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LIVE TRAPPING CARNIVORES IN TROPICAL FORESTS: TOOLS AND TECHNIQUES TO MAXIMISE EFFICACY

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ABSTRACT. — Tropical carnivores often occur at low densities and non-invasive techniques may be inadequate to meet research and monitoring goals. Live capture allows researchers to gather information such as movement and habitat use, that they would not have access to using other techniques. However, for most tropical carnivore species there have been few live trapping studies, and hence no development of cohesive protocol. For effective project design to live trap tropical carnivores, we present a review of trapping techniques from literature and personal experience. When developing a live capture study, it is important to clearly identify study goals and ensure that live trapping will provide ample data for useful inference. It is also important to increase efficacy and efficiency of the technique so the capture rate is maximised and the risk of negative side effects is minimised. To meet these needs it is important to assess different methods of live capture. The benefits and detriments of each method must be considered for applicability to the study site and target species. Once the capture method is implemented it is important to reduce the time that the animal spends in the trap, and increase efficiency of the immobilisation process to reduce stress and improve general welfare of the captured individual. To maximise the capture rate, the spatial and temporal placement of traps and the use of baits and lures should be given careful consideration. Through review of tropical carnivore capture methods and discussion of improved efficacy and efficiency, researchers can better develop successful live capture projects.

KEY WORDS. — Live trapping, carnivore, immobilisation

INTRODUCTION

Live trapping is an important tool used to gain insight into the lives of various species from a wide range of taxa (e.g., Reptilia: Bryant et al., 2010; Equine: Hampson et al., 2010; Amphibian: Strojny et al., 2010; Aves: Yabe et al., 2010; Bovid: Brown et al., 2009; Suid: Thurfjell et al., 2009). For carnivores, which often occur at low densities and are difficult to detect, live trapping provides researchers with a technique to gather information that they may not be able to obtain using other methods. One of the most common purposes of live trapping carnivores is for the placement of tracking devices (see Gitzen et al., 2013). Global Positioning System (GPS) and very high frequency (VHF) tags have allowed for identification of critical habitat (e.g., Barlow et al., 2011); assessment of movement, dispersal, and habitat preference (e.g., Rabinowitz, 1990; McCarthy et al., 2005; Rajaratnam et al., 2007; Zimmermann et al., 2007; Conde et al., 2010; Rozylowicz et al., 2010); calculation of density estimates (e.g., Hawkins & Racey, 2005; Grenier et al., 2009; Jhala et al., 2009); and the identification of kill sites (e.g., Anderson & Lindzey, 2003; Tambling & Belton, 2009). In addition to the placement of tracking devices, live capture of animals allow researchers to collect other information including morphological measurements and biological samples (e.g., Woodroffe, 2001; Sobrino et al., 2008; May et al., 2009). As human-wildlife conflict has increased in many areas of the world, live trapping has also been used, with mixed reviews, to relocate carnivores from areas of high conflict in human-dominated landscapes (Goodrich & Miquelle, 2005; Kettles & Slowtow, 2009; Athreya et al., 2010).

While live capture has the potential to provide researchers with a plethora of information, the invasive nature of the technique necessitates careful consideration of whether the outcome of the study outweighs the risk of negative animal welfare issues. As such, the use of live trapping methods requires an in depth knowledge of the method, a realistic expectation of data that can be collected, and careful consideration as to whether its use is appropriate to the study based on the research goals and objectives. These needs are exemplified in tropical forests where rugged terrain, dense vegetation, adverse weather conditions, and often a low density of the target species result in challenging trapping conditions. This is further complicated by a growing human presence within and around the edges of tropical forests, which increases the potential for disturbance to traps or trapped animals. Thus, live capture of wildlife in tropical forests often requires specialised techniques which are adapted to the biological, geophysical, and sociological conditions unique to these areas. In addition, it is also important to understand the limitations of the technique in terms of data that can be collected. For carnivores in particular, capture rates are often low due to an inherently low density. A large amount of effort (trap nights) must be extended for a relatively low number of captures. Capture rates in the tropics may be even lower at the outset of a project as there have been relatively few studies of tropical carnivores in which to develop effective trapping protocols. The implications of small sample sizes must be integrated into planned data analyses at the onset of projects.

In some cases, such as the placement of tracking devices, live capture of animals is essential and the information gained is not easily replicated through non-invasive techniques (Garshelis, 2006). However, in other cases, the use of non-invasive techniques may provide comparable data to that gained from live capture of animals, particularly in the case of detection rates and density estimates (e.g., Kohn et al., 1999; Powell & Proulx, 2003; Heilbrun et al., 2006; Hackett et al., 2007; De Bondi et al., 2010). Our goal is to provide researchers with an overview of the approaches and considerations for live trapping carnivores in tropical forests so that they may decide whether the technique is applicable to their study and maximise the efficacy if used. We focus on three objectives to meet this goal. First, we provide a review of live trap designs and other non-trapping methods, with specific focus on their use for trapping carnivores in tropical forests. Next, we discuss the potential effects of various trap types on the welfare of captured animals. Finally, we examine methods to increase the efficacy of live trapping in tropical forests and to decrease biases associated with trap type and survey design.

