs worldwide may be as high as 500 million (Hsu, Severinghaus, and Serpell 2003). Dog-to-human population densities vary from 2.2 dogs/hundred people in urban Zambia (DeBalogh, Wandeler, and Meslin 1993), to 15.8 dogs/hundred people in rural Tanzania (Cleaveland et al. 2003), to 21.3 dogs/hundred people in Katmandu, Nepal (Kato et al. 2003), and to more than 30 dogs/hundred people in white communities in South Africa (Odendaal 1994) and rural villages in Mexico (Orihuela and Solano 1995) (Table 1).

Free-roaming dog populations have emerged as both animal welfare and public health problems in developing countries. Free-roaming dogs face high mortality, malnutrition, starvation, disease, and abuse; account for 99 percent of cases of rabies transmission worldwide (WHO 2004); and are associated with more than sixty other zoonotic diseases (Beck 2000; Reece 2005). Additional social problems with free-roaming dogs include road accidents, fighting, noise, bitten children, fecal contamination, spread of rubbish, and uncontrolled breeding.

Public health and animal protection advocates share an interest in reducing dog population growth, improving the health of dog populations, and increasing responsible dog ownership. Approaches to free-roaming dog population management have changed over the past twenty years. Until recently, capture and kill policies prevailed as the primary dog-control method. While even today removal of dogs continues to be a component of dog control in some countries, the World Health Organization (WHO), leading researchers, and animal protection groups have condemned dog removal policies as ineffective and cruel.

The 1990s saw a significant expansion in the availability of post exposure treatment for dog bites and in public awareness of the need to seek treatment. Postexposure treatment dramatically reduced rabies deaths; however, treatment costs soared. Dog-vaccination campaigns have proved less costly and more effective in rabies prevention. A meeting of WHO Asia experts concluded,

> Rabies control in dogs remains the only long-term, cost-effective means of eliminating or preventing most human cases. Human public health preventive measures should be paralleled by programmes for dog rabies control. (WHO 2001)

Still, high levels of dog population turnover make it difficult to maintain vaccination coverage at threshold levels. A new consensus is emerging that rabies vaccination programs are not sustainable without sterilization, although some animal groups remain concerned about the appropriateness of returning sterilized animals to community streets.

Vaccination, habitat control, and responsible pet ownership, including sterilization, are now replacing the capture-and-kill focus of dog control. In 1992 WHO and the World Society for the Protection of Animals (WSPA) issued guidelines for dog population management that recommended dog population surveys; adoption of national legislation to regulate registration, vaccination, identification, sales, and breeding; public education, subsi-

dized neutering; and improvements in veterinary education to include early gonadectomy (Leney 2002).

More recently animal protection organizations have launched capture, neuter, and return (CNR) programs. Modeled on trap, neuter, and release (TNR) programs for cats in the United States, these programs seek to limit population growth and improve dog welfare. Widespread adoption of CNR programs for dogs, along with changes in human behavior and environment, offers a sustainable remedy for both disease and animal welfare problems posed by free-roaming dogs in developing countries.

This chapter provides an overview of animal welfare and public health problems associated with free-roaming dog populations and strategies to resolve these problems. Placing CNR programs in the context of earlier dog and rabies control methods, the chapter explores CNR's potential to overcome some of the shortcomings of earlier approaches and to improve

Table 1
Dog Populations in Developing Countries, Number of Dogs per Hundred People

Country	Dogs/100 People			Source
	All	Urban	Rural	
Argentina—La Pampa	18.30	18.3		Larrieu, Alvarez, and Cavagion (1990)
Bolivia—Santa Cruz	25.00			Widdowson et al. (2000)
Indonesia	6.25			WHO (1998a)
Bali	19.20			Peacock (2005a)
Kenya—Machakos District	13.00		13.0	Kitala et al. (2001)
Mexico—Miacatlan	33.60		33.6	Orihuela and Solano (1995)
Mexico	14.30–16.70			WHO (1998a)
Mexico—Hermasillo	12.50	12.5		Eng et al. (1993)
Nepal—Katmandu	21.30	21.3		Kato et al. (2003)
Peru—Pacoraos	16.70		16.7	Moro et al. (2005)
Philippines—Sorsogo Province	26.30			Childs et al. (1998)
South Africa	10.00			Odendaal (1994)
Asian/Colored	13.00			Odendaal (1994)
Black Urban	6.70	6.7		Odendaal (1994)
Black Rural	15.00		15.0	Odendaal (1994)
White	35.00			Odendaal (1994)
S. Africa—Soweto	8.10	8.1		McCrindle et al. (1999)
S. Africa—Maboloka	9.00		9.0	Rautenbach, Boomker, and DeVilliers (1991)
Sri Lanka—Mirgawa	17.50		17.5	Matter and Daniels (2000)
Tanzania—Serengeti District	15.80		15.8	Cleaveland et al. (2003)
Thailand	14.90			Mitmoonpitak, Tepsumethanon, and Wilde (1998)
Zambia	14.90	2.2	14.9	DeBalogh, Wandeler, and Meslin (1993)
Zimbabwe	15.40			Brooks (1990)

animal welfare, reduce dog population growth, and prevent the spread of rabies and other canine-transmitted diseases. Constraints and current debates on current implementation of CNR programs are also examined.

Functions and Dynamics of Dog Populations in Developing Countries

Cultural differences in views of dog ownership and the role of dogs in society influence the prevalence of dogs, the condition of free-roaming dogs, and dog-control policies. In some developing countries, dogs are revered. In Bali, for example, dogs are an important part of mythology, are treated with reverence, and are given ceremonial food offerings (Peacock 2005a). In Bali and many other developing countries, cultural traditions prohibit or oppose euthanasia, and the development of a network of shelters is impractical. Dogs may also be a status symbol for upper-income families in some countries (Reece 2005). The health and psychological benefits of canine companionship have been amply documented in both developing and industrialized countries (Beck 2000). In still other countries and cultural settings, particularly in some Muslim societies, dogs are reviled and are less visible. For example, it has been estimated that there are fewer than a hundred thousand dogs in all of Cairo, a Muslim metropolitan area of eleven million plus (E. Hilby, personal communication with A.N.R., 2006). These numbers would give a dog density of 0.09 dogs per hundred people—by far the lowest density ever recorded (Table 1). Finally, in some countries, dogs are considered to be food (Reece 2005).

Dogs living with humans may be classified into three or four categories: pets, community dogs, strays, and ferals. In developed countries the majority of dogs are pets (i.e., they are allowed in the house, given names, regarded as part of the family, and never eaten). Those dogs that are not pets are either stray animals or true ferals (a very small percentage). Except in some traditional communities (e.g., Native American), there are no community dogs.

In most developing countries, the main function of dogs is to protect property. Dogs in Soweto, South Africa, are used primarily to guard livestock and property and to hunt (McCrindle et al. 1999). In Machakos District, Kenya, 99 percent of households say that guard duty is their dogs' primary function (Kitala et al. 2001). In Zimbabwe 60 percent view dogs as guards, and 73.1 percent see dogs as a deterrent to wildlife that they perceive as pests, such as elephants, baboons, lions, and leopards (Butler 2000). In fact, in Africa increases in dog populations may reflect heightened security concerns (Cleaveland 1998). In New Providence, Bahamas, security is also the main reason for keeping dogs for 50.4 percent of households (Fielding and Plumridge 2005). In the Thungsong District of Thailand, 83 percent of households keep dogs as guard animals (Kongkaew et al. 2004). In Miacatlan, Mexico, 65 percent of households reported having a dog for security reasons (Orihuela and Solano 1995).

Patterns of dog ownership in many developing countries differ from those in the United States and other industrialized nations. In developing countries most dogs are community dogs who are affiliated with neighborhoods rather than with individual owners. WHO characterizes dogs in developing countries as restricted dogs, semirestricted family dogs, neighborhood dogs, and feral dogs (Reece 2005). Based on their level of reliance on humans for food, shelter, and care, dogs are fully dependent (restricted dogs), semidependent (family dogs and neighborhood/community dogs), or not dependent (feral/stray dogs).

Increasingly, researchers agree that most dog populations depend at some level on referral households (Leney and Remfry 2000). Only a small proportion of dogs in South America, Asia, and Africa rely on markets, slaughterhouses, dumps, and restaurants as their sole sources of food (Leney and Remfry 2000; Reece 2005). An estimated 10 percent of dogs are not associated with particular households (Bogel and Meslin 1990). A Zimbabwe study concluded that all dogs are at least semidependent on people and that none is completely "ownerless" (Butler 2000). In Chad, ownerless dogs comprise only 1.1–10.6 percent of owned dogs (Kayali et al. 2003). A 1999 survey in Bangkok found that 20 percent of dogs are ownerless (WHO 2001).

Dogs without a referral household have the lowest reproductive and pup survival rates. These unassociated dogs "do not play a significant role in the reproductivity of this population" (Bogel and Meslin 1990, 282). Instead, free-roaming dog populations are maintained by recruitment from owned populations (Boitsni et al. 1995; Leney and Remfry 2000; Matter and Daniels 2000; Fielding, Samuels, and Mather 2002).

Association of dogs with particular neighborhoods or individual households determines the extent to which these animals are deemed to be accessible to vaccination and sterilization programs. Unreachable strays had been assumed to represent 30–70 percent of the dog population (Cleaveland et al. 2006). However, in Katmandu Valley, Nepal, 86–97 percent percent of dogs are accessible (Bogel and

Joshi 1990). Researchers in studies around the world have confirmed that at most 15 percent of dogs may be inaccessible to vaccination (Cleaveland et al. 2006).

Nonetheless, the majority of dogs in developing countries face few restrictions on their movements. In Machakos, Kenya, 69 percent of dogs are never restricted (Kitala et al. 2001). In the Thungsong District of Thailand, 74 percent of dogs are allowed to roam freely (Kongkaew et al. 2004). In New Providence, Bahamas, 73 percent of households keep their dogs outside, and 43 percent of households allow at least one dog to roam (Fielding and Plumridge 2005).

