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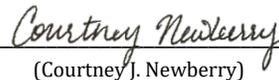
2019-2020 Honors Thesis

Small Island Taphonomy in Western Australia

Courtney J. Newberry

A thesis presented in partial fulfillment of the requirements of the Undergraduate Honors Program at the University of New Haven.

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Abstract

Forensic death investigations rely on postmortem interval estimations to establish a timeline surrounding a decedent's death. Several methods are used, often together, to make such estimations. One of the main methods is the evaluation of the stage of decomposition; although decomposition follows the same general steps, the length of the process can vary by location and environmental factors. Animal scavenging can also impact decomposition by consuming flesh and impacting insect activity on the remains.

This study investigates the scavenging guilds and rate of decomposition of pig (*Sus scrofa*) legs on Rottnest Island, Australia. Three sites with unique environments were selected for the study: Bickley Point (marine), Forbes Hill (terrestrial), and Lake Baghdad (hypersaline).

The legs were placed on the ground at each location and secured with ropes, although experimental setup varied by site as needed. Photographs and video imagery were used to monitor the legs. The imagery was processed, and information regarding the experimental day, date, scavenging species, time of event, and event duration was recorded for each scavenging event. The stage of decomposition was assessed daily. Temperature, light intensity, humidity, and depth data were collected by data loggers.

The scavenging guilds observed at each site varied greatly, as expected. The primary marine scavengers were the Australian herring (*Arripis georgianus*), Banded Sweep (*Scorpiis georgiana*), Brownspotted Wrasse (*Notolabrus parilus*), and Weeping Toadfish (*Torquigener pleurogramma*). The King's skink (*Egernia kingii*) was the primary terrestrial scavenger. No scavenging on the hypersaline legs was observed.

The rate of decomposition also varied by site. All marine legs were in the water for only one day, so decomposition stages could not be assessed. The terrestrial legs remained fresh for two days post-deployment before the active decay began, and the legs became desiccated. The hypersaline leg remained fresh for two days before the bloat stage began and persisted for the remainder of the experiment.

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Glossary

ADD	Accumulated degree days, a measure of heat loading over time
Avian	Relating to birds
Carnivore	An animal that mainly consumes meat
Desiccated	Dried out
Diurnal	An animal that is most active during the daylight hours
Endemic	Found only in a specific location
Entomology	The study of insects
Forensic Taphonomy	The study of the fate of remains between death and discovery
Guild	A group of species that play a similar roll within an ecological community
Heliothermy	The gain of heat from solar radiation
Hypersaline	A solution that is supersaturated with salt
Intensity	The scavenging time per hour
Location	The specific position of a particular replicate (e.g. Sandy Bottom)
Lux	The SI unit of illuminance. One lux is equal to one lumen per square meter and measures the intensity of light as perceived by the human eye. For reference, a bedroom is typically 300 lux, and a well-lit workshop is typically 800 lux (Adams, 2017).

Marine	Of or found in the sea
Nocturnal	An animal that is most active during the nighttime hours
Omnivore	An animal that consumes meat, insects, and plants
Perimortem	At or near the time of death
Postmortem	After death
Primary	The scavengers with the highest scavenging intensity
Scavenging	The consumption of remains or material on remains
Site	The general location of an experiment (e.g. Bickley Point)
Terrestrial	Of or on dry land
Thigmothermy	The gain of heat from direct contact with warm objects

Abbreviations

ADD	Accumulated Degree Days
ANOVA	Analysis of Variance
BORIS	Behavioral Observation Research Interactive Software
M2 and M3	Marine cameras 2 and 3
Pers comm	Personal communication
s.e.d.	Standard error of differences
T1a, T1b, T2a, and T2b	Terrestrial cameras 1a, 1b, 2a, and 2b
TSD	Time Since Death



Chapter 1: Introduction



University of New Haven
HENRY C. LEE COLLEGE OF
CRIMINAL JUSTICE AND FORENSIC SCIENCES

DEPARTMENT OF FORENSIC SCIENCE



1.1 Postmortem Interval

Postmortem interval (PMI), also known as time since death (TSD), is a valued tool in forensic science investigations (Roberts, Spencer, & Dabbs, 2017). With PMI determinations, investigators can better establish a timeline of events surrounding death, e.g. determining approximately what time a person died or how much time passed between death and being moved to a secondary location. For suspicious death investigations, this information can allow investigators to check alibis and include or exclude people as suspects. Several methods have traditionally been used for determining time since death, with varying accuracy and applicability (Madea, 2016). These include physical processes such as livor mortis and algor mortis and chemical methods such as rigor mortis and vitreous humor analysis. Often more than one method must be used in order to obtain the most accurate approximation of post-mortem interval.