LIVE TRAPS AND OTHER METHODS FOR USE IN CAPTURING CARNIVORES

There are various types of live trap that may be used to capture carnivores. We focus on the most frequently used traps, and those that may be most applicable in a tropical forest setting. These include cage and box traps, barrel traps, foot-hold traps, and snares. We also discuss darting and chemical immobilisation of free-ranging wildlife.

Cage and box traps. — Cage and box traps are two of the most commonly used trap designs in field research. Both traps are designed to capture the animals in a cage-like device; the primary difference being that the cage traps are generally constructed of wire mesh sides, while box traps have solid walls. Cage traps may be commercially purchased from several companies (e.g., Havahart, Tomahawk Trap Company, and Duke Trap Company), or self-constructed (Kolbe et al., 2003). They consist of a galvanised mesh cage that is open on one, or both ends. Box traps may also be purchased (e.g., Wildlife Damage Control) or constructed using wood or metal sheeting. For both types of trap, the animal enters the trap and generally steps on a treadle or pan, releasing a trigger that closes the door. Some trap designs use a thread trigger system that is pulled forward as the animal walks through the trap, allowing the door to close (McCarthy, 2009).

Kamler et al. (2002) experimented with different trap set ups and found that capture success for some carnivore species was highly correlated to the type of set that was used. In tropical forests, traps are often set on or adjacent to trails or roads, with the bottom of the trap covered with leaves or soil so there is continuity in substrate as the animal enters the trap (Grassman et al., 2005a). The trap itself may also be covered with vegetation to blend into the surrounding environment and provide cover for trapped animals (Fig. 1). Although live traps are usually set on the ground, researchers in South America have successfully used cage traps in trees to target arboreal small mammals (Malcom, 1991). Cage and box traps may be made or purchased in many different sizes. The appropriate size of trap is dependent on the size and preferences of the target species. Grassman et al. (2005a) and Grassman (1998) used hand-made box traps (250 × 90 × 100 cm), and cage traps (150 × 40 × 50 cm) to catch 17 carnivore species in Thailand. J. Ross and A. J. Hearn used three sizes of locally made steel cage traps (Small: 100 × 50 × 40 cm; Medium: 150 × 60 × 60 cm; large: 200 × 100 × 100 cm) to catch leopard cats (*Prionailurus bengalensis*) and Malay civets (*Viverra tangalunga*). Rajaratnam et al. (2007) caught leopard cats with Tomahawk cage traps (107 × 38 ×

51 cm) in the Tabin Wildlife Reserve, Sabah. Dunstone et al. (2002) used Tomahawk cage traps (105 × 50 × 37.5 cm) to capture Kodkod (*Leopardus guigna*) in Chile.

Cage and box traps are commonly used in live trapping studies due to their perceived safety in comparison to other techniques (Dietz, 1984). However, animals captured in cage or box traps often incur minor injuries; most commonly involving trauma to the face, teeth, or paws as they attempt to escape (Arthur, 1988; Mowat et al., 1994; Blundell et al., 1999; Way et al., 2002; Powell & Proulx, 2003; Frank et al., 2003; Woodroffe et al., 2005; Michalski et al., 2007; Munoz-Igualada et al., 2008). Species with long tails may be at risk for tail injuries if the trap door closes on their tail. Rarely are injuries serious enough to require euthanasia (Frank et al., 2003). The severity and rate of injury may be diminished by tailoring the trap design to the target species, using an appropriate trap and mesh size, routinely surveying the inside of the trap for sharp or rough edges, and eliminating gaps between wood slats and at the doors (Arthur, 1988; Kolbe et al., 2003; Woodroffe et al., 2005). Traps should also be tripped daily to ensure that the door closes completely, to prevent an animal from injuring itself trying to squeeze through a partially closed door (Grassman, pers. comm.).

Although the use of cage or box traps generally carries a low risk of serious injuries, there are several costs for their use in tropical forests which may outweigh the benefit. The weight and bulkiness of the traps makes it difficult to deploy numerous traps in areas that are inaccessible to vehicles or in rugged terrain (Blundell et al., 1999; Frank et al., 2003), both attributes common to tropical forests. Cage and box traps also have low selectivity, resulting in increased captures of non-target species (Mowat et al., 1994; Catling et al., 1997; Shivik et al., 2005). This can be a problem in the tropics where there is relatively high species diversity and overall numbers of animals in most areas, and there may be an increased risk of capturing rare and endangered species. In addition, many carnivores are reluctant to enter cage or box traps and thus capture rates may be low, resulting in a large expenditure of effort for minimal captures (Way et al., 2002; Shivik et al., 2005).