While most dogs may depend on a particular household or neighborhood, the resources provided at "home" sites are often insufficient. Most dogs roam to forage for food since they are not fed daily by owners (McCrindle et al. 1999; Kitala et al. 2001; Fielding, Mather, and Isaacs 2005). Owners also allow dogs loose because they believe unrestricted dogs can better protect property (Fielding, Mather, and Isaacs 2005).

The Welfare of Free-Roaming Dogs

Free-roaming dog populations suffer from extremely poor welfare. The New Providence, Bahamas, animal control unit's visual inspection of dogs indicated that 70 percent are suffering from disease (Fielding, Mather, and Isaacs 2005). Echinococcus, toxocara, parvovirus, heartworm, leptospirosis, and venereal tumors are among the diseases that plague free-roaming dogs (Boitsni et al. 1995; HSI 2001; Fielding, Mather, and Isaacs 2005). Many dogs have infectious skin diseases, such as mange, along with secondary bacterial infections. A study in Mexico found that 34 percent of stray dogs had mites and 23 percent suffered from *Demodex canis* (Rodriquez-Vivas et al. 2003). In a rural community in South Africa, 51 percent of the dogs had a serious clinical condition; of this population 10 percent were acutely ill and half were chronically ill (Rautenbach, Boomker, and DeVilliers 1991). Because of their undeveloped immune systems, puppies are particularly susceptible to diseases (Robinson 2000). Free-roaming dogs constantly face starvation, malnutrition, and dehydration (Matter and Daniels 2000; HSI 2001). Dogs also are poisoned, harassed by people, and hit by vehicles (HSI 2001; Hargreaves 2002).

Dogs contract rabies. The length of time between a dog being exposed to rabies and exhibiting symptoms is two to eight weeks (Wandeler and Bingham 2000), at which time he becomes aggressive and seeks other animals to bite (Wandeler and Bingham 2000). Dogs die from rabies within two to three days from the onset of symptoms. In addition to dog rabies deaths, the fear of rabies has resulted in the inhumane killing of dogs who are unfamiliar or who are suspected of having rabies (Cleaveland et al. 2006).

As a result free-roaming dogs have high rates of mortality. The life expectancy of dogs in Zimbabwe communal lands is 1.1 years (Butler 2000); 71.7 percent of dogs died in their first year. Of households with dogs in the Machakos District, Kenya, 67 percent reported that a dog had died recently and a replacement was being sought (Kitala et al. 2001). In New Providence 35 percent of the dog population is lost each year (Fielding and Plumridge 2005). Of households surveyed in Bali, 31 percent had a dog die in the previous year. Very few dogs die of old age (Butler 2000); nutritional, parasite, and disease problems account for high mortality rates, especially in puppies (Matter and Daniels 2000). Pups also are often left unattended, which increases their risk of predation (Matter and Daniels 2000). Because of high mortality rates, dog populations are skewed toward younger dogs. In the Machakos District, Kenya, half of the dogs are less than one year old (Kitala et al. 2001).

Dogs receive little veterinary care in developing countries, which contributes to the spread of disease and high mortality among dogs. Only 40.5 percent of households surveyed in Zimbabwe said they would take their dogs to the veterinarian if they were ill; 12.8 percent would try to cure their dogs with traditional medicine; and the remainder would seek no treatment (Butler 2000). Dogs who are allowed to roam are even less likely to receive veterinary care. Restricted adult dogs in New Providence are more likely to be spayed than are those kept outside (Fielding and Plumridge 2005). The health of fenced dogs is much better than that of free-roaming dogs, since the former are not exposed to fighting and communicable diseases (Fielding, Mather, and Isaacs 2005). In Thailand researchers found that dogs kept in the house are more likely to be vaccinated than are those who are allowed to roam freely (Kongkaew et al. 2004).

Female dogs are less likely to be vaccinated, sterilized, or licensed than are males. Only 15 percent of male dogs—but no female dogs—in the Machaskos District, Kenya, are sterilized (Kitala et al. 2001). Of male dogs 35 percent are vaccinated, compared with only 20 percent of females. In Zimbabwe, only 0.7 percent of females are spayed, compared with 16.3 percent of male dogs who are neutered (Butler 2000). In Bali only 11 percent of female dogs are neutered, compared with 44 percent of males (Margawani and Robertson 1995). Exceptions to this trend are New Providence, where similar sterilization rates are reported for female and male dogs (Fielding and Plumridge 2005), and Thailand, where female dogs have a higher sterilization rate

than do males (Kongkaew et al. 2004). In addition, in New Providence more male dogs (59 percent) than female dogs (41 percent) are licensed (Fielding, Mather, and Isaacs 2005).

Female dogs also have shorter life spans. Higher female mortality is related to lower levels of care provided to female dogs. Female dogs are more likely to be abandoned (Fielding, Mather, and Isaacs 2005) and are killed as puppies to avoid pregnancies (Boitsni et al. 1995; Matter and Daniels 2000). People also dispose of female dogs in estrus to disband groups of male dogs (Matter and Daniels 2000). In the Machakos District, Kenya, the life expectancy of male dogs is 3.5 years; for female dogs it is 2.4 years (Kitala et al. 2001). The median age of dogs in New Providence is 1.5 years for females and three years for males (Fielding, Mather and Isaacs 2005).

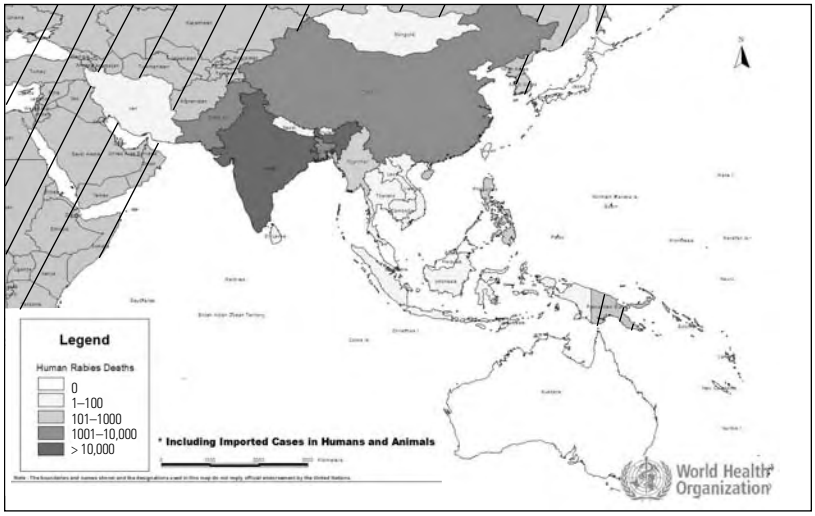
In most developing countries, preferences for male dogs and higher mortality of female dogs result in sex-based population imbalances (Matter and Daniels 2000). In Istanbul, Turkey, there are 6.8 male dogs for every female dog (WHO 1998b). In Thailand the ratio of male to female dogs is 2:1 (Kongkaew et al. 2004). Of dogs kept in Bali, 85 percent were male (Margawani and Robertson 1995). When it responded to the post-tsunami disaster that hit Sri Lanka in 2004, Humane Society International (HSI) veterinary relief teams found that male dogs outnumbered females by 3:1.

Preferences for male dogs are related to the belief that they make better guard dogs (Kitala et al. 2001). Owners also want to avoid responsibility for dogs in estrus or for litters (Margawani and Robertson 1995; Hsu, Severinghaus, and Serpell 2003). In addition, people choose male dogs more often as pets (Boitsni et al. 1995).

Overpopulation itself is a welfare problem for dogs. In addition to the physical consequences of repeated pregnancies, lactation, and competition for food, overpopulation of dogs results in human society devaluing them. Dogs who can be obtained for little or no cost are at the greatest risk of abandonment (Hsu, Severinghaus, and Serpell 2003). As Thorton (1992, 660) has stated, "Not allowing the excess [in companion animals] is the only effective way to address their welfare."

Figure 1
Rabies Deaths in Asia

Number of human rabies deaths per country, Asia, 2004



Source: WHO (2007).

Human Health Risks and Free-Roaming Dogs

Rabies

Free-roaming dogs who suffer from disease and overpopulation pose risks of zoonoses, contact injuries, and environmental pollution to human populations (Beck 2000). Rabies is the most lethal of canine transmitted diseases. Despite the development of a rabies vaccine more than a hundred years ago, WHO (2004) reports that half of the world's human population is at risk for rabies. Every fifteen minutes one person dies from rabies, and three hundred are exposed to the disease (Rupprecht, Hanlon, and Hemachudha 2002). Rupprecht, Hanlon, and Hemachudha (2002, 327) state, "[f]rom a global health perspective...rabies is the most important viral zoonosis."

Ninety-nine percent of rabies deaths take place in developing countries (WHO 2004). Fifty-six percent of rabies deaths are in Asia and 44 percent in Africa. Rabies mortality ranges from 0.001 per hundred thousand in the United States to eighteen per hundred thousand in Ethiopia, with mortality levels of 0.01 in South Africa, 0.47 in Thailand and Vietnam, 0.57 in Sri Lanka, 1.75 in Bangalesh, and 2–4 in India (Haupt 1999) (Figure 1). Bangladesh, India, and Pakistan are among the countries with the highest incidence of rabies (WHO 2001), and half of all human rabies deaths occur in India (WHO 1996).

Dogs are the main rabies vector in Africa and Asia (WHO 2001), and younger dogs pose a greater bite and rabies risk. A study in Thailand found that 62 percent of rabid dogs examined are younger than one year old (Mitmoonpitak, Wilde, and

Tepsumetanon 1997). U.S. studies have found that younger dogs are more likely to bite and their bites are more severe (Wright 1991).

Male dogs are responsible for 59–70 percent of bites (Wright 1991). The rabies virus is more prevalent in male dogs, and the sex of the dog is identified as a risk factor in Bolivia (Widdowson et al. 2000). Differences in bite rates and rabies fatalities between female and male dogs likely stem from the fact that canine aggression is hormonally related (Lockwood 1995). Unneutered males have particularly high bite rates (Lockwood 1995).