Livor mortis, or lividity, is one of the early observable physical processes observed after death. When the heart ceases to beat upon death, blood no longer circulates and settles to lowest parts of the body due to gravity (Goff, 2010). Consequently, these parts become discolored, and a defined line exists between the upper and lower portions of the body (Figure 1.1 a). If a body was in a seated position after death, lividity sets in in the abdomen, the backs of the thighs, the calves, the feet, and sometimes the forearms (Camps, 1968). Since the lividity pattern can indicate postmortem posture, it can help investigators reveal a misleading or staged scene if the body was moved after lividity had set in (Camps, 1968). Lividity begins almost immediately after death but is not visible until approximately an hour postmortem, and it is fully developed between hours three and four (Goff, 2010). Within this timeframe, the

blood remains liquid, and applied pressure to the skin can force the blood out of the surrounding area, which is known as blanching (Figure 1.1 b); the blood returns when the pressure is lifted if the lividity has not set. This setting occurs at approximately 9-12 hours postmortem (Goff, 2010).

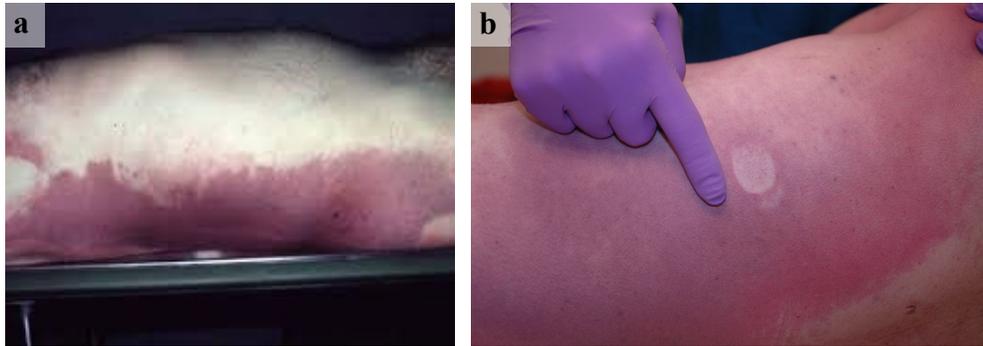


Figure 1.1 a-b. (a) Livor mortis (Goff, 2010). (b) Blanching (“Livor Mortis,” n.d.).

Algor mortis is the cooling of the body after death, when the body can no longer maintain its internal temperature and begins to equilibrate with the ambient temperature over the first 18-20 hours (Goff, 2010). While long believed to follow an exponential trend with a steep decline in temperature immediately after death that gradually levels off, body cooling actually follows a sigmoid trend with a plateau for the first one to three hours after death (Camps, 1968). The hot temperatures that are common during the summer months can lengthen this plateau by maintaining the core body temperature and may result in underestimated PMI estimations (Ondruschka, et al., 2019). Cooling rates are also affected by other factors like wind, humidity, rain, body weight, mass:surface area ratio, body posture, and clothing (Madea, 2016). Higher body mass has been associated with delayed body cooling, which increases the rate of early decomposition stages (Roberts et al., 2017).

Rigor mortis is the stiffening of muscles due to chemical changes that occur during the early stages of decomposition (Figure 1.2) (Goff, 2010). The body typically goes limp immediately upon death, but as time progresses, ATP is converted to ADP, producing lactic acid. Since lactate can no longer undergo gluconeogenesis in the liver, a buildup of lactic acid develops and lowers cellular pH. The increased acidity in muscles locks chemical bridges between actin and myosin in the muscles (Goff, 2010). Every muscle in the body undergoes this process, and chemical bridges become fully locked in skeletal muscles (Camps, 1968). The first signs of rigor can be observed in the face, which has the smallest muscles, by 2-6 hours postmortem and continue to develop in the rest of the body in first 12 hours (Gill-King, 1997; Goff, 2010). Rigor typically persists for 24 to 84 hours before muscles begin to relax, but ambient temperature, the body's perimortem metabolic state, body mass, and algor mortis can affect its onset and duration (Goff, 2010). Low ambient temperatures can cause rigor to set more rapidly and persist longer, while high temperatures produce the opposite effect. Varetto and Curto (2005) used mortuary refrigerators to simulate winter conditions of temperate regions and found prolonged periods of rigor when cadavers were kept at 4°C. In the 146 bodies in the study, complete rigor persisted between 10 and 16 days, and two corpses showed persisting signs of partial rigor until day 28 (Varetto & Curto, 2005). Perimortem metabolic state is affected by the activity the decedent was doing immediately before death; vigorous activity results in a more rapid onset of rigor (Goff, 2010). Secondary flaccidity is the softening of muscles and disappearance of rigor as putrefaction develops. The disappearance of rigor disappears follows the same pattern as its onset, with changes first seen in the facial muscles (Camps, 1968).