Fig. 1. A cage trap covered with vegetation. (Photograph by: J. L. McCarthy).

Barrel traps. — Metal barrel or culvert traps have been used extensively for the capture of ursids, including in the tropics (Wong et al., 2004), and appear to cause relatively little stress in the captured animals (Cattet et al., 2008). However, barrel traps may be less effective than box traps for some other carnivore species (Lofroth et al., 2008), and given their size and weight, would be difficult to deploy in remote areas (Powell & Proulx, 2003).

Foot-hold traps. — Foot-hold traps are designed to capture the animal by the foot and keep them restricted to the trapping location. The traps consist of jaws which close when a pressure activated pan in the middle of the trap is pressed. The trap is attached to a cable or chain, which is then anchored into the ground, or another solid object. Occasionally the trap is attached to a drag device or grapple. This allows the animal to move a small distance from the trapping location before the drag device becomes entangled and restricts further movement. For scientific purposes, the foot-hold traps used are soft-catch traps, in which the metal jaws are covered with rubber to soften the grip of the jaws (e.g., Oneida Victor). The jaws may also be offset to further reduce pressure on the leg. For most carnivore species, foot-hold traps are most effective when set along well traveled trails, near baits, or near kills (Munoz-Igualada et al., 2010). In Sumatra, foot-hold traps were set between two small logs that required the animal to step over them. This was intended to increase the likelihood that the animal would step into the trap. The capture rate was further increased by using a double set, or one trap before the log and one after (McCarthy, 2009). Soil is usually used to cover the traps, but in tropical environments, the heavy clay composition of the soil and the copious rainfall may allow mud to impede or slow the trap closure. This can be prevented by using torn leaves underneath the trap and also to cover the trap rather than soil (McCarthy, 2009).

Foot-hold traps are still thought of as dangerous by many people. They hold an image of the toothed steel-jawed traps used by early trappers and poachers who had little concern for animal welfare (Andelt et al., 1999). In reality, soft-catch traps used by researchers today have been shown to have reduced risk of stress and injury compared to unpadded foothold traps (Olsen et al., 1986; Kreeger et al., 1990; Phillips et al., 1996; Fleming et al., 1998; Earle et al., 2003; Frame & Meier, 2007; Marks, 2010). With accurate knowledge of the technique, foot-hold traps can be a very safe and effective tool for a wide variety of species (Michalski et al., 2007; Belfiore, 2008; Munoz-Igualada et al., 2010). In particular, foot-hold traps can greatly increase capture efficiency for trap-shy animals, or wary carnivores that may not readily enter a cage trap (Mowat et al., 1994; Shivik et al., 2005; Michalski et al., 2007).

Although foot-hold traps can be very effective if used correctly, their use is not without risk. Serious injuries are possible, but most often injuries are minor and limited to swelling and slight abrasion where the foot is restrained (Mowat et al., 1994; Kamler et al., 2000; Shivik et al., 2005; Michalski et al., 2007). The risk of injury can be reduced by using a strong anchor in a clear area, using at least two swivels to allow the animal to pivot freely around the anchor, and by placing a high quality spring in line with the tether as a shock absorbing device (Mowat et al., 1994). If properly used, the use of a grapple or drag in lieu of stakes may also reduce the risk of injury and stress. They usually allow the animal to seek shelter a short distance from the trapping site before the grapple becomes entangled in vegetation and restricts further movement (Earle et al., 2003; J. L. Belant pers. comm.).

While the risk of injury to captured animals is often minimal, for non-target species the risk may be greater and more serious (Kamler et al., 2000). This is of particular concern in tropical forests where species diversity and overall animal abundance is high. By selecting the minimum size of trap appropriate to the study species, not only is the risk of injury to the study animal decreased, but the selectivity of the trap can be increased to exclude animals larger than the target species (Powell & Proulx, 2003). In Sumatra, size 1 ½ traps were successfully used to capture viverrids and small felids, while excluding tigers and other large mammals (McCarthy, 2009). Adjustment of the pan tension or use of a pan tension device (Fig. 2) can further increase the trap selectivity, and in some cases may nearly eliminate the capture of smaller non-target animals (Kamler et al., 2000; Phillips & Gruver, 1996).

