Scat counts

For some species, the faeces (scats) are more conspicuous than the animal itself, and provide a good method of detecting their presence or absence (Sutherland 1996). Scats may also be used to monitor carnivore populations, with two main approaches to estimating abundance: calculating the standing crop or total amount of scats in a given area, or determining the rate of accumulation of scats in fixed sample plots that are regularly cleared (Putman 1984).

Calculating the standing crop is most likely beyond the resources of most studies (Wilson & Delahy 2001; Saunders & McLeod 2007), but measurement of the rates of faecal accumulation has been used successfully in nationwide fox surveys in Great Britain (Baker *et al*. 2002; Sadlier *et al*. 2004). It has also been used in North America, where it has been found to be reliably correlated with coyote (*Canis latrans*) and swift fox (*Vulpes velox*) abundance (Andelt & Andelt 1984; Schauster *et al*. 2002). The use of scat counts has not been widely used in Australia, although a variation on the technique, using free-feed attractants to encourage scat deposition, was found to have potential for reliable measurement of the abundance of relatively stable fox populations (Sharp *et al*. 2001). However, this index performed poorly when there was a rapid turnover of individuals within the population.

There are numerous factors associated with scat counts that can confound their use as a monitoring technique: defecation rates vary with diet and according to the age structure of the population; diet can vary opportunistically with plagues of mice or locust, and seasonal food items such as blackberries. The persistence of scats varies with diet and weather conditions. The distribution and accumulation of scats change as a result of seasonal variations in scent-marking behaviour, and the removal of scats may influence subsequent defecation rates. The identification of scat by species is prone to error; observer skills can vary, and scats can be destroyed by other human and animal activity (Wilson & Delahy 2001; Davison *et al*. 2002; Sadlier *et al*. 2004).

Experimentation can be used to address some of these potential sources of error, but this is again beyond the resources of most studies (Wilson & Delahy 2001; Sadlier *et al*. 2004). The reliance on various conversion factors for estimating density has led to recommendations that scat counts are best suited to providing indexes of relative abundance (Cavallini 1994; Wilson & Delahy 2001). This technique is not suited to monitoring short-term changes such as pre or post-control programs, because of the confounding factors mentioned above, and it is probably most appropriate for long-term studies such as those conducted in Great Britain (Sharp *et al*. 2001; Saunders & McLeod 2007).

Determining indexes from scat deposition and accumulation rates involves walking a transect to initially clear it of any scats, and then walking the transect again after a given time (e.g. 2–6 weeks) and counting the number of scats deposited. Transects are most often fire trails or tracks, as foxes and wild dogs use them for movement and territorial marking, and they also provide easily accessed monitoring sites (Triggs 1996; Corbett 2001). Scats are often found in prominent positions on, or next to, roads, such as on grass tussocks, in or under conspicuous plants, or on novel items, such as discarded mud-flaps from vehicles.

Passive scat count

Materials required

Count sheet

Gloves

Collection bags – paper bags if scats are to be used for dietary or DNA analysis

GPS

Disinfectant, water and hand towels

How to do the count

- Select sites to be monitored and record location on map using GPS.
- Walk the transect and remove all fox scats, place scats in individual paper bags and record the location with a GPS if scats are to be used for dietary or DNA analysis.
- Repeat the walked transect within 2–6 weeks, and count the number of fresh fox scats.
- Calculate scat density (S) for each period as:
  $S = C \div LD$

  where C = number of scats counted on the second visit; L = transect length in km; and D = number of days between visits.

Repeat the count every season or at the same time each year.

To calculate the number of animals in each transect, it is necessary to estimate defecation rates and detection probability (Sadlier *et al*. 2004)

Standards

Route – use the same transect for each count.

Sampling time – conduct survey at the same time of year.

Training required

Identification of scats: dog, fox, cat and quoll scats can be mistaken for each other (see Triggs 1996).

Use of GPS

Worked example

Scats were collected from a national park annually to monitor the effect of baiting on fox abundance. There were 10 transects with a total length of 63 km.

Year 1
Scats collected: 136
Days between visits: 20
$S = 136 \div (63 \times 20) = 0.108$

Year 2
Scats collected: 122
Days between visits: 23
$S = 122 \div (63 \times 23) = 0.084$

Year 3
Scats collected: 109
Days between visits: 27
$S = 109 \div (63 \times 17) = 0.064$

These data and future data could be plotted on a graph to map any trends in abundance. To make statistical comparisons, data need to be statistically analysed using a logarithmic transformation (Sadlier *et al*. 2004).

Active scat count

Materials required

As above

In addition, bait material such as kangaroo meat

How to do the count

- Select sites to be monitored, and record location on map using GPS.
- Set up bait stations: dig a small hole for bait, about 10 cm deep, place the bait and cover with soil, and mark with a stake or flagging tape.
- Separate bait stations by 500 m and place on alternate sides of the road.
- Create a unique name for each station and mark individual bait station positions on a GPS.
- Change the bait in bait stations every 14 days.
- Before baiting, count the fox scats in a 3 m radius of the bait station.
- Continue counts for three or more baitings, and remove unused bait material at the completion of the count.
- Calculate scat density (S) for each individual period as: $S = C \div LD$

  where C = number of scats counted on the second visit, L = transect length in km and D = number of days between visits.
- Recalculate the mean seasonal deposition to obtain a seasonal index.
- Repeat the count every season or at the same time each year.

Training required

Identification of scats: dog, fox, cat and quoll scats can be mistaken for each other (Triggs 1996).

Use of GPS

Den counts

The fox generally produces one litter per year, with an average surviving litter size of four cubs (Saunders *et al*. 1995). Consequently, counts of active breeding dens have been used to indicate fox density and are considered the only accurate method of determining this, provided that the size of family groups and social organisation is known (Trewhella *et al*. 1988; Sadlier *et al*. 2004). Assuming that the number of active breeding dens per unit area is a function of the number of adult animals in that area, indexes of abundance can be calculated.