A study of medical records at Centro de Salud in Mexico found that 65 percent of bite victims were bitten at their residence, 32 percent in public locations, and 2 percent at their workplace (Eng et al. 1993). Nolan (2006) noted that domestic dogs cause more serious bites than do feral dogs. These data confirm U.S. studies that have found that dogs owned by neighbors have the highest victim rate and that bites by stray dogs are over-reported (Beck 2000).

Some estimate that only 3 percent of rabies deaths are reported in developing countries (Knobel et al. 2005). Rabies is underreported because patients seek treatment from traditional healers, causes of death are often not reported to central authorities, and rabies may be unrecognizable to medical staff without laboratory confirmation (Cleaveland et al. 2002). An Indian household survey found that only 36.4 percent of residents said they would visit a doctor if they were bitten by a dog (Singh and Choudary 2005).

To compensate for underreporting of rabies, some researchers use dog bite statistics to predict numbers of rabies deaths. Using a dog-bite probability model, 55,270 deaths per year or 1.38 deaths per hundred thousand people are predicted (Knobel et al. 2005). These fatalities include 19,713 deaths in India, 2,336 in China, 9,489 in other parts of Asia, and 23,705 in Africa.

Eighty-four percent of rabies deaths are in rural areas (WHO 2004). In India there are an estimated 2.49 deaths per hundred thousand people in rural areas, compared with 0.37 deaths per hundred thousand people in urban areas. In Africa there are 3.60 deaths per hundred thousand in rural areas, compared with 2.00 per hundred thousand in urban areas (Knobel et al. 2005).

Poverty is also associated with rabies vulnerability. An Indian survey involving twenty-one medical colleges found that 87.6 percent of adults who died of rabies between 1992 and 2001 were poor (Sudarshan 2005). The risk of canine rabies in Mexico is greater in lower-income areas (Eng et al. 1993). Poor children also face great risk. Children under the age of fifteen comprise 40–60 percent of rabies victims (WHO 2001). Half of the world's malnourished children live in rabies-endemic areas (Sampath et al. 2005).

At the same time, rabies is 100 percent preventable for both humans and dogs. Deaths occur when dog bites go unreported, unrecognized, untreated, or are discovered too late (WHO 2001). The lack of awareness about rabies among the public, health practitioners, and authorities; the shortage of rabies immunoglobulins and funding for modern vaccine; and the lack of priority given to canine rabies control have undermined rabies-prevention efforts (Dodet 2006).

As a result of improvements in postexposure treatment (Mitmoonpitak, Wilde, and Tepsumetanon 1997), rabies deaths did decline in the 1980s and 1990s. Ten million people currently receive postexposure treatment each year (WHO 2002). Predicted deaths worldwide without postexposure treatment would be 327,160 (Knobel et al. 2005). While rabies cases have declined in some areas of the world, they have increased in others. The rabies situation in Sri Lanka worsened after the 2004 tsunami because of increases in the number of ownerless dogs (Dodet 2006). The Philippines also has seen an increase in rabies deaths (WHO 2004).

Difficulties in controlling the spread of rabies have been associated with the migration of people and dogs from infected areas. WHO (2004) attributes the spread of rabies to the growth of dog populations in sub-Saharan Africa associated with human population growth and movement. Movement of infected animals into new areas produces outbreaks (Rupprecht, Hanlon, and Hemachudha 2002).

Other Canine-Transmitted Diseases

Free-roaming dogs are associated with a variety of other bacterial, viral, and parasitic infections that may pose a risk to humans. Echinococcosis and toxocariasis are among the most prevalent of these health hazards (Chomel and Arzt 2000; Overgaauw and van Knapen 2000) and often occur in low-income areas (Rubel et al. 2003).

Echinococcosis (hydatid disease) is a common parasitic infection in dogs in developing countries that results from improper livestock slaughter practices (Jiminez et al. 2002; Seimenis 2003; Reece 2005). Sheep, goats, camels, cattle, pigs, and horses serve as intermediate hosts (Meslin et al. 2000). Dogs contract echinococcosis by consuming the offal of infected livestock near slaughterhouses or areas of home slaughter. Young dogs (ages three to twenty-five months) and female dogs are more likely to be infected with echinococcosis (Moro et al. 2005). In endemic areas, 1–40 percent of cattle, 1–80 percent of sheep, and 0.2–50 percent of dogs may be infected (Meslin et al. 2000). The disease spreads to humans through ingestion of dog feces. In humans the disease develops in the

Table 2
Levels of Dog and Human Echinococcosis in Selected Developing Countries

Place	Percentage of Dogs Infected	Humans/ 100,000	Source
Algeria	9.4–12.0	2.26	Seimenis (2003)
China— North Central Xinjiang	82.3	80.00	Jenkins, Romig, and Thompason (2005)
Egypt	3.0–10.0	4.29	Seimenis (2003)
Morocco	35.0–48.4	5.20–7.10	Seimenis (2003)
Peru—Pacaraos District	51.0	Not available	Moro et al. (2005)
Tunisia	30.0–68.0	1.50–2.05	Seimenis (2003)
Uruguay—La Poloma	20.0	Not available	Cohen (1998)

liver (70 percent), lungs (20 percent), or elsewhere in the body (10 percent) (Jenkins, Romig, and Thompason 2005). Echinococcosis can cause serious illness or death.

The disease is most prevalent in the Middle East and North Africa (Sadjadi 2006), Western and Central Asia (Jenkins, Romig, and Thompason 2005), the Mediterranean (Jiminez et al. 2002; Seimenis 2003), and sheep-rearing areas in South America and Australia (Meslin et al. 2000) (Table 2). The highest prevalence of echincoccosis is found in Tibetan populations in Sichuan Province, China (Li et al. 2005). In endemic areas, 2–20 people per hundred thousand contract echinococcosis (Meslin et al. 2000). In hyperendemic areas, up to 12 percent may be infected.

Toxocara canis is a common dog roundworm that is spread indirectly through dog feces. Analysis of dog fecal samples revealed toxocara infection rates of 36 percent in Pretoria, South Africa; 19 percent in Jordan; 13.5 percent in Santiago, Chile; and 10.5 percent in La Plata, Buenos Aires (Rubel et al. 2003). Dog infection rates range from 3.5 percent in adults to 79 percent in puppies (Overgaauw and van Knapen 2000). Puppies often acquire the disease through their mothers. Toxocara eggs do not become infectious until three weeks to several months after their introduction to the environment (Overgaauw and van Knapen 2000); infectious eggs can survive up to a year. The disease is transmitted through contaminated soil and unwashed hands. Children ages one to three are especially susceptible to exposure.

Improved hygiene, public education, removal of feces, enhanced health of animals, and reduction in free-roaming dog populations can significantly reduce disease transmission of both echinococcosis and toxocariasis from dogs to humans (Rubel et al. 2003). Reduction in the proportion of puppies in the population also helps to control toxocariasis spread (Rubel et al. 2003).

Free-Roaming Dogs: Risks to Livestock and Wildlife

Free-roaming dogs also may present predation and disease risks to both livestock and wildlife. While some claim that free-roaming dogs may prey upon livestock, Boitsni et al. (1995) concluded that feral dogs actually pose little threat to domestic animals. A study of the relationship between dogs and wild carnivores in Zimbabwe found that the small body weight and group size of dogs make them poor predators (Butler, du Toit, and Bingham 2004). However, others have expressed concern that stray dogs may harm civet populations in Hong Kong (Dahmer 2002) and iguanas, giant tortoises, and flightless cormorants in the Galapagos Islands (Matter and Daniels 2000).

The disease risk of free-roaming dogs to livestock and wildlife is of greater concern. WHO (1996) estimates that 25,000–27,000 domestic production animals contract rabies as a result of exposure to dogs or other rabies vectors. While dogs pose little predation threat to African wildlife, leopards, lions, and hyenas do prey on dogs. Wild carnivore predation on dogs creates the risk of disease transmission for rabies, distemper, and parvovirus (Butler, du Toit, and Bingham 2004). Wild dog populations were reduced by one-third as a result of rabies outbreaks in Tanzania and Kenya (Cleaveland 1998). Increased vaccination, especially along preserve boundaries, reduction of dog populations through birth control, and improvements in waste disposal would reduce transmission of canine rabies to wild animals (Butler, du Toit, and Bingham 2004).

Predecessors to Capture, Neuter, and Return

Capture and Kill

The capture and killing of stray dogs has been the dominant strategy to reduce dog populations and dog zoonoses. In the late 1980s, lethal dog-control programs were

challenged on both ethical and efficiency grounds. Mass removal strategies have been criticized because they fail to discriminate between owned and stray dogs and use cruel methods of removal. Dogs frequently are captured using nooses and chains, kept in vehicles without food and water for hours or days, then electrocuted, gassed, or drowned (Reece 2005).

For example, culls of dogs occurred in China 2003–2006 in response to increases in rabies deaths. China has the second highest rate of death and illness from rabies in the world. From 2001 to 2004, the number of rabies deaths more than tripled, from 854 to 2651 (Tang et al. 2005).

The upsurge in rabies deaths in China has been attributed to increases in dog populations, an extremely low rabies vaccination rate of only 3 percent, and inadequate postexposure treatment (Tang et al. 2005; Zhang et al. 2005). With a dog-human ratio of 1:9, the dog population in China has grown to between 80 and 200 million (Tang et al. 2005). In the four southwestern provinces with most of the recent rabies cases, 70 percent of households have one or more dogs (Zhang et al. 2005). In China dogs are the vectors in 85–95 percent of rabies cases.

In 2006 in southwestern China, government officials killed 50,000 dogs in five days in one province in an effort to end a rabies outbreak. Dogs who were not killed by their owners as ordered by the government were beaten to death. Both vaccinated and unvaccinated and owned and unowned dogs were killed.