Snares. — Foot and neck snares have been used effectively to catch wildlife. Foot snares are similar to foot-hold traps in that they are designed to hold the animal by the leg in the location in which they are caught. Like foot-hold traps, foot snares are usually most effective when set on the trail, or when several are set around a kill (Logan et al., 1999; Goodrich et al., 2001; Frank et al., 2003; Fig. 3). The trap is anchored into the ground, or to another solid obstacle, with one or two inline swivels which allow the animal to pivot around the anchor point after capture. The most common types of foot snare used are actively-triggered (e.g., Aldrich foot snare or Belisle foot snare). These snares consist of an activation device which is similar to the pressure activated treadle of the foot-hold trap. When the pan is depressed by the animal, a compressed spring is released which throws a large loop of cable up the animal's leg. The loop is then tightened mechanically by the expanding spring around the leg of the animal. Neck snares consist of a loop of wire secured to a supporting anchor wire. A lock stop prevents the loop from closing tighter than a certain diameter which is set according to the size of the target species.

Fig. 2. A pan tension device being inserted to a foot-hold trap (PTD). (Photograph by: J. L. McCarthy).

To reduce bycatch and increase capture efficiency some researchers have created modified snare designs that are more specific to the target animal (Logan et al., 1999; Reagan et al., 2002; Powell, 2005; Lemieux & Czetwertynski, 2006; McCarthy, 2009). A breakaway device may also be used to allow larger non-target species to break out of the snare (Munoz-Igualada et al., 2010; Etter & Belant, 2011). Neck snares, although less common, can be used and may be passively or actively triggered. New technological innovations have increased the efficacy of neck snares for some carnivore species (Pruss et al., 2002; Munoz-Igualada et al., 2008, 2010). With proper adjustment of the snare height, loop size, breakaway device, cable lock stop, and with consideration of the site characteristics, neck snares may provide a method of high efficiency with very low bycatch of non-target animals (Munoz-Igualada et al., 2008, 2010; Etter & Belant, 2011).

Snares are an appropriate choice for many carnivore studies because they are a low cost, safe, effective means of capturing carnivores with greater efficiency than cage traps (Logan et al., 1999; Frank et al., 2003; Powell, 2005; Munoz-Igualada et al., 2008). They are also lightweight and easy to deploy in remote areas which are inaccessible by vehicles (Logan et al., 1999; Goodrich et al., 2001; Frank et al., 2003). However, there may be general reluctance to use snares, primarily due to their similarity of appearance to illegal snares. While the use of snares does carry a risk of injury to the captured animal, many innovations and adjustments have been made to increase the efficacy and safety of snares used for research, and they are much different than the wire snares used by poachers and local hunters. Snares have a similar risk of injury to that of padded foot-hold traps, and lower risk than unpadded leg-hold traps (Darrow et al., 2009). The most commonly reported injury from snares is transient edema in the restrained leg (Logan et al., 1999;

Fig. 3. Several foot snares set around a kill. (Photograph by: Brietenmoser-Würsten).

Goodrich et al., 2001; Frank et al., 2003). Minor lacerations are also common, while moderate and severe injuries such as fractures are rare (Poole et al., 1998; Logan et al., 1999; Goodrich et al., 2001; Frank et al., 2003). Increasingly, rubber padded snares have been employed to reduce the risk of injury to the restrained leg, however there have been mixed reports as to their efficacy (Lemieux & Czetwertynski, 2006; Darrow et al., 2009).

Other types of live capture. — While the trapping methods already discussed are the most commonly utilised in wildlife studies and the most applicable to work in tropical forests, there are other methods available as well. Direct darting of free-ranging carnivores is also possible, and under some circumstances may cause less stress and exertion than restraint-based methods (Powell, 2005). In India, tigers (*Panthera tigris)* are often darted from the backs of elephants (Smith et al., 1983), and in Africa, habituated felids are commonly darted directly from a vehicle (Frank et al., 2003). Even darting from a helicopter has been shown to be fairly effective and of low stress for the animals as long as the pursuit time is minimal (Goodrich et al., 2001; Cattet et al., 2003; Cattet et al., 2008a). In tropical forests, darting by helicopter or vehicle is rarely feasible as the terrain is usually rugged and the forest cover is extensive, but other methods of direct darting may be applicable. Trained cat hounds have been used extensively for the capture of puma (*Puma concolor)* in the Americas (Logan et al., 1986) and have also been successfully used to capture jaguars (*Panthera onca*) in Paraguay and Brazil (Soisalo & Calvalcanti, 2006; McBride & McBride, 2007). McBride & McBride (2007) reported no injuries of captured jaguars and no capture of non-target species. In addition, extended monitoring indicated no long term effects on the movement of captured individuals. Ryser et al. (2005) developed a minimally invasive capture system (MICS) consisting of a dart gun remotely controlled by two built-in cameras and equipped with telemetry darts. Telemetry darts are commercially available (e.g., Pneu Dart) and emit a signal which allows the researcher to locate the animal once immobilised. The MICS is usually set at a kill site and allows researchers to operate the system from a distance of 400 m, thereby eliminating chase or restraint. Although this system is costly, it provides complete selectivity of the animal being darted, appears to result in low stress for captured animals and can be deployed in multiple habitat types.