As dens are usually only occupied for a limited time each year, surveys can be conducted annually. The most appropriate time to conduct surveys is early summer, when cubs become active and dens are most prominent (Saunders *et al*. 1995). Active dens can be identified by trampled grass, fox tracks, remains of fresh prey, scats, sightings, strong odour and freshly dug soil (Coman *et al*. 1991; Marks & Bloomfield 1999; Heydon *et al*. 2000). Systematic searches are needed to locate all dens within a study area, but help from the public, particularly in urban areas, can reduce the effort required (Saunders *et al*. 1995; Marks & Bloomfield 1999).

The accuracy of den counts can be affected by not locating all active dens, foxes moving cubs to new den sites, different litter sizes, high cub mortality, social groups other than monogamous pairing, and the presence of itinerant foxes. Den surveys usually take a long time and the technique is suitable only for small areas.

Materials required

GPS

Count sheets

How to do a den count

- Select site to be monitored.
- Determine the method to be used: systematic, randomly selected grid such as 1 × 1 km squares within 5 × 5 km squares, or transect counts.
- Count all dens located within study site and categorise as active or not active.
- Record the locations of all dens found, using a GPS.
- Determine the independence of adjacent dens by counting the number of cubs seen at each den after consecutive surveys during the same evening. More than three cubs at each den equates to independence.
- Estimate the density:
  $D = O \times F \div A$

  where D = density estimate; O = observed number of active dens; F = estimated number of adults per den (may be assumed as 2, but this can be confirmed by individual den observation); A = area of study site (km^2)
- If a complete count of the study area is not possible, use two counts with different observers and use the following formula (Magnusson *et al*. 1978) to estimate the number of dens in the study site, and then estimate the density of foxes as above:
  $N = (S_1 + B + 1) \times (S_2 + B + 1) \div (B + 1) - 1$

  where N = estimate of the total number of dens in the study area; S_1 = number of dens found by first observer but not the second observer; S_2 = number of dens found by second observer but not the first observer; B = number of dens found by both observers

Standards

Observers – use the same observers for each count.

Timing – perform counts during the breeding season from July–October each year.

Training required

Some training may be required to identify active dens

Use of GPS

Worked example

The first observer locates 14 active dens and the second observer locates 19 dens, 11 of which were found by the first observer. The study area is 3000 ha.

$S_1 = 3\ (14 - 11),\ S_2 = 8\ (19 - 11),\ B = 11$

therefore, $N = (3 + 11 + 1) \times (8 + 11 + 1) \div (11 + 1) - 1$

$N = 24$

The standard error (S.E.) can be calculated from the variance (Var):

$Var = [S_1 S_2 (S_1 + B + 1) \times (S_2 + B + 1)] \div [(B + 1)^2 \times (B + 1)]$

$S.E. = \sqrt{Var}$

therefore, $Var = 3.85,\ S.E. = 1.96$

Therefore, the estimated number of active dens in the study area is 24 (S.E. = 1.96).

The study area is 3000 ha (30 km^2) and there are 24 dens in this area. To obtain the number of dens per square kilometre, divide the number of dens by the area, and then multiply by the number of foxes per den to calculate the fox density.

fox density = number of dens $\times$ number of foxes per den $\div$ area (km^2)
$= 24 \times 2 \div 30$
$= 1.6$

Assuming two adults per den, the density estimate is 1.6 foxes km^2.

Capture–recapture: trapping and telemetry

Capture–recapture methods are based on multiple sampling, and use repeated capture or sightings of marked or tagged individuals to estimate population size. Animals in the first sample are marked uniquely and then released back into the population.

A second sample is captured from the same population. That sample should contain marked and unmarked animals; these are marked and released, and so on, until the monitoring has finished. The resultant capture history is used to produce an estimate of the population. Various capture–recapture methods are available for both closed or self replacing populations and open populations where immigration replaces foxes lost to control programs. These methods have been reviewed in detail elsewhere (Seber 1982; Pollock *et al*. 1990; Schwarz & Seber 1999; Buckland *et al*. 2000). All these methods make assumptions that should be satisfied in order to produce valid estimates. Assumptions common to all mark–recapture models (Southwood 1989; Krebs 1999) are that:

1. all animals have equal catchability. Marked animals at any given sampling time have the same chances of capture as unmarked animals
2. marked animals are not affected in behaviour or life expectancy by being marked
3. marks are not lost or overlooked, and all previously marked animals can be distinguished from unmarked animals.

The most common monitoring techniques that utilise capture–recapture methodology are trapping and radio-telemetry. Trapping of canids in Australia has long been used as a control measure, and has been useful to capture animals for research (Saunders *et al*. 1995; Fleming *et al*. 2001). Successful and humane trapping requires extensive training and experience. Trapping by inexperienced operators may cause pain and suffering. Consequently, the wily fox, wary at the best of times, learns to avoid the disturbance associated with traps, and these animals are classified as 'trap-shy'. Toothed or steel-jawed traps, traditionally used by trappers in Australia, are not as efficient as padded leg-hold traps and treadle snares at capturing and holding foxes. To reduce foot injuries sustained by both the fox and non-target animals, padded jaw or cage traps are mandatory for research (Fleming *et al*. 2001).

Capture efficiency (CE) of traps varies with trap type, and Fleming *et al*. (1998), in a review of trap performance for wild dogs and foxes, found CE ranges from 1.56 to 2.45 trapped target animals/100 trap nights. Padded Lane's and Soft-Catch® traps were the most efficient, followed by toothed Lane's and then treadle snares (Fleming *et al*. 1998). This range is equivalent to 41–64 trap nights per target animal, but capture rates for foxes can involve up to 150 trap nights per animal (Meek & Saunders 2000; Kay *et al*. 2000). Soft-Catch traps are more commonly used, as they are generally more efficient than treadle snares (Bubela *et al*. 1998). They are also more compact and pack conveniently for transport. Cage traps can also be used to capture foxes (Baker *et al*. 2001), but they have low success rates in locations other than urban areas, where foxes may be less suspicious, and their use is limited (G. Saunders pers. comm.). Trapping is time-consuming and labour-intensive, and is therefore suited only to small areas.