Rather than reducing rabies risk, the culling of dogs in countries increases population turnover and movement, which, in turn, facilitate disease transmission. Following the elimination of dogs, new dogs repopulate the areas through compensatory breeding and migration (Bogel and Meslin 1990). Capture and kill programs remove vaccinated dogs from the population who are then replaced by unvaccinated dogs (Cleaveland et al. 2006). According to Cleaveland et al. (2006, 45),

> Dog elimination programmes, may, in fact, be counter-productive and reduce the proportion of immunized individuals in a population, because some vaccinated dogs are killed and community response to dog elimination campaigns is generally to buy new puppies or adopt free-roaming (unvaccinated) dogs.

Capture and kill programs do little to reduce the size of dog populations. Lethal dog population control strategies require the elimination of 50–80 percent of dogs a year (WHO 1989), which is neither financially possible nor ethically acceptable in most countries (Rupprecht, Hanlon, and Hemachudha 2002). Most catch and kill programs remove only 3–5 percent of dogs per year (Bogel and Meslin 1990). While WHO initially supported the culling of stray dogs, it now concedes that removal of dogs does not significantly reduce dog populations or the spread of rabies (WHO 2001).

The culling of dogs also generates hostility toward dog-control officials, which undermines cooperation with rabies canine vaccination efforts (Cleaveland et al. 2006). In addition, killing of stray dogs negatively affects tourism (Leney and Remfry 2000).

Postexposure Rabies Treatment

The number of people receiving postexposure treatment has increased dramatically over the past decade. For example, the number of people who received postexposure treatment in Thailand climbed from 93,641 in 1991 to 350,535 in 2001 (Lumlertdacha et al. 2006). Improved public awareness of the need for treatment, reductions in vaccine costs, intradermal regimens, and administration of immunoglobulin at injection locations, all have resulted in some progress in rabies prevention in Asia (WHO 2001; Wilde, Khawplod, and Khamoltham 2005; and Lumlertdacha et al. 2006). The shift in most countries from the Semple vaccine (a vaccine, prepared in the brains of adult sheep, that induces severe and long-term side effects such as allergic encephalomyelitis) to cell culture vaccine also has improved treatment (WHO 2004). To further reduce rabies risks, preexposure vaccination is now recommended for at-risk groups such as young children and people who work with animals (WHO 2001; Wilde, Khawplod, and Khamoltham 2005; Dodet 2006).

However, progress in rabies prevention is at a standstill; no new Asian country has eradicated rabies in recent decades (Wilde, Khawplod, and Khamoltham 2005). Canine rabies remains endemic in India, Pakistan, Vietnam, Thailand, the Philippines, and most African countries.

Canine Rabies Vaccination Campaigns

Most experts agree that dog-vaccination campaigns are a more cost-effective approach to rabies prevention than is postexposure treatment alone (Cleaveland 1998; Kitala et al. 2001, 2003; Wilde, Khawplod, and Khamoltham 2005). Canine-vaccination programs cost 25–56 percent of postexposure treatments (Bogel and Meslin 1990). According to WHO (2001, 4),

> Rabies control in dogs remains the only long-term, cost-effective means of eliminating or preventing most human cases. Human public health preventive measures should be paralleled by programmes for dog rabies control.

Based on epidemiological research, researchers estimate that 70 percent vaccination coverage will prevent rabies outbreaks (Coleman and Dye 1996; Coyne et al. 2001; WHO 2002; Cleaveland et al. 2003). In the field the level of coverage at which protection has been achieved has varied. For example, in Korea 30–40 percent coverage has eliminated rabies (Cleaveland et al. 2003). However, even with 56–80 percent coverage, rabies remains endemic in Mexico. Average dog-vaccination coverage is currently only 9.7 percent in Asia and 10.3 percent in Africa (Knobel et al. 2005). With community participation Bogel and Meslin (1990) believe that 70–75 percent of dogs populations are accessible to rabies vaccination campaigns.

WHO (2004) recommends that vaccination campaigns use only inactivated vaccine, that all staff involved receive preexposure vaccination, and that dogs be registered to provide permanent identification of those who have been vaccinated. Rabies surveillance and dog population surveys are urged to measure population size, turnover, growth, sources of ownerless dogs, degree of supervision of owned dogs, and distribution and accessibility of dogs to be vaccinated (Kitala et al. 2001). Dog density and frequency of immunization campaigns influence vaccination coverage success (Cleaveland et al. 2003).

WHO (2004) advocates campaigns that begin in one area and expand to cover larger areas, country-wide campaigns, or campaigns in geographically separate hot spots followed by expanded coverage (WHO 2001). WHO also supports free dog immunization. Dog-vaccination campaigns along national borders also are recommended to provide an "immunity belt" (WHO 2001).

Many Latin American countries have had success in controlling the spread of rabies through mass canine rabies vaccination campaigns and improved postexposure treatment (Organizacion Panamericana 2005). In 1983 the Pan American Health Organization (PAHO) and WHO set 2005 as the target date for elimination of canine rabies (PAHO and WHO 2005). Each year forty-four million dogs in the region are vaccinated (Organizacion Panamericana 2005). In many areas 80 percent coverage has been achieved quickly (WHO 2004). As a result of these efforts, human rabies cases dropped by 91 percent and dog rabies cases dropped by 93 percent between 1982 and 2003. Panama, Costa Rica, Chile, Uruguay, most of Argentina, and southern Brazil have been rabies free for more than ten years (Organizacion Panamericana 2005).

The Latin American experience also makes clear the need to sustain vaccination programs. After twenty-five years without rabies in Argentina, outbreaks occurred in two provinces in 2004 (PAHO and WHO 2005). Rabies outbreaks also occurred that year in Bolivia and in the state of Zulia in Venezuela. Political commitment, financial support for canine rabies-control programs, surveillance and dog population ecology data, and coordination are necessary to sustain rabies prevention in Latin America (WHO 2001). With canine rabies under some control, bat transmission of rabies has become Latin America's new challenge (Organizacion Panamericana 2005).

Targeted mass dog-vaccination campaigns in Africa have achieved some success as well. In rural northwestern Tanzania, the first campaign reduced rabies incidence by 70 percent (Cleaveland et al. 2003), and a second campaign reduced the disease by 97 percent. In Tanzania advertisements through primary schools and meetings with community leaders took place before the vaccination campaign. A central vaccination point was set up in each village, and all dogs brought to the vaccination points were registered and vaccinated for rabies, distemper, and parvovirus free of charge. Colored plastic collars were placed on treated dogs. Vaccination coverage was assessed at each of four phases through household surveys, observation of dogs, and number of rabies doses used in proportion to dog population. Researchers also collected data from hospitals on rabies and dog bite incidences at each stage. Vaccination coverage of 60–70 percent of dogs in this area of Tanzania has provided sufficient protection from canine rabies (Cleaveland et al. 2003).

Similar mass rabies vaccination campaigns have been held elsewhere in Africa and in Asia (Perry et al. 1995). In Nairobi central point vaccination sites were opened for five days and supplemented with door-to-door coverage during the last three days of the campaign. In Nepal vaccination campaigns achieved 75–80 percent coverage and involved public education, household surveys, central vaccination points for nineteen days, and teams that went door-to-door in areas where vaccination levels were insufficient (Bogel and Joshi 1990). Mass vaccination campaigns have improved attitudes toward animals and animal welfare (Cleaveland et al. 2006).

Although dog-vaccination campaigns are more cost-effective than postexposure treatment, countries may experience a decline in rabies without a concomitant decrease in demand for postexposure treatment (Cleaveland et al. 2003). For example, in Tunisia and Thailand rabies cases in dogs and humans declined significantly; however, postexposure treatments remained at the same level or increased. Dog rabies may need to be virtually eliminated before demand for postexposure treatment decreases (Cleaveland et al. 2003).

Oral vaccine as a supplement to current parenteral vaccination campaigns is viewed as an addi-

tional strategy to increase vaccination coverage (Cleaveland 1998; WHO 2004; Denduangboripant et al. 2005). Trials of this drug, developed initially to control rabies in wild animal populations, were as of 2006 underway on bait delivery, safety for target and nontarget animals, safety for dogs under ten weeks, and possible virus excretion in dog saliva (WHO 1998a,b). Results that far showed no adverse effects on target or nontarget species (WHO 2004). Making baits available to owners in central locations, placing baits in select locations, door-to-door delivery, and giving baits to dogs in the street have been suggested as oral vaccine distribution strategies (Cleaveland 1998; WHO 1998; Wandeler and Bingham 2000). WHO (2001) has endorsed oral immunization for dogs.

Despite widespread agreement about the ineffectiveness of stray dog removal to control rabies transmission and limit population growth, some countries such as Sri Lanka have continued to combine mass vaccination campaigns with removal of dogs. Because of their perceived inaccessibility for parenteral vaccination, stray dogs are eliminated by capture and killing in mobile vehicles with gas chambers (Matter et al. 2000). As a part of the immunization campaign in Sri Lanka, twelve vaccination points were set up (Matter et al. 2000). The campaign was announced through posters and a loudspeaker on a vehicle, and stapled collars made it possible to identify vaccinated dogs by geographic area. Dogs under three months were excluded from the campaign. In Sri Lanka 492,000 dogs are vaccinated annually, but coverage remains below 70 percent (WHO 1996; Matter et al. 2000).

High population turnover for dogs as a result of dog removal and mortality undermines the success of mass vaccination programs (Cleaveland 1998; WHO 2001; Wilde, Khawplod, and Khamoltham 2005; Bauhloul et al. 2006; Cleaveland et al. 2006). Few dogs live long enough for booster vaccinations (Mitmoonpitak 1997). Subsequent migration of unvaccinated dogs to areas from which dogs have been removed further reduces vaccination coverage.