THE EFFECT OF STRESS AND CHEMICAL IMMOBILISATION ON TRAPPED CARNIVORES

Live trapping of carnivores can have unwanted effects on the animal's health. They may suffer injury or even die due to increased levels of stress and the struggle to escape capture devices. Furthermore, chemical immobilisation can cause loss of thermoregulatory control and may leave the animal vulnerable to predation if left unattended before completely recovered. Comprehensive veterinary training of research personnel and the use of proper trapping techniques is necessary to limit the effect of stress during capture, as well as the effect of immobilising agents on thermoregulation and predator avoidance. Researchers should not lead a live trapping study until they have sufficient experience in the presence of a mentor in both live trapping and immobilisation, particularly if working with a rare species.

Stress. — Any restraint or anesthetisation of an animal results in some level of stress for that individual. This is especially important to consider when live trapping in a tropical environment as captured animals are often exposed to high temperatures which exacerbate the effects of struggle against the trap. There are three critical components leading to stress in captured animals. First is the amount of time spent in the trap after capture. For many, the first hour of capture seems to be the period of most intense struggle (Marks et al., 2004). Some species or individuals will struggle briefly (Frank et al., 2003) while for others the struggle is more prolonged. Blood chemistry of American black bears (*Ursus americanus*) captured in snares indicated exhaustion and dehydration. This was especially evident in juveniles who tended to struggle more than adults (Powell, 2005). Overall, blood chemistry indicative of increased exertion was also correlated with an increased risk of injury (Powell, 2005). American black bears caught in foot snares exhibited higher cortisol levels than those caught in barrel traps, indicating increased stress (J. L. Belant, unpublished data). This is hypothesized to be due to a perceived vulnerability and exposure of individuals in the snares that was more stressful for captured individuals (J. L. Belant, unpublished data). Although rare in carnivores, extreme exertion and stress may lead to fatal exertional myopathy in some species (Cattet et al., 2008b). Second, is the proximity of humans before immobilisation. Many severe injuries occur when animals attempt to lunge away as the researcher or veterinarian approaches the trap for anesthetisation (Goodrich et al., 2001). This indicates that an increase in the efficiency of the anesthetisation process decreases the risk of injury (Goodrich et al., 2001; Pruss et al., 2002). Furthermore, when foot-holds or snares are used, ensuring that the anchor chain is short enough to prevent a captured animal from getting much velocity into its escape lunge will help to minimise injury (Goodrich et al., 2001). The use of drags or grapples may also help to decrease stress and injury by allowing the animal some restricted movement in order to seek shelter. Third is the animal's capture history. There is some indication that multiple captures of the same individual may lead to a corresponding reduction in body condition (Cattet et al., 2008a). High levels of stress during the capture process may also contribute to future trap shyness, as well as influencing the subsequent movement of the animal for up to six weeks (Logan et al., 1999; Cattet et al., 2008a). Even an animal that becomes "trap happy" may be detrimentally affected through continual capture and constant confinement.

Tranquilizer Trap Devices (TTDs) are a tool that may be used to reduce stress and risk of injury for captured animals (Balser, 1965; Sahr & Knowlton, 2000; Pruss et al., 2002; Marks et al., 2004). When the animal is captured they frequently begin to chew at the trap, so the TTD is a tabular form of tranquilizer placed in a prominent area on the trap where the animal will be likely to ingest it. The use of

TTDs has been shown to successfully reduce the frequency and severity of facial, foot, and leg injuries, by decreasing the length and intensity of the animal's struggle in the trap (Balser, 1965; Zemlicka et al., 1997; Sahr & Knowlton, 2000; Pruss et al., 2002). TTDs may also lower the risk of escape, as trapped animals do not try as vigorously to escape while tranquilized (Balser, 1965; Sahr & Knowlton, 2000). There has been some concern that non-target animals caught in a TTD-equipped trap may be at risk of a tranquilizer overdose. However, Sahr & Knowlton (2000) showed that TTDs were effective in reducing injuries to captured non-target animals, and posed little risk of overdose for most species.