Trapping alone can be used as an index of abundance, by comparing trapping events via catch per unit of trapping effort. It can also be used in capture–recapture studies and combined with radio-telemetry. This involves trapping the fox as discussed above, but instead of being removed these animals are tagged with an ear tag or radio-collar, and released at the point of capture after measurements such as sex, weight, reproductive condition of females and age are taken. Subsequent sightings, such as spotlight counts, can be used to gain recaptures and population estimates. The movements of collared animals are measured by signals received by hand-held directional antennae and portable scanner/receivers. Alternatively, fixed receiver stations or immobile towers with greater range than hand-held receivers can be used to determine animal locations. Radio-telemetry is useful for home-range estimation and habitat use.

Trapping

Materials required

Traps – approved soft-jaw traps suitable for catching foxes must be used, such as Victor Soft-Catch® trap #1½ or #3. Treadle snares and Ecotraps® may also be used. Cage traps are suitable for urban areas, where they are not such a novel item and foxes may not be as trap-shy.

Lures (or decoys) – a mixture of fox faeces and urine or a commercially prepared synthetic fermented egg lure.

GPS

How to trap

- Service and maintain traps prior to conducting a trapping program.
- The locations of all trap sites must be accurately recorded. This information should be readily available to others, in case the trapper is unable to return to check the traps.
- Preferably set the traps at the end of each day and check them each morning. If traps are left set during the day they should be checked again in late afternoon.
- Do not place traps in areas where they may be damaged or stolen.
- Olfactory stimuli and commercially prepared lures, such as synthetic fermented egg, may be used to lure the fox into a trap. A handful of meat bait may be placed near or inside the trap. Rabbit, chicken, beef, lamb, and kangaroo have all been successfully used as bait. Attractiveness and palatability of the lures and bait will vary with season and location.
- Traps should be set where the fox is most likely to find and investigate an unfamiliar odour, such as scent pads, scratch points and carcasses.

Leg-hold traps and treadle snares:

- Traps should only be anchored to stakes or fixed objects if there is a shock-absorbing device (such as a spring) fitted to the anchor chain and a swivel attaching the chain to the trap. Use a short length of chain (about 50 cm). Alternatively, the trap could be tied to a solid piece of steel or small logs that move when the animal pulls against the trap – known as a 'drag'. A 'drag' reduces dislocation of joints and resultant injury.
- Prepare the hole in the ground, set the trap, tie to a drag and cover with fine soil and leaf litter. A piece of foam or sponge rubber under the trip plate prevents debris from blocking the action. Ensure that the surrounding shrubs or debris will not interfere with the spring mechanism.
- Camouflage the trap with leaves, grass or debris, but leave an area covered in fine soil,10–15 cm in diameter, over the trip plate.
- Place a lure on a slightly elevated clump of grass, a stick, or a rock behind the trap. The distance from the trip plate of the trap to the decoy is critical, and should be roughly equivalent to the distance between the fox's front feet and nose when leaning forward to smell. The bait can be covered with a light dusting of soil, to reduce foraging by crows and to mimic cached food.
- Treadle snares need to be checked at least every 4–8 hours, to prevent severe tissue damage and fractures.

Fox caught in cage trap

Cage traps:

- Where possible, place the traps parallel to objects such as fences, logs or sheds, with the rear of the cage against an obstruction, to prevent animals from taking the main bait without going into the trap. It may be useful to partly enclose cage traps in a large hessian bag, to prevent the animals from attempting to take the bait through the side or back of the trap. This also helps to reduce the visibility of bait to non-target species, such as raptors and corvids.
- Cage traps should be set squarely on the ground and the doors of the trap bent upward to increase the openness of the trap space.
- Cover the floor of the trap with soil.
- The trap should be pegged to the ground, to prevent the animal from tipping it over and injuring itself and/or releasing the trap door.
- Place meat baits inside the trap and lures in suitable positions inside and outside the trap. A handful of meat bait is placed at the rear of the cage.
- Most cage traps have a rear door, so it may be possible to bait the trap and open both doors so the fox can pass though a couple of days before setting the trap.
- Capture efficiency can be improved by using bait that reflects the staple prey of foxes in the area.
- Set traps at the end of each day and check early each morning. When traps are open during the day there is a greater risk of birds, such as magpies and currawongs, entering and triggering the trap.

Ecotrap®:

- Place the trap into position and peg to the ground, to prevent animals from moving it or tipping it over when trapped, and thus escaping.
- Ensure that surrounding shrubs or debris will not interfere with the spring mechanism. Set the trap.
- Place meat baits inside the trap behind the trip wires, and place lures in suitable positions inside and outside the trap. Capture efficiency can be improved by using bait that reflects the target animal's staple prey for the area, rather than being novel.
- These traps should be checked at regular intervals (at least every 4–8 hours) to reduce distress in entangled animals.

Training required

Trapping techniques

Animal handling

Firearms training

GPS

Fox fitted with radio transmitter collar

Radio-telemetry

Materials required

Suitable trapping equipment

Radio transmitters and receivers

GPS

Data sheets

How to do it

- Check that all transmitters and receivers are operating prior to trapping.
- Capture foxes, using standard operating procedures.
- Sedate foxes with an appropriate dosage of an intramuscular injection.
- Record physical condition, sex, weight, reproductive condition and approximate age.
- Clean capture injuries and treat with an antiseptic solution.
- Attach radio-collar with unique operating frequency around neck of fox.
- Record details of radio-collar frequency, and double check that transmitter is functioning correctly.
- Allow the animal to recover from anaesthetic, and release at point of capture.
- Start tracking after several days, to allow animals to become accustomed to the radio-collars and exhibit normal behaviour.