Other barriers to dog vaccination include lack of sustainable human and financial resources, inaccessibility of a large fraction of dogs, low-quality and high-cost vaccine, lack of public awareness or collaboration among agriculture and health departments, poor immune response, and movement of human and dog populations (Perry et al. 1995; Cleaveland 1998; WHO 2001; Adeyemi et al. 2005; Bauhloul et al. 2006; Lodmell et al. 2006; Lumlertdacha et al. 2006).

To achieve and maintain adequate vaccination coverage, successive vaccination campaigns are necessary. Mass vaccination campaigns need an initial two-year phase to achieve 75 percent coverage (Bogel and Meslin 1990). Annual vaccination of 50 percent of dogs for four years is necessary to consolidate the 75 percent coverage, along with surveillance and vaccination at borders and points of entry for international travelers. Some researchers suggest that vaccination campaigns should be conducted every six to eight months because of high population turnover (Cleaveland 1998). WHO (2004) also supports more frequent vaccination campaigns where population turnover is particularly high.

Excluding young puppies from vaccination programs is another obstacle to rabies prevention. Despite the fact that young dogs are most involved in rabies transmission, puppies under three months are rarely vaccinated during campaigns. Perry (1995), Cleaveland (1998), WHO (2004), and Bauhloul et al. (2006) maintain that including puppies under three months will improve vaccination coverage. In Mexico puppies are vaccinated at one month as a part of rabies-control efforts (WHO 1998a).

While researchers identify mass canine rabies vaccination as the most effective and affordable rabies-control strategy, they acknowledge that vaccination campaigns often are not adequate to maintain a 70–75 percent vaccination coverage because of the high turnover of dogs (Kitala et al. 2001). However, many reports on mass rabies vaccination and dog population issues in Africa ignore (Dodet 2006) or dismiss (Kitala et al. 2001) sterilization, particularly of female dogs. According to Kitala et al. (2001, 228), "The spaying of bitches is a specialized feature and conceivably out of reach for most rural poor." However, with the help of international animal protection organizations, sterilization combined with vaccination has been instituted in some communities with very interesting outcomes.

Capture, Neuter, and Return/ Release

Public Health and Animal Welfare Benefits

Mass vaccination campaigns and improvements in postexposure treatment have significantly reduced dog and human rabies cases. Vaccination campaigns also have demonstrated community support for dog treatment programs, the accessibility of free-roaming dogs for vaccination and other treatments, and important techniques for reaching dogs. Capture, neuter, and return/release (CNR) programs directly confront the problem of high turnover of dog populations, which mitigates against extensive rabies vaccination coverage and dog population control.

CNR programs have as their goal the stabilization—not elimination—of street dog populations and

the control of rabies transmission (Help in Suffering 2003). CNR for dogs in developing countries has been modeled on trap, neuter, and return (TNR) programs for feral cat colonies in the United States (HSI 2002). For TNR programs, people who put out food for stray and feral colonies trap cats and bring them to a veterinary facility, where the cats are sterilized and vaccinated for rabies and other diseases. The cats are ear-tipped to identify them as having been sterilized and then returned to the colony. Cats who test positive for feline leukemia virus (FeLV) or other diseases that are not treatable are euthanized humanely. Kittens more than seven weeks old are removed from the colonies, sterilized, socialized, and placed for adoption. The cats are usually returned to caretakers on the same day as surgery and then may be kept overnight before being returned to their colonies. In TNR treated feral cat colonies continue to be managed and monitored.

The TNR management of cats has been viewed as more effective than euthanasia because it allows cats to continue to "occupy environmental niches" that otherwise would be filled by unvaccinated and unsterilized cats (Hughes, Slater, and Haller 2002). In this way TNR colonies provide "a substantial barrier of vaccinated individuals against disease" (Slater and Shain 2005, 46). TNR also encourages colony feeders to participate in feral cat management and, if done properly, leads to a decline in the colony size. TNR has been endorsed by the American Veterinary Medical Association and most leading animal protection organizations. TNR also has won the support of caretakers of feral cat colonies who oppose euthanasia of healthy cats and are needed to implement TNR programs.

By controlling population growth and reducing dog mortality, CNR programs discourage migration and compensatory breeding of dogs to fill ecological niches left vacant by dog losses. Return of sterilized dogs to their home territories prevents a "vacuum effect" of attracting new dogs to unoccupied territories (Leney and Remfry 2000). Return of dogs to the territories from which they were captured also diminishes the stress and vulnerability of the returned dogs after surgery. These programs reduce the number of puppies in the population, who are at the greatest risk for transmission of rabies and other diseases. Similar to vaccination programs, a 70 percent sterilization rate is necessary to stabilize dog populations. Some argue that dog overpopulation will continue to be a problem until the proportion of breeding females is less than 20 percent (Fielding and Plumridge 2005). Like TNR programs, CNR programs have strong public support where catch and kill programs do not (Leney 2002).

CNR programs also have pressed for changes in waste disposal. As Help in Suffering (2003, n.p.) notes, "The overall, ultimate answer to street dog population control is to control the availability of edible wastes." Waste disposal is a major factor in free-roaming dog populations and bite incidences. In New Providence 25 percent of garbage discarded each week was edible (Fielding, Mather, and Isaacs 2005). In Nepal stray dogs are able to feed at garbage dumps that line the streets and frequent the makeshift slaughter facilities in Katmandhu where offal is disposed of. In Japan, where there is no loose garbage, stray dog populations are lower (Kato et al. 2003).

Central to the success of CNR programs are improvements in the health, longevity, and behavior of free-roaming dogs in addition to reductions in population growth. For many years researchers have reported the health benefits of sterilization and contraception. Repeated pregnancies can physically stress animals, while the absence of pregnancy can improve animal health, making the animal less vulnerable to predation, reductions in food supply, bad weather, and other challenges. In addition, sterilization minimizes risks of some debilitating and fatal diseases.

TNR programs for feral cats highlight some of these benefits. Mean feral cat colony size decreased from 7 to 5.1 after Florida spay-and-neuter programs (Centonze and Levy 2002). Neutering of free-roaming cats improved body weight, body condition, and life span (Scott et al. 2002; Levy, Gale, and Gale 2003). Eighty-two percent of feral cat colony caretakers observe that spaying and neutering has improved the quality of cats' lives (Centonze and Levy 2002). Scott et al. (2002, 212) conclude, "in addition to halting reproduction, neutering may have other effects that, combined, improve the welfare of feral and free-roaming cats."

Contraceptive trials involving wild animals further document improved body condition and reduced mortality as a result of temporary or permanent sterilization. Pregnancy prevention with the immunocontraceptive porcine zona pellucide (PZP) enhanced the body condition of female deer (Kirkpatrick 1996, 2005; McShea et al. 1997; Rutberg 2005). The health of wild horses on Assateague Island, Virginia, also improved as a result of the PZP contraceptive program (Turner and Kirkpatrick 2002). Before PZP introduction, the mortality rate was greater than 10 percent for adult horses and 3 percent for foals. With the contraceptive program, adult mortality decreased to less than 4 percent and foal mortality to about 1 percent (Turner and Kirkpatrick 2002). The mean age at death of mares that have not been contracepted is 6.4 years, whereas it jumps to 19.9 years in mares who have been contracepted for three or more years (J. Kirk-

patrick, personal communication with A.N.R., n.d. 2005).

Dogs derive other health benefits from sterilization in addition to fewer pregnancies. Spayed and neutered dogs do not face the risk of ovarian, mammary, and prostate diseases and disorders (Kustritz 2002). Cancer is less likely in both female and male dogs after sterilization (Michell 1998, 1999). The cancer risk of female dogs who have been spayed declines even more significantly than it does for male dogs. Castration reduces the duration of chronic bacterial prostatitis infection in male dogs (Cowan et al. 1991). In addition, all CNR programs provide a range of treatments for parasites, nutritional deficiencies, and other health problems as well as vaccination and sterilization.

Several studies have examined the relative benefits of early gonadectomy. Comparing spay and neuter for shelter dogs at twelve weeks, twelve to twenty-three weeks, and more than twenty-four weeks of age, Howe (1997) found fewer minor complications for earlier procedures and no difference in major complications. Another study concluded that the benefits of early gonadectomy outweigh the risks (Spain, Scarlett, and Houpt 2004). While some researchers have suggested that urinary incontinence may result from ovariohysterectomy (Holt and Thrusfield 1993), other studies have revealed that urinary incontinence is less frequent in dogs who undergo the procedure before first estrus than those who do after first estrus (Kustritz 2002). Salmeri et al. (1991) saw little difference in health outcomes for spay and neuter at seven weeks versus seven months, although they found more growth plate closure delayed in early-neutered dogs that they did in intact dogs.

As a result of improved body condition and diminished susceptibility to disease, sterilized dogs enjoy longer life spans than do intact dogs. Spayed female dogs in one study gained an additional year over intact female dogs (Michell 1998). In this study, longevity differences between neutered and intact male dogs were insignificant. However, another study found removal of testis increases the life expectancy of male dogs (Waters, Shen, and Glickman 2000). Neutered dogs in New Providence, The Bahamas, were found to live longer than did intact dogs as a result of a reduction in sexually transmitted diseases, exposure to disease, and stress of mating and fighting (Fielding, Mather, and Isaacs 2005).

CNR programs also have the capacity to produce behavioral changes in dogs that limit bite and disease risk. In TNR programs caretakers report that feral cats were friendlier, less aggressive, and less likely to roam after they were sterilized (Scott et al. 2002). Sterilization also reduces roaming and aggressive behavior in male dogs (Lockwood 1995). Fewer escaping behaviors have been reported after gonadectomy (Spain, Scarlett, and Houpt 2004). Fewer females in heat also reduces fighting and pack formation (Help in Suffering 2003; Nolan 2006). For 60 percent of dogs in one study, castration reduced urine marking, roaming, and mounting, and one-third of dogs showed significant decreases in aggressive behavior (Neilson, Eckstein, and Hart 1997).