Chemical immobilisation. — For recommendations of immobilising agents for specific species, see Kreeger & Arnemo (2007). There are several techniques for the administration of anesthesia, including a syringe pole, blow gun, dart gun or hand injection. All are appropriate for use in tropical environments, depending on the individual trapping situation. Syringe poles require a close approach, and are typically used for animals restrained in cage traps (e.g., Arthur, 1988; Rabinowitz, 1990). They have occasionally been used for species captured in foot-hold traps or snares (Beecham, 1983), however, the necessity of a close approach increases the chance that the animal will struggle and pull out of a foot-hold trap, thus endangering themselves and the researchers (Goodrich et al., 2001). Blow guns and dart guns are often used when a close approach may be more difficult or dangerous for the research team, and the animal is large enough to target with some accuracy (e.g., Smith et al., 1983; Wenger et al., 2010; Barlow et al., 2011). Careful assessment of the necessary power (dart velocity) reduces the risk of penetration injuries (Jessup, 2001). Hand injection is often used for smaller animals and in conjunction with a method of physical restraint (netting or noose poles when foot-holds or snares are used, and squeeze boards with cage or box traps; Blundell et al., 1999; Belfiore, 2008; McCarthy, 2009). For all methods, needle gauge and length should be given careful consideration to limit penetration injuries. Larger gauge needles will minimise tissue damage when the immobilising agent is administered under pressure, and shorter needles limit the depth of the injection (Grassman, pers. comm.).

For many species, one of the major risks while immobilised is loss of thermoregulatory control (Kreeger, 1996; Shindle & Tewes, 2000; DelGiudice et al., 2001; Dzialak & Serfass, 2002). In tropical forests where high temperatures are common, the risk of hyperthermia is greater than the risk of hypothermia. By moving the animal to the shade after induction, researchers are often able to prevent rapid increases in temperature. Body temperature should be continually monitored and if it does become elevated (see Kreeger & Arnemo, 2007 for species specific temperature information), water, ice or alcohol should be readily available and used for cooling with particular attention to the thermal windows to maximise efficacy (i.e., paws, groin, and forearm; Kreeger, 1996; Shindle & Tewes, 2000; DelGuidice et al., 2001). Other common side effects seen during immobilisation include abnormally long or short immobilisation times, muscle rigidity, convulsions, and depressed respiration (Kreeger, 1996; Grassman et al., 2004; Grassman et al., 2006; Jacquier et al., 2006). These risks may be reduced by employing general methods to minimise stress during immobilisation, including accurate dosage estimation and administration, talking quietly, reducing visual stimuli by using a blindfold, and maintaining an adequate distance during induction (Kreeger, 1996; Rolfe et al., 2001). Importantly, the reduction of stress during the immobilisation period also contributes to a decreased risk of subsequent capture-related mortality (Roffe et al., 2001; Arnemo et al., 2006). A safe shaded area for recovery must be provided and the animal must not be released until completely recovered. This decreases vulnerability to predators (Arnemo et al., 2006) and also eliminates post-immobilisation injuries such as falling from trees which is possible if an animal is released before normal reflexes have returned (Arnemo et al., 2006).

TRAP CONTROL

Perhaps the single most important step to take in order to decrease both the stress that an animal experiences during the trapping process and the risk of injury, predation, or discovery by humans, is to minimise time the animal spends in the trap (Logan et al., 1999; Goodrich et al., 2001; Cattet et al., 2003). This is also important because of the risk of capturing a lactating female and keeping her from her young for an extended period. Historically, researchers manually checked traps once or twice daily. Not only is this labour and time intensive, but manual checks increase the possibility that the animal will be in the trap for an extended period between checks. By manually checking traps, capture efficacy may also be decreased because of the disturbance created by visiting the trap site multiple times and the human scent left behind that may deter animals from the trapping area (Arthur, 1988). Trap monitors are a tool that can be used to increase trap efficacy by eliminating the need for frequent manual checks (Nolan, 1984; Arthur, 1988; Halstead et al., 1995), as well as decreasing the time that the animal spends in the trap (Goodrich et al., 2001; Larkin et al., 2003). Trap monitors can be used on most trap types and send a signal to a receiver when the trap closes (Nolan, 1984; Marks, 1996). This allows the researcher to know the instant an animal has been captured and remove the animal from the trap within minutes or hours, thus reducing both the risk of injury (Larkin et al., 2003; O'Neill et al., 2007) and the risk that a predator or poacher will find the animal in the trap. Traditionally, trap monitor signals have been VHF based (Halstead et al., 1995; Marks, 1996), but more recently GSM models have emerged (Larkin et al., 2003; O'Neill et al., 2007). We caution that while trap monitors reduce the need for frequent manual trap checks, it is important to still check the traps daily to ensure that the devices are working properly (O'Neill et al., 2007). Grassman et al. (2005b) used trap timers to measure the length of time a captured carnivore was in the trap prior to sedation. This method may be useful to determine the amount of care an animal may require, particularly if it has been in the trap for an extended period of time.