Walked radio-tracking:

- Locate radio-collared animals by following the transmitted signal's increasing strength.
- Track signal as close as possible while causing minimal disturbance to the behaviour of the animal.
- Once located, record the animals' position using a GPS.
- Record time, habitat and animal behaviour.
- Obtain radio fixes every hour for duration of tracking session.

Vehicle radio-tracking:

- Use antenna attached to vehicle roof.
- Locate radio-collared animals by scanning appropriate radio frequencies while driving on roads in study area.
- Once a radio signal is detected, use the relative strength of the signal to direct the vehicle to the animal.
- Once located, track the animal on foot.

Radio telemetry receiver with antenna in the background

Fixed-tower tracking:

- Establish two (or more) fixed-location radio-tracking towers in elevated positions approximately 3–4 km apart.
- Take radio fixes every 15 minutes during a tracking session, assess 24-hour movements over two or three days.
- Use triangulation to determine target animal position (White & Garrott 1990; Kenward 2001)

Training required

Trapping techniques

Animal handling

Firearms training

Use of radio-telemetry equipment and software training for determining home range

Global Positioning Systems (GPS) telemetry

A further development of telemetry techniques is the utilisation of satellites and GPS to monitor the movement of appropriately collared animals. GPS telemetry utilises GPS receivers (attached to animals like foxes) and signals received from satellites to determine the animals' location. There are two main methods of data storage and retrieval, onboard data storage and remote downloading to a receiver (Mech & Barber 2002). Onboard data storage relies on the retrieval of the collar and the downloading of the data to a receiver. Retrieval is normally by recapture of the collared animal or triggering an automatic or remote drop-off mechanism to release the collar; the GPS unit is then located by Very High Frequency (VHF) receiver. Remote-downloading GPS units utilise VHF signals to send data to a portable receiver. The receiver must be within VHF receiving range of 5–10 km ground-to-ground or 15–20 km air-to-ground, allowing data to be retrieved daily, and minimising data loss.

The weight of GPS collars make their use with foxes prohibitive, as, in general, collars weighing more than about 3% of body mass tend to have adverse effects on the target species (Kenward 2001). The smallest GPS collar at present weighs about 300 g (K. Lay, Sirtrack, pers. comm.), and thus would probably alter the behaviour and foraging ability of the average fox with live weight of about 5 kg. However, GPS telemetry will become a valuable monitoring tool for foxes in the near future, as technological advances will allow ever-lighter collars to be produced.

Meat bait radio transmitter

Fox being fitted with portable transmitter (radio collar)

The accuracy of GPS telemetry may suffer from interference from habitat and topography, such as canopy cover, which may impede satellite signals. Frequent movement in steep terrain by collared animals may influence positional error (Di Orio *et al*. 2003). When evaluating the performance of GPS collars in different habitat types in California, Di Orio *et al*. (2003) found that almost 90% of fixes were within 25 m of the true location, but noted that as canopy cover and density increased the corresponding positional error also increased. GPS collar testing and monitoring of moose (*Alces alces*) movements in North America have similarly found that canopy cover influences the proportion of successful locations, and that this may introduce bias into habitat-use studies with more successful locations when the animal is in open habitat (Moen *et al*. 1996; Dussault *et al*. 1999; D'Eon *et al*. 2002). In spite of these disadvantages, GPS telemetry is the most accurate currently available method of tracking animals.

The great advantages of GPS telemetry are low fieldwork requirements, a high number of locations per animal, the ability to be used in all weather conditions and little disturbance of the target species. Animals need only to be captured to attach the collar and recaptured to retrieve the transmitter, with no other fieldwork required. Disadvantages include the high cost of GPS collars. The lifespans of GPS collars are low when compared with those of VHF systems, but this is determined by the sample rate used, such as constant surveilance, every hour or every 12 hours.

Genetic sampling

Sampling the DNA of animals may help overcome some of the limitations of traditional monitoring techniques by providing accurate identification of samples of the species and individual level (Piggott & Taylor 2003). DNA collection can be invasive (using blood and tissue samples) or non-invasive (with faecal and hair samples) with the latter samples being much simpler to collect, as the target species (such as the fox) does not need to be handled or observed. This type of sampling may be used for population and home range estimation, and may yield the sex ratio and source of populations.

The development of extraction methods for DNA contained in faeces and hair offers the most appealing opportunities for more precise population estimates, through the derivation of genetic profiles of individual animals (Kohn & Wayne 1997; Piggott & Taylor 2003). Coyote (*Canis latrans*) abundance has been estimated using a large sample of presumed coyote scats (651) collected from roads; these scats were positively identified from diagnostic sections of mitochondrial DNA (Kohn *et al*. 1999). The scats were genotyped to determine individual animals, and the cumulative number of unique microsatellites was expressed as a proportion of the number of scats sampled. The asymptote of this curve was determined as an estimate of local population size.

Capture–recapture models may be used with this type of data. A population of endangered wolverines (*Gulo gulo*) in Norway was monitored using scats as a source of DNA to estimate population size, sex ratio, immigration rate and reproductive contribution from immigrants (Flagstad *et al*. 2004). Scats that were successfully analysed were treated as one trapping event, and the number of trapping events was recorded.

Hair sampling has been used to estimate the size of grizzly bear, *Ursus arctos* populations (Mowat & Strobeck 2000; Poole *et al*. 2001). Bears were sampled by capturing hair at bait sites surrounded by a single strand of barbed wire, and using microsatellite profiling of the root portion of the hair to identify individuals. Subsequent sampling provided recaptures.

Other types of monitoring tools that can be used with DNA population studies are catch per unit effort (Romain-Bondi *et al*. 2004) and presence/absence studies.