CNR Programs

Despite CNR's promise, it has been introduced only in India, Thailand, island areas, and a handful of other countries. In many of these countries, CNR programs were launched in direct response to threatened or actual mass killings of dogs by government officials in attempts to reduce populations and decrease rabies transmission. Some CNR programs operate from fixed clinics, others depend on mobile clinics. The programs vary in their duration, use of local and visiting veterinarians, target populations, and sterilization levels. Table 3 provides an overview of selected CNR programs.

India

With an estimated population of twenty-four million dogs, India has been the site of pioneering CNR programs. ABC (Animal Birth Control) programs were introduced following WHO and WSPA's publication of *Guidelines for Dog Management*, which addressed the ineffectiveness of capture and kill as a dog-control strategy. According to WHO (2004, 54), the goal of ABC programs is to "reduce dog population turnover as well as the number of dogs susceptible to rabies and limit aspects of male dog behavior (such as dispersal and fighting) that facilitate the spread of rabies."

ABC programs in India were launched in response to the use of strychnine poisoning and electrocution as the dominant animal-control strategies (Help in Suffering 2003). In 1992 New Delhi's court required that ABC programs replace cruel and ineffective methods of dog control (Help in Suffering 2003). A pilot program by Help in Suffering (HIS) in 1994 and 1995 demonstrated the effectiveness of CNR in several Jaipur districts. The program then expanded to all of Jaipur. ABC programs have begun in Bombay, Delhi, Calcutta, Madras, Bangalore, Hyderabad, Uidapur, and Jodhpur. The Jaipur program has developed new techniques for counting street dogs and for the capture and return of such dogs (Help in Suffering 2003).

For the ABC program, HIS (2003) selects an area of the district, subdivides the district, and establishes a quota for the number of dogs to be captured in each area. Before working in the area, HIS informs people about the ABC program, what will be done to the dogs, and the benefits of the program. Staff then travel through the areas capturing as many female adult dogs and older

Table 3
Selected Capture, Neuter, Return Program Locations, Duration, Sterilization Levels, and Components

Place/ Duration	Type of Clinic	Vets	Number of Sterilizations	Postprogram Sterilization Level	Education Programs	Source
Abaco (February 2000–October 2000) 4–6 days per clinic 8 clinics	Fixed	Local	540 dogs and cats 432 dogs (75 percent) 108 cats (25 percent) Dogs (59 percent female, 41 percent male)	N/A	No	HSI (2001); Hargreaves (2002)
Bali (September 1998–May 2005) Ongoing	Mobile Fixed	Local Visiting	13,790 dogs	51 percent	Yes	Peacock (2005a); Listriani (2002)
Galapagos Islands (May 2004–May 2005) Isabela Island—6 weeks Santa Cruz—3 weeks San Cristobal—4 weeks All three islands—9 additional days	Mobile	Visiting	2,601 dogs and cats	N/A	Yes	Animal Balance (2005, 2006)
Jaipur (February 1997–May 2006) Ongoing 12 dogs captured per day, 7 days a week	Fixed	Local	> 23,000 dogs adult males and < 3 months excluded	68 percent	No	Help in Suffering (2003)
Sri Lanka (January–May 2005) 13 sites 81 days in field	Mobile	Visiting	1,833 dogs (34 percent female, 66 percent male)	70–90 percent	No	Peacock (2005b)

puppies of both sexes as possible. With the exception of puppies, male dogs are excluded from the program. Sterilization of female dogs is seen as more cost-effective, since one male dog can impregnate multiple females. In addition, there is a belief that intact male dogs are more territorial, which will prevent immigration of new dogs into territories (Nolan 2006). Puppies under three months also are not captured. Dogs are captured in the early mornings and early evenings by hand or with sacks and hoops. Staff receive incentives to encourage high catch rates and capture of sick dogs beyond their quotas. The dogs are then transported to the clinic.

At the clinics the dogs rest for twelve to twenty-four hours (Help in Suffering 2003), and food is withheld from them overnight. Anesthetized female dogs are spayed using the keyhole flank procedure, with the exception of heavily pregnant dogs on whom a midline spaying procedure is performed. Anesthetized male dogs are castrated. All dogs are vaccinated and identified with individualized tattoos and an earmark. After surgery a veterinarian determines which dogs are ready for release and which need to stay longer. The average release time is 3.79 days for females and 3.25 days for males. The dogs are then returned to the areas where they were captured. Two dogs are released at a time to minimize problems among the dogs and between the dogs and the public. Approximately 10 percent of the dogs brought into the shelter are euthanized because they are terminally ill, badly injured, too aggressive, or suspected of being rabid or having come in contact with another rabid dog.

HIS (2003) has sterilized and vaccinated 68 percent of the dogs in the population and has performed more than twenty-three thousand spay-and-neuter procedures. While there has been some opposition to the capture of dogs and to their return, the program generally enjoys widespread public support (Nolan 2006). In her evaluation of the Jaipur program, Nolan (2006, n.p.) observes, "Surgical spay and neutering of dogs appeared [to be] well accepted. Human population control and health care campaigns may have

helped raise awareness of this concept."

WSPA also evaluated the Jaipur program recently. WSPA found that, while there was a relatively rapid increase in the proportion of females sterilized (10–60 percent over the first three years), the increase over the next six years (to about 75 percent sterilized) has been much slower. As a result of the ABC program, the dog density also declined by one third between 1997 and 2002. However, these decreases have not continued. The possible addition of dogs to the population from the reproduction of dogs whose owners have kept them on private property to avoid ABC capture, inadequate ABC coverage in some areas, and migration or acquisition of dogs from outside of the district may have prevented further population declines. Higher reproductive and pup survival rates among dogs in protected environments also may contribute to higher than expected population levels (E. Hiby, personal communication with A.N.R., n.d. 2006).

Among the challenges the Jaipur program has faced is difficulty in getting commitments from municipal authorities to refrain from capturing or killing dogs (Help in Suffering 2003). Municipal officials receive pressure from residents who see dogs as a nuisance and fear rabies. Officials also are concerned that CNR success will result in reductions in animal-control jobs.

The absence of information on street dog behavior and lack of trained resources, staff, equipment, and medical supplies also have been problematic. HIS had initial difficulties in identifying Indian veterinary surgeons to participate in the program because few local veterinarians have experience or training in small-animal medicine (Nolan 2006). In addition, problems with other nongovernmental organizations inflating their sterilization numbers have undermined the reputation of ABC programs (Help in Suffering 2003). Nonetheless, other cities in India have also reported success with their ABC programs (Krishna 2005). Chennai has recorded a substantial decline in human rabies cases since it launched its ABC program in September 1996 (Figure 2), and the Jaipur rabies data are also impressive (Figure 3).

It is not immediately apparent why ABC programs should have this impact. If they are significantly reducing the number of young male dogs (the main rabies vectors) from the streets, it is conceivable that even a small reduction in teenage male dogs could break the infection cycle for rabies. The ABC program in Jodhpur has been set up to try to answer some of these questions. A desert city, Jodhpur is essentially an island consisting of

Figure 2
Number of Rabies Deaths in Chennai, India, 1996–2003

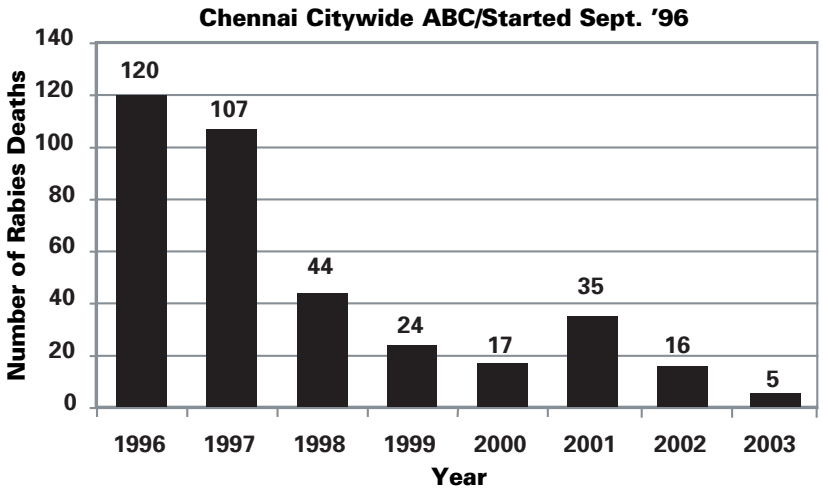
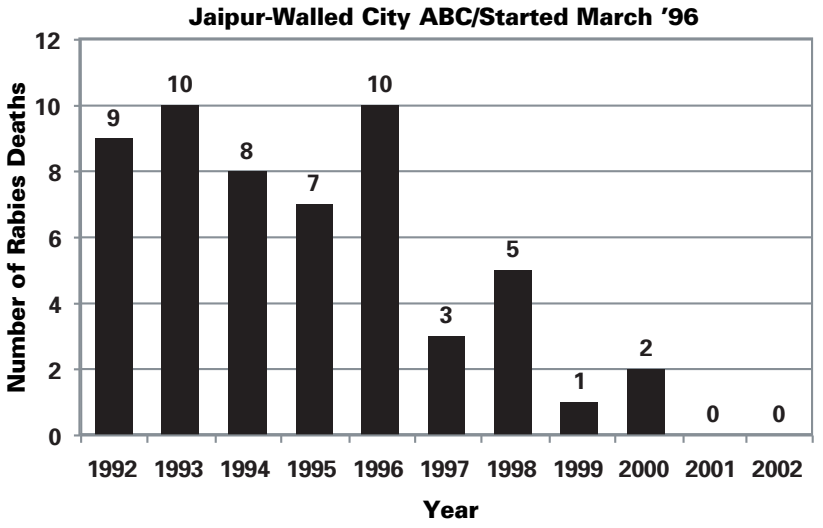


Figure 3
Number of Rabies Deaths in Jaipur, India, 1992–2002



about 950,000 people and 46,000 dogs (or 4.9 dogs per hundred people) (K. Doyle, personal communication with A.N.R., n.d. 2006).