SURVEY DESIGN – INCREASING THE EFFICACY OF THE SELECTED CAPTURE TECHNIQUES

Owing to the rare and elusive nature of most carnivores, it is important to maximise efficacy and efficiency of the trapping effort. The choice of which type of trap to use is imperative, but of equal importance is trap location, number of traps deployed, and the bait and lure used. Finally, it is important to acknowledge biases inherent to the trapping process to ensure that appropriate inference is made from resulting data.

Setting traps and trap locality. — The goal of the study and the target species dictates the number of traps needed and how they should be distributed across the study area. In tropical forests, efforts are often constrained by the logistics of working in remote and inaccessible areas. Researchers must be able to effectively monitor each trap which may consequently reduce the number of traps deployed and/or area covered. The location in which traps are deployed is integral to capture success. Traps placed in areas of known activity have higher success than randomly placed traps (Dietz, 1984). By using data from other sources such as camera trap studies, sign surveys, anecdotal reports, or point counts, researchers are often able to identify habitat types or high usage areas where live trapping may be most effective (Dietz, 1984; Powell & Proulx, 2003; Grassman et al., 2005a; McCarthy, 2009). However, for many carnivore species in tropical forests, there is limited ecological data which makes it difficult to know where traps should be set for the highest chance of capture. In these instances, a few simple rules may help to improve capture rates. For example, setting traps in corridors or areas of constricted travel (i.e., ridge lines, valleys, along rivers, or at river crossings) often increases trapping success (Lofroth et al., 2008). Trapping along well travelled trails and at habitat edges is also recommended (Dietz, 1984). For arboreal species, traps can be set in areas where the animals would presumably be forced to descend from the canopy, such as along ridgelines, at openings in the canopy, and at the bases of trees (Arthur, 1988). However, when choosing the trap locations, it is important to avoid setting traps near overhanging limbs, water, or cliffs where a trapped animal may injure themselves, or where the animal may be at risk when immobilised or on release (Goodrich et al., 2001; Powell & Proulx, 2003; Belfiore, 2008). Cage, box, and barrel traps must be placed on flat ground and all traps must be placed with adequate shelter, especially if traps are to remain set during the day. Traps should be left in place for a minimum of four weeks to allow habituation, but may be moved to a new location if still unsuccessful (Grassman, pers. comm.).

Baits and lures. — When trapping carnivores, baits and scent lures are often essential to attract individuals to the trap site, or entice them into the trap (Schemnitz, 1996; Powel & Proulx, 2003). There are numerous commercial baits and lures that can be used individually or in combination. Many have been formulated specifically to attract a certain species or taxa (Arthur, 1988) For most carnivores, this usually consists of the scent of decaying meats, but may also include plant extractions such as valerian or anise (Schemnitz, 1996). The use of these targeted baits and lures may be so effective that they actually increase the selectivity of the trap by attracting only the intended species (Shivik & Gruver, 2002). The individual's response to baits and lures may also change seasonally, with some being very effective during the breeding season and completely ineffective at other times of year (McCarthy, 2009).

Most commercial scent lures are designed specifically for furbearing species commercially trapped in North America or Europe and not for carnivores found in tropical forests, so their efficacy is questionable. A. J. Hearn & J. Ross experimented with commercially available scent lures and also visual lures in the form of feathers suspended internally from the top of the cage trap, but found that neither increased trapping success for leopard cats in Sabah, Borneo (unpublished data). The effectiveness of scent lures may be decreased by the copious precipitation in tropical forests, so in Sumatra, J. L. McCarthy used several different methods to deploy scent lures. Cotton balls soaked in scent lure were placed inside an inverted film canister which was hung above the trap; or scent lure was placed on the undersides of rotting logs, the undersides of foliage, on under hangs and the undersides of branches (unpublished data). None of these methods increased effectiveness of the lures and there was no noted increase in captures with their use.

While some of the more general commercial baits may be feasible to use, researchers in tropical forests typically use non-commercial alternatives of either dead or live animal bait. Live bait usually consists of chickens or other small poultry caged at the trap site. Dead bait may consist of an animal's own kill that has been relocated to the trapping area, domestic poultry, or other meat sources. Both live and dead bait should come from reliable sources and should be carefully assessed for signs of disease prior to use. When live bait is used, it is placed into a separate compartment of the cage trap, so that it is not accessible to the trapped individual. However, the sound and smell of a live animal is usually the most efficient at attracting carnivores (Michalski et al., 2007). A combination of live rats and sound lure (electronically produced sound of prey) was found to increase trapping success for leopard cats and Malay civets in Sabah (A. J. Hearn & J. Ross, unpublished data; Fig. 4). Rajaratnam et al. (2007) also successfully used live rats to capture leopard cats in Sabah, and Grassman et al. (2005a) successfully caught several carnivore species using live chickens as bait. Dead bait may draw in more non-carnivores, but dead, whole chickens were successfully used to catch felids and viverrids in Sumatra (J. L. McCarthy, unpublished data; Fig. 5). Dunstone et al. (2006) used cat food, tinned tuna and sardines to capture kodkods (*Lepardus guigna*) in Chile. Ensuring that either live or dead bait is well secured to the cage reduces incidences of bait stealing and tripped, but empty, traps (Lofroth et al., 2008). If live bait is used it is essential to provide food, water and shelter for the bait animal and to check its welfare daily. It must also be noted that it is illegal to use live bait in many countries and the advantages of using live bait must, therefore, be weighed against the legal, logistical, and welfare implications.