Figure 1.2. An example of rigor mortis (Mesri, Behzadnia, & Dorooshi, 2017).

1.2 Stages of Decomposition

Payne (1965) established a series of five stages of decomposition from death to skeletonization both with and without the presence of insects. These stages delineated decomposition largely in terms of insect activity and odors of decay, with some physical descriptions. Carcasses in the “fresh” stage attracted insect activity within five minutes of deposition and had no odors of decomposition. The “bloat” stage was marked by abdominal inflation, the formation of bubbles of blood around body cavities, prolific insect activity, the tightening of abdominal skin, and the permeation of decay odors around the body. The “active decay” stage is characterized by continued insect activity that penetrates the skin, the complete removal of flesh from the head and anus, and the presence of maggots. The “advanced decay” stage is characterized by the removal of most of the flesh from the carcass and the fading of decomposition odors. The “dry” stage occurs when only dry skin, cartilage, and bones are present (Payne, 1965).

Galloway (1997) established a series of five stages of decomposition from death to skeletonization in the Arizona Sonoran Desert. These stages defined each stage in

terms of carcass appearance. A variation of Galloway's (1997) stages of decomposition were used to evaluate the decomposition of pig legs in this study.

1. Fresh Remains
 - a. Fresh, no discoloration or insect activity
 - b. Fresh burned
2. Early Decomposition
 - a. Pink-white appearance with skin slippage and some hair loss
 - b. Gray to green discoloration, some flesh relatively fresh
 - c. Discoloration to brownish shades particularly to fingers, nose, and ears; some flesh still relatively fresh
 - d. Bloating with green discoloration
 - e. Post bloating following rupture of the abdominal gases with discoloration going from green to dark
 - f. Brown to black discoloration of arms and legs, skin having leathery appearance
3. Advanced Decomposition
 - a. Decomposition of tissues producing sagging of the flesh, caving of the abdominal cavity, often accompanied by extensive maggot activity
 - b. Moist decomposition in which there is bone exposure
 - c. Mummification with some retention of internal structures
 - d. Mummification of outer tissues only with internal organs lost through autolysis or insect activity
 - e. Mummification with bone exposure of less than half the skeleton
 - f. Adipocere development
4. Skeletonization
 - a. Bones with greasy substances and decomposed tissue, sometimes with body fluids still present
 - b. Bones with desiccated tissue or mummified tissue covering less than one half the skeleton
 - c. Bones largely dry but still retaining some grease
 - d. Dry bone
5. Extreme Decomposition
 - a. Skeletonization with bleaching
 - b. Skeletonization with exfoliation
 - c. Skeletonization with metaphyseal loss with long bones and cancellous exposure of the vertebrae

(Galloway, 1997)

Even after skeletonization is reached, the degradation of remains is not complete. Dry bones located on the surface of the ground become weathered with time and exposure to the elements. Behrensmeyer (1978) investigated bone weathering as a predictable and measurable method of bone aging and established the discipline in the scientific community. The groundbreaking study on bones in the Amboseli Basin investigated bones in six habitats: swamp, dense and open woodland, plains, bush, and lakebed. The study established a series of six bone weathering stages (Figure 1.3 a-e) (Behrensmeyer, 1978). Stage 0 is defined by the absence of cracks and flakes and the presence of grease. Tissue, skin, and muscles may still be present. Stage 1 is defined by some longitudinal cracking; mosaic cracking may be present on articular surfaces. Stage 2 is defined by flaking on the outermost thin layers of bone. Long, thin flakes that are still partially connected to the bone on one side are common. Stage 3 is defined by patches of rough, uniformly weathered compact bone, and all external bone layers have been removed. Weathering penetrates a maximum of 1.5 mm at this stage. Stage 4 is defined by a coarse, fibrous texture and the presence of splinters of varying sizes. Stage 5 is defined by a weak bone structure, which may fall apart in situ and is easily broken by moving. Large splinters may be present lying around the bone, and the original bone shape may be indistinguishable (Behrensmeyer, 1978).