Molecular scatology can be used to correct scat counts by accurately identifying scats to species. In North American scat surveys, correct assignment to species occurs in only 50–66% of cases (Halfpenny & Biesot 1986). In Great Britain, surveys of the endangered pine marten (*Martes martes*) have relied on morphological identification of scats in the field by expert naturalists, who have since been found to fail to reliably distinguish pine marten scats from those of red foxes (Davison *et al*. 2002). In Australia, all of the larger mammalian carnivorous species (wild dogs, foxes, cats and quolls) produce scats that could potentially be mistakenly identified by morphology.

One of the main limitations of DNA sampling is the high cost of extraction from scats and hairs owing to the low quantity and quality of the DNA typically recovered from these types of sample (Harrison *et al*. 2002; Davison *et al*. 2002; Piggott & Taylor 2003). DNA degrades over time, so fresh samples are required and must be stored correctly. Storage methods are rapid-freezing at −20 °C, dehydration by air-drying or alcohol treatment, or saturation in a buffer containing high concentrations of salts or other chemicals that interfere with enzymes (Foran *et al*. 1997; Kohn *et al*. 1999; Piggott & Taylor 2003). Piggot & Taylor (2003) investigated faecal preservation and DNA extraction methods for mammals found in Australia, and developed a protocol that was found to be optimal for five different species, including the fox. This method involved air-drying the fresh scats in paper bags (ideal for field collection) followed by a surface wash to collect cells for the DNA extraction process. There is also an inherent error rate in the process of DNA amplification using polymerase chain reaction (PCR), which may lead to misleading results, such as population overestimation (Wilson & Delahy 2001; Piggott 2004). Scats less than a week old will give the most accurate results, and this needs to be taken into consideration when planning a monitoring program. It has been recommended that a minimum of three PCR replicates be used for genotyping fox scats in summer and eight replicates for winter samples (Piggott 2004). These methods, when used for population estimation, rely on assumptions such as defecation rates being equal among sexes and age classes, and independent of social class, and that capture recapture assumptions are not violated (Kohn *et al*. 1999; Mowat & Strobeck 2000).

In spite of these problems, DNA sampling can be an effective and efficient way of monitoring a species that is difficult to observe, exists at low densities, and has large home ranges (Piggott & Taylor 2003). Collecting scats is a relatively easy way to obtain DNA samples, with the additional benefit of dietary information. Hair samples could be easy to obtain by using lures, such as synthetic fermented egg (FSE), to attract foxes (Saunders & Harris 2000). FSE has been shown to elicit a scent-marking behavioural response in foxes, they by rubb or roll themselves on the source of the odour (G. Saunders pers. comm.). Simple hair snares (such as carpet squares with protruding nails to snag hairs), with an appropriate attractant sprayed onto them, can be attached to trees, and have been used successfully to monitor lynx (*Lynx canadensis*) populations (McDaniel *et al*. 2000). This is effectively a variation of a scent station, where, instead of footprints, hair is left behind to indicate a visit. The advantage of this technique over traditional scent stations is that the DNA sampling can give a population estimation.

Remote photography

Remote camera trapping involves the use of one or more cameras, set up to be triggered by an animal tripping a line, passing through an infrared beam, activating pressure-sensitive plates, or motion or heat sensors (Gese 2001). The technique has mostly been used to identify predators at bait stations or nests, examine feeding ecology, and detect the presence of a species (Foresman & Pearson 1998; Cutler & Swann 1999; Gese 2001). The use of sand pad and bait stations relies on the tracks left behind by visiting species to determine bait uptake. Remote camera traps can be used to accurately monitor the identity of the species taking the bait, thus reducing misinterpretation of the results when more than one species has visited a bait station or tracks have been destroyed by weather (Belcher 1998; Glen & Dickman 2003a). In recent times, remote camera traps have been used to estimate target species abundance via mark and recapture methodology. Again they have proved useful in studying species that are secretive or aggressive and difficult to observe such as tigers (*Panthera tigris*) and grizzly bears (*Ursos arctos*) (Minta & Mangel 1989; Karanth 1995; Karanth & Nichols 1998; Gese 2001). The unique stripe patterns of tigers have been used to distinguish between individuals. Population sizes and densities have been estimated from photographs taken by remote cameras set up on transects (Karanth 1995; Karanth & Nichols 1998). Alternatively, artificial tags (used in traditional mark or recapture studies) or radio-collars could be utilised to identify individuals. However, the assumptions of this method can be violated if there are difficulties in distinguishing all previously marked animals from unmarked animals.

The advantages of remote camera trapping include the facts that it is less invasive, less time consuming, and cheaper than long-term direct observation of animals, and it is ideally suited to studying animals that are difficult to observe due to cryptic or aggressive behaviour (Cutler & Swann 1999; Wilson & Delahy 2001). Observer bias and associated problems may be limited by this technique, thus improving monitoring efforts (Gese 2001; Glen & Dickman 2003a). However, the equipment involved with remote photography can be expensive, although simple units can be inexpensive (Glen & Dickman 2003a) – but vulnerable to theft and damage (Wilson & Delahy 2001). Remotely operated digital cameras require regular maintenance and technical expertise in order to repair malfunctioning trigger systems, (Cutler & Swann 1999). Care must be taken to avoid leaving scent on the equipment, as this may repel target animals (Wilson & Delahy 2001). There are problems with non-target animals triggering cameras. Other factors that may affect population estimates are unequal capture probabilities of different age and sex classes, length of monitoring period, and the number and spacing of the cameras (Karanth 1995; Jacobson *et al*. 1997; Koerth *et al*. 1997; Cutler & Swann 1999).

Remote photography may be useful for accurately determining bait-take. This may be valuable in areas where there is concern over effects on non-target species, such as quolls, in poison control programs. Detecting the presence of foxes may be more cost-effectively undertaken with other methods, such as track and scat counts.

MONITORING FOX IMPACTS

This section discusses the different methods that can be used to monitor the impact caused by foxes. The summary tables at the end of this handbook summarise these methods and compare them with the methods of monitoring fox abundance discussed in the previous section.