Temporal considerations. — The timing of trapping efforts can influence the capture success as well as the age and sex composition of the sample. For many carnivore species, a large proportion of individuals are captured during a specific time of the year (Beecham, 1983; Arthur, 1988; Lofroth et al., 2008; McCarthy, 2009). This may be during the breeding season (McCarthy, 2009), or in response to certain weather or temperature conditions (Lofroth et al., 2008). In tropical forests seasons are limited to wet and dry and in Sumatra there has been some indication of increased carnivore captures during the shifts between these two seasons (McCarthy, 2009). In addition to a greater number of animals, different age classes or sexes may have higher capture probabilities during specific times of year (Arthur, 1988). Owing to differing activity patterns (i.e., diurnal, nocturnal, or crepuscular), even the time of day that the trapping occurs may influence the capture rate for species (Belfiore, 2008). For most tropical carnivores, there is a paucity of ecological data and therefore little information on the most effective times to trap. However, it is important to recognise that timing of the trapping effort may bias the sample and influence capture efficacy. By trapping during all seasons at the outset of the study, it is possible to identify any temporal biases that exist and concentrate later trapping efforts during the most effective time of year.

Fig. 4. Example of an electronic lure. A small box hidden in the vegetation at the bottom of the trap emits the sound of bird song and the plastic bird spins around when the sound plays. (Photograph by: J. Ross and A. J. Hearn).

Fig. 5. Dead bait and commercial lures being deployed in Sumatra. (Photograph by: J. L. McCarthy).

Technique biases. — There are also biases introduced from the choice of capture technique. It is well known that certain types of traps may be more effective for some species, but certain types of trap may also be more successful in capturing one sex or another. Austin et al. (2004) found that cage traps were more effective for capturing female northern raccoons (*Procyon lotor*) than male northern raccoons, indicating that a study which uses only cage traps may have a sample which is heavily female biased. Lofroth et al. (2008) found that they were able to dart more male wolverines (*Gulo gulo*) from the air, while a larger proportion of females were captured in box traps. In this case, they hypothesized that this was due to the fact that males were often using open habitat and were easily spotted by helicopter, while females were using more forested habitat. For many species males and females may use different habitats or micro-habitats, and thus the habitat in which traps are deployed and the exact placement of traps in the landscape may have a large effect on which sex will be captured (Conde et al., 2010). The different sexes may also respond to trapping efforts differently. Logan et al. (1999) found female puma often became trap shy after a period of trapping, while males did not. As a result, at the beginning of the trapping effort, there was no sex bias, but by the end more males than females were being captured. Male American black bears are much more likely to be attracted to bait than are females or yearlings of both sexes (Belant et al., 2011). It is important that in any live trapping study, care be taken to identify and acknowledge any bias that might exist in the sample so that inferences from the analyses are appropriate. For most tropical carnivore studies, sample sizes are often small, exacerbating the effect of any biases. For example, if your technique is biased towards female captures, you may capture six individuals, but only one male. Your inferences in this situation about male movements or habitat use are more limited than if you had a larger sample size with the same sex bias (e.g., 60 individuals, 10 males). Identification of biases is also important if you are intentionally trying to capture more individuals of a certain sex or age class. Applying several different trapping systems at the onset of a study allows not only for the identification of differing capture efficiency between trap types, but may also help to lower the risk of trap shyness.

CONCLUSIONS

Tropical forests are home to some of the rarest carnivores in the world. Owing to their elusive nature, there is little information on many tropical carnivore species and their ecology is generally unknown. Live trapping is an important tool to elucidate the habitat use, demography, movement, and biology of many carnivore species. Selection of trap types, the use of appropriate stress and injury reduction techniques, the proper placement of traps and the limiting and acknowledgement of biases are key to the success of live trapping in tropical forests. Unfortunately, research projects across the tropics are often disjointed, and novel techniques used successfully in one region of the world may be unknown in another. We have made an initial effort to gather basic information for tropical carnivore ecologists but hope this work will engender future sharing of new and improved methodologies across projects.

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