Thailand

In 1995 Thailand set the goal of being rabies free by 2000 (Wasi et al. 1997). Under Thailand's 1992 Rabies Prevention Act, every owned dog must be vaccinated at two to four months of age and receive annual vaccinations (Wasi et al. 1997). Vaccination and sterilization campaigns focused on community dogs who live around temples and schools (Kamoltham, Singhsa, and Promsaranee 2003). Methods of sterilization included injections of medroxyprogesterone acetate, surgery, and use of natural plant hormones. Outreach to the medical community and local residents encouraged bite victims to seek treatment (Kamoltham, Singhsa, and Promsaranee 2003). Mass vaccination campaigns achieved 53 percent coverage (WHO 1996). Although rabies declined from two thousand cases in 1993 to fewer than twenty in 2003, vaccination levels of 40–70 percent in parts of the country are viewed as inadequate, particularly in view of the migration of infected dogs from suburban and rural areas (Denduangboripant et al. 2005). Moreover, stray dog populations tripled between 1992 and 1999 (Lumlertdacha et al. 2006).

With a population of six to ten million dogs, Thailand implemented a new program of capture, neuter, vaccination, and return in 2002. This program has been the target of criticism because it is limited to Bangkok and lacks adequate financial and staffing resources (Denduangboripant et al. 2005). Programs in Thailand faced difficulties in hiring veterinarians who are trained in small-animal surgery. When they could not hire enough veterinarians for surgery, Thailand officials built kennels to house captured dogs (Clifton 2002). This capture strategy has only served to facilitate migration of infected and intact dogs into new territories. Targeted CNR campaigns in isolated geographic areas such as southern Thailand are viewed as more viable (Denduangboripant et al. 2005).

Island Nations

CNR programs have operated successfully in island areas, including Abaco, Bali, the Galapagos, and Sri Lanka. In Abaco, an island in the Bahamas, a spay/neuter incentive program (SNIP) was launched in 1999 with support from HSI and the Pegasus Foundation. In 2000, after the success of the initial program, SNIP and Abaco Animals Require Friends (AARF) initiated "Project Potcake" as a CNR program (HSI 2001). Most "potcakes" (local dogs) are unowned, but these dogs are recognized and supported by specific neighborhoods.

For Project Potcake, two local veterinary clinics ran eight spay-and-neuter programs for four to six days each (HSI 2001). Volunteers canvassed neighborhoods and transported dogs to the clinics, where the animals were sterilized for free. The program focused on female dogs, but also included male dogs and cats. Project Potcake exceeded its target goals (HSI 2001). After the program had successfully reached both owned and socialized dogs, it attempted without success to use baited traps to capture less accessible dogs (HSI 2001). At the clinics dogs received additional medical treatment, including antibiotics, fluid replacement, and diagnosis of skin conditions (HSI 2001).

Initially, the program offered incentives of $10 for each male dog brought in and all cats and $15 for each female dog. Incentives were important in overcoming initial community suspicion, but could be decreased or eliminated as the program gained community support. Transportation for the dogs to and from clinics was viewed as more important than the financial incentive (HSI 2001).

The Abaco program was considered a success: the proportion of owners with sterilized dogs increased from 62 percent before the four clinics to 76 percent after the clinics (HSI 2001). With the popularity of the program, AARF was asked to run makeshift clinics in other neighborhoods (HSI 2001). Obstacles to the program have included the lack of owner participation and the numbers-driven program approach that on occasion has resulted in more captured dogs than could be sterilized (HSI 2001).

In Bali, an island with 3,151,000 people, there are an estimated 550,000–600,000 dogs (18–18.5 dogs per hundred people). Eighty-five percent of these animals are street dogs (Listriani 2002). Since its inception in 1998 by the Bali Street Dog Foundation (Yayasan Yudisthira Swarga [YYS]) the program has sterilized 13,790 dogs and provided veterinary care to an additional 31,718 (Peacock 2005a). YYS started with a "catch, treat, and release" program to treat skin diseases, parasites, and wounds. YYS now operates both mobile and fixed clinics; the former comprise two doctors, one dogcatcher, and a driver/field assistant. The "M.A.S.H.-style" surgery unit goes out four days a week, and the CNR program is directed at both female and male dogs. Before the mobile clinics began to visit villages, about 24 percent of the dogs were sterilized. After seven years of operation, an estimated 51 percent of dogs are now sterilized. Of the spay-and-neuter surgeries, 74 percent are performed by the mobile clinics (Peacock 2005a). It is evident that the increased proportion of sterilized dogs cannot be due solely to YYS activities. However, YYS has stimulated a change in community and veterinary behavior such that sterilization is now more common.

Veterinary education and training have been a major focus of YYS's work. WSPA initially trained staff in spay procedures using a spay hook (Listriani 2002). Since then YYS's fixed clinic has become a teaching facility for local veterinarians and veterinary students. Regular seminars are held in conjunction with the Indonesia Veterinary Association, and YYS offers internships for veterinary students and hosts visiting veterinarians from other countries. YYS also runs "kindness" classes for children and undertakes other public education efforts.

To stop the poisoning of dogs and cats by the Galapagos National Park Service (GNPS), Animal Balance introduced CNR to the Galapagos Islands (Animal Balance 2005, 2006). The local government provided clinic space, and municipal representatives did an initial door-to-door survey to inform residents about the upcoming spay-and-neuter program. A list of interested residents was given to Animal Balance, which then invited people to bring their dogs and cats to the clinic, and GNPS provided vehicles to transport the animals. Additional door-to-door canvassing covered every house on several of the islands to encourage participation. Radio commercials publicized the program and provided public education on dog care. Dog training and school-based humane education programs also supplemented the treatment of dogs and cats.

Before the Animal Balance program, no veterinary services were available on the islands for dogs and cats. Clinic equipment was brought to the Galapagos, and volunteer veterinarians from abroad were recruited to perform surgeries in the clinics. Animal Balance had run seven campaigns by 2006. In 2004 initial clinics were held on Isabela Island for six weeks and on Santa Cruz Island for two weeks. A four-week clinic was held on San Cristobal Island in 2005, along with another week-long clinic on Santa Cruz Island. In 2006 simultaneous campaigns were held on all three islands for nine days. Through these campaigns Animal Balance has sterilized 2,601 dogs and cats. After 2007 municipal administrators were to assume responsibility for the project.

The program has faced two recent challenges. Animal Balance (2006) is working with quarantine officials to contend with importation of purebred dogs to the islands, which could compromise vaccination and sterilization coverage. The organization also forged a compromise in response to the demand for puppies on San Cristobal Island. Previously hunters had refused to have their dogs sterilized. Animal Balance agreed to rescue and make available for adoption excess puppies that otherwise would be killed by hunters.

CNR programs also have been implemented in rapid response to natural disasters that precipitate fear of rabies. After the huge tsunami in 2004, the Sri Lankan military threatened to eradicate street dogs to prevent rabies outbreaks (HSI 2005a,b,c). The tsunami had displaced community dogs from familiar neighborhoods, making it difficult for them to locate food and shelter. Sri Lankan officials agreed to suspend plans for shooting and poisoning dogs after HSI made a commitment to launch a CNR program to vaccinate and sterilize free-roaming dogs. Working with a Sri Lankan animal hospital, veterinarians and other volunteers from HSI, YYS, and The Humane Society of the United States' Rural Area Veterinary Services set up thirteen successive field clinics across the country. In addition to capturing, vaccinating, neutering, and returning community dogs, the field clinics encouraged owners to bring in their pets.

Field clinics sterilized and vaccinated an estimated 70–90 percent of the dog population at each site. In total 1,430 dogs were treated between January and May 2005 (Peacock 2005b). The program developed strong community support, helped improve attitudes toward animal welfare, and increased appreciation of the need for veterinary services (HSI 2006).

The Success of CNR: Outcomes, Ingredients, and Constraints

CNR programs have been able to stabilize and, in some cases, reduce free-roaming dog populations. The ABC program in Jaipur achieved an initial population reduction of 28 percent (Help in Suffering 2003). In Abaco 50–75 percent fewer dogs were seen roaming the streets after Project Potcake than during the year before the program (Hargreaves 2002), and the number of dog roadkills declined significantly. Few litters of pups and pregnant or nursing potcakes were observed (HSI 2001; Hargreaves 2002). With the YYS program, the overall dog to human population ratio in Bali declined from 1:5.6 to 1:5.2 (Peacock 2005a). The population of dogs in targeted villages in Bali was reduced by over half when 75 percent of the village dogs were spayed or neutered. The population of puppies in these areas has decreased from 32 percent to 25 percent. In the Galapagos Islands, Animal Balance (2006) anticipated pet populations would be stabilized on Isabela, San Cristobal, and Santa Cruz islands by 2007.

Another measure of CNR success is reduction in canine rabies transmission. In Jaipur the ABC program has been associated with a significant decrease in rabies cases. In 2002 and 2003, no rabies

cases were reported in Jaipur (Figure 2) in districts in which CNR programs have been implemented. In areas in which the program did not operate, the number of rabies cases increased or stayed the same. After declines in rabies deaths throughout the 1990s and no rabies deaths in 2002 in Thailand, three people died of rabies in Bangkok in 2003 (Lumlertdacha et al. 2006). The migration of people and dogs from affected areas, which, in turn, diminished rabies vaccination coverage, most likely contributed to this spike in the disease (Denduangboripant et al. 2005; Lumlertdacha et al. 2006). In Sri Lanka CNR possibly forestalled rabies outbreaks in the wake of the tsunami.

In many CNR program areas, recapture of treated dogs and field observations have demonstrated improved dog health. In Abaco dogs who had been sterilized showed weight gain, improved coat luster and quality, improved skin conditions, and fewer parasites and venereal tumors (HSI 2001). Following CNR implementation in Bali, the proportion of dogs classified as having poor welfare status decreased from 33 percent to 13 percent (Peacock 2005a). As of 2006 ABC dogs in Jaipur were in better condition than was the rest of the dog population (Help in Suffering 2003). HIS (2003) was in the process of developing more precise body condition scoring techniques to quantify improvements. These techniques were being applied elsewhere. In addition, fewer dogs were observed in emaciated condition after clinic-based sterilization programs in Abaco (HSI 2003). Little research on dog behavior has been carried out before and after CNR programs, although evidence from Bali suggests the proportion of aggressive dogs has decreased (from 8 percent to 3 percent [Peacock 2005a]), and other sites report that treated dogs are less likely to roam or fight (Help in Suffering 2003; Animal Balance 2005).