Monitoring economic costs

Costs of control

The cost and/or effort involved with annual fox control can be used as a surrogate for estimating trends in fox abundance. The average costs of fox control using 1080 have been calculated for a 2000 ha property, assuming baiting by one person using a 4WD diesel utility and 60 bait mounds (Saunders *et al*. 1997). The cost of regional fox control strategies can be similarly monitored using the quantity of bait dispensed.

Example of costs of ground baiting

Miscellaneous costs, such as travelling to the appropriate authority to collect baits, telephone calls to notify neighbours, have not been included (adapted from Saunders *et al*. 1997 with 2006 costings).

LABOUR	
Time taken to lay 60 baits	8 h
Time taken to check and replace bait line	5 h × 7 days
Total	43 h
Labour cost ($12.60/h + 15% on-costs)	$623.07
VEHICLE	
Average of 33 km per trip to lay and check baits	264 km
Total cost @ $0.798/km	$210.67
MATERIALS	
81 Foxoff Econobait® baits used @ $33.90/tray of 30	$101.70
10 × 1080 warning signs @ $2.20 each	$22.00
Total cost	$123.70
AVERAGE TOTAL COST PER PROGRAM	**$957.44**
COST/ha (ONCE/YEAR BAITING)	**$0.48**

Other costs

It is difficult to accurately estimate the agricultural costs attributable to foxes in Australia on a national, state or regional level (Bomford & Hart 2002). Conservative estimates of the annual cost of foxes have been put at a monetary value of $227.5 million (McLeod 2004). However, this value is based on information extrapolated from sources such as government agency estimates and landholder surveys and has been acknowledged that there are many gaps in the knowledge (Bomford & Hart 2002; McLeod 2004). Individual landholders may play a significant role in filling these gaps, by calculating

The result of fox predation on lambs

Dead lamb fitted with radio collar

and monitoring all the costs attributable to foxes. These costs include control expenditure, and others such as shooting or trapping; checking, moving and sheltering ewes during lambing; lamb, poultry and goat losses; and installation and maintenance of fencing The inference made from monitoring costs is that a decline in costs is associated with a decline in fox abundance.

Table 9. Example of a sheet used to monitor other costs

ACTIVITY	LABOUR ......h @ $ h^{-1}	MATERIAL	COST $
Shooting		Vehicle @ $ km^{-1} Ammunition Firearm maintenance	
Trapping		Vehicle @ $ km^{-1} Trap maintenance Ammunition Firearm maintenance	
Exclusion fence maintenance		Posts Wire	
Ewe/lamb protection			
Lamb losses		Ewe scanning @ $ ewe^{-1}	

Monitoring lamb predation

There are two main approaches to determining the impact of fox predation on lambs: surveys or reports from landholders across a regional scale, or experimental studies comparing areas with and without predator control. Surveys and reports suffer from problems such as inaccurate estimates, variable response rates, and variations in recognition of predation. Overestimation may be caused by the classing of some lamb carcasses as fox kills and assuming that missing lambs have been killed by foxes, when they could die from a range of unrelated causes (Moberly *et al*. 2003). As a result, landholder surveys may not give objective indications of areas with predation problems and trends over time.

Most studies have inferred lamb predation after the examination of carcasses and the occurrence of lambs in fox diet (e.g. Rowley 1970; Jordan & Le Feuvre 1989; Lugton 1993). In some situations it is difficult to find carcasses, despite significant predation (Lugton 1987). Scanning of ewes to determine the maximum reproductive potential of the flock, combined with an evaluation of all causes of lamb loss, such as mismothering, disease and other predators, would be needed to accurately determine the full extent of fox predation (Saunders *et al*. 1995). Alternatively, comparing pastoral areas that have had predator management with those that have not, over a number of years, would provide a more accurate measure of lamb losses. This is difficult to achieve, as few

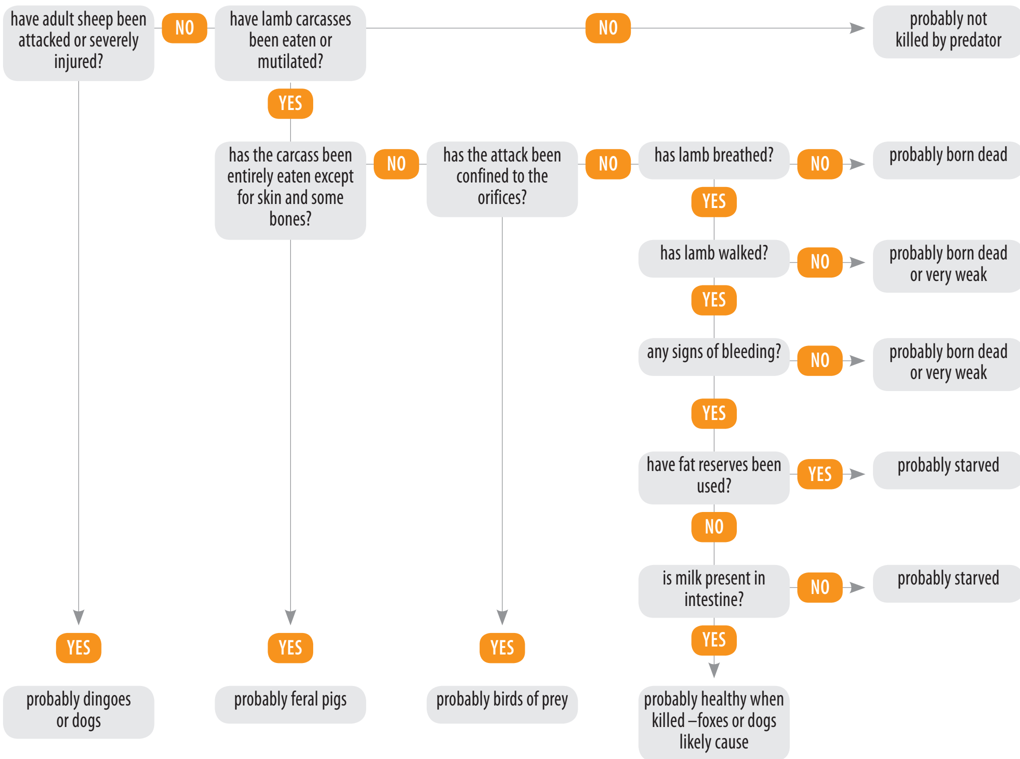

Figure 3. A decision tree for determining the causes of lamb death (WA Department of Agriculture 2001)

landholders would be prepared to leave productive areas of properties free of fox control. However, there have been two experimental evaluations of lamb predation by foxes (Mann 1968; Greentree *et al*. 2000). These studies both concluded that fox control or exclusion had little effect of on lamb production. These two methods are most likely beyond the resources of most landholders, making it difficult to determine, on economic grounds, the feasibility of undertaking fox control (Saunders *et al*. 1995).

Vulnerable prey – Yellow-footed rock wallaby

Monitoring vulnerable prey species

The impact of fox predation on threatened or vulnerable native species can be estimated by monitoring the populations of these species. Their population densities could be monitored before extensive control plans have reduced the density of foxes. However, this has rarely been adequately attempted (Meek & Kirwood 2003), although recent threat abatement plans for foxes and feral cats have incorporated this type of monitoring into proposed management plans (NPWS 2001; DEC 2004). Kinnear *et al*. (2002) showed that 11 medium-sized species responded to fox control by first increasing population size and then expanding distribution. Twenty-six years of mammal monitoring in south-western Australian forests has shown that native mammal abundance is related to the level of effort expended to control foxes (Burrows & Christensen 2002). Techniques for monitoring vary with species and habitat, and are thus situation specific. A combination of trapping and dung counts was used to monitor the response of black-footed rock wallabies (*Petrogale lateralis*) to fox control in south-western Australia (Kinnear *et al*. 1988; Kinnear *et al*. 1998). The apparent decline of fox densities in the vicinity of rock wallaby colonies led to population increases. However, some wallaby colonies also increased in the presence of unmanaged fox populations (Kinnear *et al*. 1988), leading to cautions over the interpretation of these results (Hone 1999). Other monitoring of vulnerable prey species has included radio-tracking and counts of active nests of mallee fowl (*Leipoa ocellata*) (Priddell and Wheeler 1995; Priddell & Wheeler 1997) and track counts and small mammal trapping, to compare native faunal species abundance between areas with high and low fox density (Catling & Burt 1994; Catling & Burt 1997a).

It is often necessary to implement integrated management to ensure that the outcomes of conservation management projects are realised and that focusing on one aspect does not lead to increases in other pressures.

In situations where foxes are being controlled for native species protection, it is important that other feral predators, such as wild dogs and cats, be simultaneously controlled, as they may replace the fox as a threat to some native species (Burbidge & McKenzie 1989). There is also the possibility that the density of cat populations may increase in the absence of foxes, with some evidence for interference competition between these two predators (Molsher 1999) and increases in cat density after fox removal (Short *et al*. 1994). Furthermore, feral cat predation on small mammals has been observed to increase when fox numbers are reduced (Risbey *et al*. 2000). Control of feral competitors of the species targeted for protection may also be necessary in conjunction with predator control. For example, in NSW the endangered mallee fowl has shown little recovery after predator control (Priddell 1991), with competition for food with rabbits a likely cause (Frith 1962).

Mapping fox damage and population density

Mapping the distribution and density of fox predation occurrences over a given area, such as an individual property or region, facilitates the development and assessment of fox management plans (Saunders *et al*. 1995). Regular updating of these plans allows for the modification of existing management. These maps may be simple hand-drawn property maps, more detailed and accurate topographic maps or computerised maps generated with GIS software. The choice of map type will depend largely on the scale of the area involved, the cost, availability of the technique, and the extent of the fox problem (Saunders *et al*. 1995). These maps may include the locations of fox dens and poison baiting trails, to indicate gaps in the coverage of control programs; the locations of areas of rabbit infestation, which may indicate areas for fox control (the rabbit being the predominant prey of foxes); and refuge habitat and preferred habitat of endangered species. These may not necessarily overlap. These maps can be used as part of the overall property management plan, and to assess progress over the years. At a larger scale, the NSW Department of Primary Industries has surveyed NSW Rural Lands Protection Boards and NSW National Parks and Wildlife Rangers to develop state-wide maps of pest species distribution and abundance (West & Saunders 2003). These GIS-generated maps are regularly updated to determine changes in the population densities of these species (P. West pers. comm.).

The following information should be included on maps:

- scale and north
- name and location of property
- size of property
- property boundaries, permanent fences, gates, and roads
- topographic features, such as watercourses, hill contours, rock outcrops
- refuge habitat – vegetation other than pasture/crop, such as woodland or shrubland
- lambing paddocks
- fox abundance estimates and spotlight indices
- den locations
- areas of fox damage, with a scale of damage and number of lambs lost
- areas of rabbit infestation
- type of agricultural or other activities on this and adjoining properties.

SUMMARY OF FOX MONITORING TECHNIQUES

It is important to make new maps with each new assessment. In this way, new maps can be compared with the previous map to evaluate the current management.

The various fox abundance and impact monitoring techniques discussed in this manual, and their advantages and disadvantages, are listed in Table 10. Table 11 compares the different monitoring techniques.