While documentation of CNR program outcomes is preliminary, CNR and vaccination campaign experiences, epidemiology, and dog ecology and behavior suggest several lessons for future programs. Dog population surveys are crucial to developing CNR and vaccination programs and monitoring their success (Matter and Daniels 2000; Wandeler and Bingham 2000; WHO 2004). Measurement of dog populations requires household surveys; collection of information on dog survival, fecundity, sex ratio, age structure, keeping practices and human population; use of capture-mark-recapture strategy to estimate owned and ownerless population; and field observation to ascertain reproduction, survival, habitat use, food sources, and social behavior (Matter and Daniels 2000).

CNR experiences in developing countries reveal important issues regarding the involvement of the veterinary community. Few veterinarians in developing countries have training or experience in small-animal medicine and surgery (WHO 2001). Most veterinary training is oriented toward agricultural use of animals. To be successful, CNR programs must incorporate a training component for local veterinarians. The Bali program, in which visiting veterinarians are provided with training capacity, has done this most successfully. In addition, the YYS veterinary teams have trained veterinarians in Sri Lanka and India.

CNR and sterilization programs also have identified some conflicts with local veterinarians. In Taiwan, for example, veterinarians have been reluctant to support spay-and-neuter programs because they "believe [the] resulting reduction in the dog population will be bad for business" (Hsu, Severinghaus, and Serpell 2003, 15). In Bali YYS also experienced initial resistance from local veterinarians that disappeared when YYS activities led to an increased demand for veterinary services.

Involvement of local veterinarians is imperative to meet legal requirements in some countries (Hargreaves 2002), to strengthen support for CNR programs, and to ensure long-term availability of spay-and-neuter services (HSI 2002). CNR programs increase local veterinarians' interest in small-animal medicine. Following the same pattern in the United States, low or no-cost spay-and-neuter programs not only make services available and affordable, but they also spur local veterinarians to provide them (HSI 2002). At most locations CNR clinics were the first veterinary services provided to dogs and helped build public support for veterinary care.

Community involvement is essential to the success of CNR and vaccination programs. Residents play an important role at all sites in assisting program implementation through bringing dogs to sites and monitoring the animals. In many programs community leaders or "village mentors" provide entrée into local communities and facilitate public education and participation. Other programs enlist the involvement of "dog mommas," who serve as caretakers for neighborhood groups of dogs (HSI 2002). At all sites programs gained strong community support and saw improved attitudes toward animal welfare.

Field experiences also demonstrate the importance of transportation of dogs to clinic sites and mobile clinics. Experiences in Abaco, Jaipur, and other settings suggest that people who are responsible for dogs are often unwilling or unable to bring their animals to a location that is any distance from their home. Rabies vaccination campaign surveys have found that the proportion of vaccinated dogs

diminishes as the distance from vaccination points increases (Matter et al. 2000). Owner inability to handle animals is another obstacle to participation in clinics that could be ameliorated through transportation of dogs (Matter et al. 2000). To reach the maximum number of dogs possible, dogs must be brought to clinics for spay-and-neuter procedures, or the clinics must be brought to the dogs.

Attitudinal surveys conducted around CNR and vaccination programs reveal some of the obstacles to convincing owners to seek care for their dogs. Overall, residents are supportive of spay-and-neuter programs because they want to avoid the animals' having litters (HSI 2001). However, in Abaco, for example, some owners did not have their dogs neutered because of the young age of the dog, they had missed a previous clinic, or they did not want to sterilize male or purebred dogs (HSI 2001; Fielding, Samuels, and Mather 2002). Older owners are more likely than are younger ones to have their dogs spayed (Fielding, Samuels, and Mather 2002). Owners often let females have one litter before spaying (Fielding and Plumridge 2005). In Africa the desire for more guard dogs may outweigh concerns about overpopulation.

Owned dogs clearly play an important role in maintaining or increasing population levels of free-roaming dogs. Study after study has found that ownerless dogs who do not depend on humans have low reproductive rates and cannot maintain their population levels without new recruits. New recruit dogs come from the owned population whose members are allowed to roam freely and are not sterilized. Door-to-door canvassing and other strategies to incorporate owned dogs are central to the overall success of CNR.

CNR success in Abaco, Bali, Sri Lanka, and the Galapagos has been enhanced by their island locations. At these more isolated sites, risks of migration or introduction of infected or unsterilized dogs were minimal. In contrast, the size of Thailand and India and territorial borders make the integration of new dogs more likely to occur and harder to manage. The failure of recent CNR programs in Thailand makes clear this threat to maintaining both vaccination and sterilization thresholds. As Thailand studies of the distribution of different rabies virus strains confirm, dog populations move with human populations. CNR programs need to address these population shifts of humans and dogs to maintain stable dog populations and to achieve ongoing population reductions. "Immunization belts" and "sterilization belts" at borders of CNR program areas, as well as revaccination campaigns, are important to maintain population stabilization and vaccination coverage. Another threat to CNR progress in Thailand and elsewhere is the continued capturing and/or killing of dogs, which further encourages movement and increased breeding among the remaining intact animals.

Researchers have greeted sterilization programs in general and CNR programs in particular with some initial skepticism. While most experts agree that control of reproduction may help in rabies prevention and with other problems associated with free-roaming dogs, some do not believe these programs are sustainable, affordable, or sufficient (WHO 1989; Wilde, Khawplod, and Khamoltham 2005).

Many of the concerns over the cost and ability of CNR to reach sufficient numbers of dogs could be addressed with the availability of an antifertility vaccine (Leney and Remfry 2000; Wheir, Dunbar, and Prasad 2005). Immunocontraceptive vaccines provide a possible fertility-control approach for many species of animals, although an immunosterilant would be much more useful. Immunocontraceptives need to be administered annually or every two years, which presents a major logistical problem in developing countries. Although some have suggested that the PZP immunocontraceptive could lead to sterilization of dogs (Fayrer-Hosken, Dookwah, and Brandon 2000), the data are not strong, and no one has shown conclusively that PZP is effective in any canid even as an immunocontraceptive.

The difficulty of monitoring dogs after surgery in a field setting is yet another concern. WSPA traditionally only favors CNR as a short-term strategy when dogs can be monitored for health and welfare, the environment can support free-roaming dogs, and government and public support guarantees animal safety (Leney 2002; WSPA 2006). In her research on gonadectomy, Howe (1997) found greater risks after sterilization the shorter the postsurgical holding period in U.S. shelters. CNR programs vary in the amount of time they keep dogs before and after procedures. In Jaipur dogs usually spend the night at the clinic before surgery and are generally not released until three to five days after the operation (Nolan 2006). In Abaco, Bali, Sri Lanka, and the Galapagos, surgery was performed immediately, and the dogs were returned to their territories after relatively short (same-day) recovery times. In addition to logistical, resource, and medical concerns, postsurgical release time has competing animal welfare implications (Nolan 2006). On the one hand, keeping dogs longer can avoid postoperation complications. On the other hand, returning dogs sooner reduces stress to the animals and permits sterilization of more animals.

Another obstacle to CNR and dog-vaccination programs has been the lack of a single governmental department to claim responsibility and adequate resources for these programs (WHO

1996; Reece 2005). In most countries successful programs need the collaboration of veterinary, health, and sanitation departments as well as animal welfare nongovernmental organizations (NGOs) (WHO 2001; Help in Suffering 2003). Political commitment also must be sustained for effective and enduring rabies control (PAHO and WHO 2005). While government support has varied across CNR programs, Thailand is the only country in which CNR has been a government-run activity.

Puppies have the greatest risk of contracting and transmitting rabies. The mortality of puppies also contributes to high population turnover. Most vaccination and CNR programs, however, exclude puppies under three months of age. In Jaipur younger puppies are not included in CNR because of belief that they should not be separated from adults and that the capture and procedure would be too stressful (Nolan 2006). While scientific literature suggests that prepubertal gonadectomy is a safe procedure with no increased incidence of complications, health, or behavioral problems in developed countries (Howe et al. 2001), concern also has been expressed about neutering puppies under eight weeks of age outside a well-equipped clinic (Leney and Remfry 2000) and before their immune systems have matured (Cardwell 1993). Modification of CNR programs to include on-site vaccination of puppies could promote rabies prevention and dog health. Sterilization of puppies in field settings in which some supervision is available also might be a viable strategy. Because of differences in dog ownership patterns in developing countries, adoption of street puppies has not been a part of CNR (as is adoption of feral kittens in TNR programs).

CNR programs show great promise as a strategy to decrease public health risks and improve animal welfare. The ability of rabies vaccination campaigns to reach up to 90 percent of dogs, and their success in achieving sterilization rates of 51–85 percent with CNR, demonstrates the viability of the CNR approach. Because of different dog ownership patterns in developing countries, private, low-cost, and no-cost sterilization programs will never reach enough dogs to achieve population stabilization or reductions. CNR addresses the reluctance of owners to take dogs for treatment and the fact that community dogs often are not affiliated with individuals who take responsibility for their veterinary care.

CNR also addresses the primary limitation of mass vaccination campaigns: high population turnover. The combination of vaccination, sterilization, and return of dogs to their territories appears to enhance the health, longevity, and stability of dog populations, reducing movement and breeding of unsterilized and unvaccinated dogs. Lower dog population levels decrease the risk of rabies, echinococcosis, and toxocariasis. In the case of free-roaming dogs, animal welfare and human health are closely linked. Ultimately, problems with free-roaming dogs cannot be separated from human population growth, urbanization, and increased waste.

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