Table 10. Advantages and disadvantages of the monitoring techniques discussed in this manual

MONITORING TECHNIQUE	ADVANTAGES	DISADVANTAGES
Spotlight counts	• quick and simple • inexpensive	• counts can be highly variable between observers • ability to see can be affected by height of pasture, vegetation or habitat type • unreliable method in wet and windy conditions • difficult to compare counts between variable weather conditions
Bait stations	• quick and simple • inexpensive – can be part of a control program • control of foxes at the same time (toxic baits) is quick and simple • target animal doesn't need to be sighted	• unreliable method in wet and windy conditions • may alter normal behaviour of target species • bait-shy animals undetected • road-based sampling may be not representative of area • potential for interference by travelling vehicles
Track counts	• can monitor several different species at the same time • quick and simple • target animal doesn't need to be sighted	• unreliable method in wet and windy conditions • unknown relationship to density • road-based sampling may not be representative of area • potential for interference by vehicles
Scat counts	• inexpensive • target animal doesn't need to be sighted • can be used in difficult terrain • sampling schedule flexible	• inappropriate for monitoring short-term changes • road-based sampling may not be representative of area • identification of scats prone to error • defecation rates will vary with season and diet
Den counts	• inexpensive • can fumigate dens at the same time	• may only be conducted once a year • foxes may move cubs • different litter sizes • different social group sizes • occurrence of itinerant foxes
Capture–recapture	• accurate estimate of abundance • other information, such as home range, may be collected at the same time	• expensive • labour intensive • time consuming • difficulty of capture
DNA sampling	• target animal doesn't need to be sighted • improved accuracy of scat counts • density estimates possible	• expensive • correct storage important • time consuming
GPS telemetry	• improved ability to monitor animals in rugged and remote terrain • reductions in travel and field work time	• expensive • difficulty of capture • accuracy of fixes can be variable

Table 10. Advantages and disadvantages of the monitoring techniques discussed in this manual (cont'd)

MONITORING TECHNIQUE	ADVANTAGES	DISADVANTAGES
Costs of control	• inexpensive if part of control program • can be incorporated into existing economical management	• unreliable if degree of effort or methodology changes • costs increase each year • need to account for inflation
Lamb predation	• increases awareness of potential predation problems	• difficulties in determining cause of lamb death • experimental studies are expensive
Remote photography	• accurate identification of species taking bait • allows interpretation when more than one species has visited a bait station or tracks have been destroyed by weather • less invasive, time consuming, and costly than long-term direct observation of animals	• vulnerable to human interference, theft and damage • regular maintenance and some technical expertise to repair component failure
Vulnerable prey species	• prey species may be easier to monitor than foxes	• difficulties in determining whether abundance is related to fox predation
Other cost monitoring	• inexpensive • can be incorporated into existing economical management	• assumed relationship with fox abundance

Table 11. Fox monitoring technique ranking table

	LABOUR	START-UP COST	EXPERTISE AND TRAINING	SPECIALISED EQUIPMENT	HUMANENESS	OH&S RISK	COMMENTS
Vehicle spotlight counts	Moderate	Moderate	Low	Low	High	High	OH&S risks can be decreased by all doing all spotlighting from within the vehicle using a roof mounted spotlight
Distance sampling	Moderate	Moderate	Moderate	Moderate	High	High	As above
Bait stations	Moderate	Low	Low	Low	Moderate	Low	
Track stations	Moderate	Moderate	Low	Low	High	Low	
Road counts	Moderate	Moderate	Low	Low	High	Low	
Passive scat count	High	Low	Low	Low	High	Low	
Active scat count	High	Low	Low	Low	High	Low	
Den counts	High	Low	Low	Low	High	Low	
Mark-recapture (trapping)	High	Moderate	High	Moderate	Low	Moderate	
Mark-recapture (radio-telemetry)	High	High	High	High	Moderate	Moderate	
DNA sampling	Moderate	High	Low	High	High	Low	
Satellite and GPS telemetry	High	High	High	High	Moderate	Moderate	
Remote photography	Low	High	Low	High	High	Low	

GLOSSARY

Allen index

The mean number of animal tracks per transect per day.

Angle board

Estimation of the sighting angle relative to the transect line can be accomplished using an angle board. By collecting and recording distance and angle measurements for each animal seen, perpendicular distance can be calculated.

Associative learning

Learning or conditioning that occurs when two different events occur or happen together, and are thus 'associated'.

Bait-station night

The number of bait stations multiplied by the number of nights of baiting.

Canid

Member of the Canidae family of carnivorous animals. Includes wolves, jackals, foxes, coyotes, domestic dogs and dingoes.

Catling index

The percentage of station nights with animal tracks.

Corvid

Member of the family Corvidae, including crows, ravens and magpies.

Dispersal

Movement of an animal from its place of birth to another area where it reproduces. This process is important to population dynamics, because dispersal is when immigration and emigration occur.

Index of abundance

A relative measure of the abundance of a species (for example, catch per unit effort).

Microsatellite

Repeated stretches of short sequences of DNA used as genetic markers to track inheritance in families. They are short sequences of nucleotides (e.g. ATGC) that are repeated over and over again in tandem.

Mitochondrial DNA

The genetic material of the mitochondria, the organelles that generate energy for the cell. Mitochondrial DNA is passed down from the mother to all her children, males and females.

Neophobic aversion

A tendency for a behaviour to be extinguished or a thing avoided as a result of the development of a new fear, usually in relation to a noxious stimulus.

Polymerase chain reaction (PCR)

A powerful method of amplifying specific DNA segments that exploits certain features of DNA replication.

Presence/absence study

An approach to determining diversity in an ecosystem by determining what species are present in the ecosystem.

Quadrat

An ecological sampling unit that consists of a square frame of known area. The quadrat is used for quantifying the number or percentage cover of a given species within a given area.

Stratified random sampling
(also called proportional or quota random sampling)

When the population is divided into homogeneous subgroups and a simple random sample is taken from each subgroup.

Track-station night

The number of track stations multiplied by the number of nights of tracking.

Transect

A straight line placed on the ground, along which ecological measurements are taken. A fixed transect is one that is set out for use in all further surveys so that valid comparisons with prior surveys can be made.

Trap night

The number of traps placed out multiplied by the number of nights of trapping.

Treadle snare

A trap that consists of a hole covered by sticks, over which a loop of cord attached to a bent stick is placed. When the animal steps on the sticks it falls into the hole and its foot is snared by the noose.

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