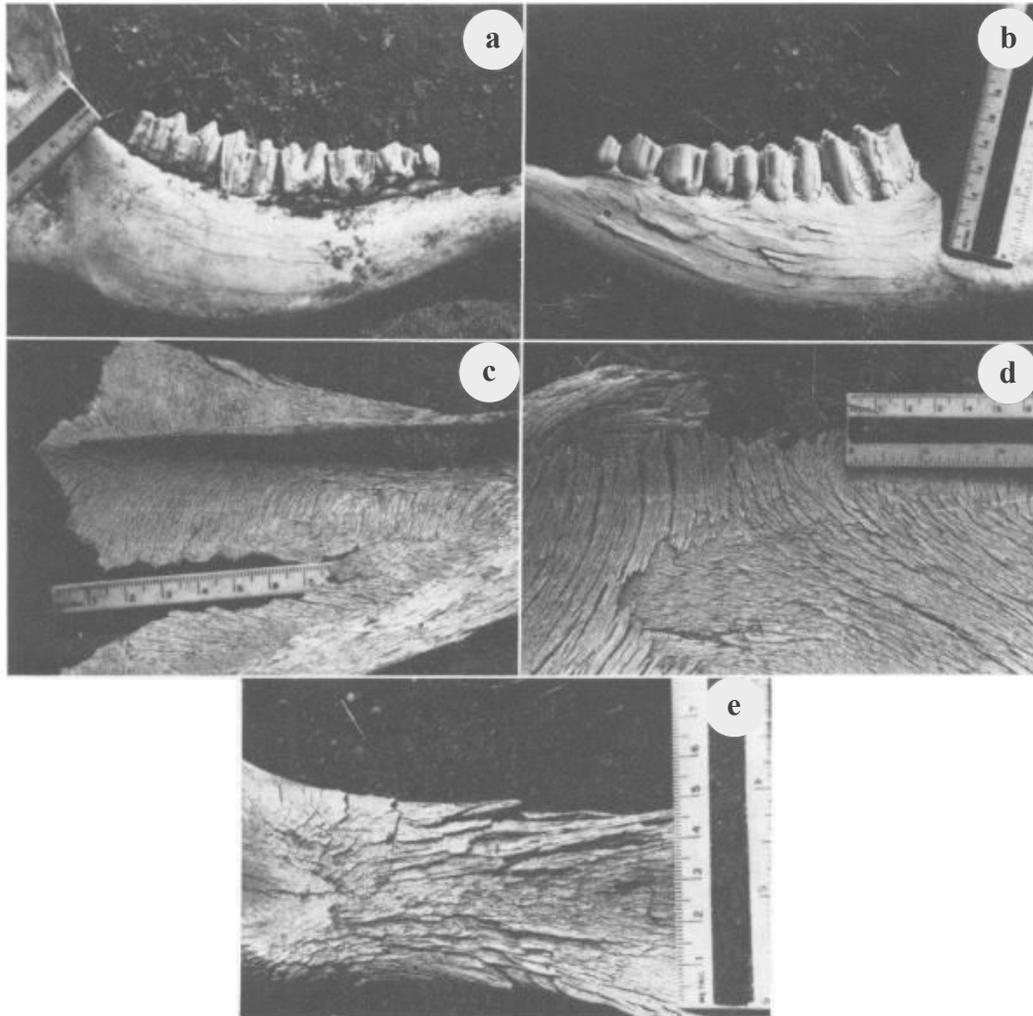


Figure 1.3 a-e. Five stages of bone weathering: **(a) Stage 1:** initial longitudinal cracking, **(b) Stage 2:** flaking of outer bone layers, **(c) Stage 3:** a fibrous, rough texture, **(d) Stage 4:** deep cracking and layered fiber structure, and **(e) Stage 5:** deep cracking and splitting (Behrensmeyer, 1978).

1.3 Factors That Influence Decomposition Rates

1.3.1 Temperature

Temperature has some of the greatest influence on the rate of decomposition (Mann et al., 1990). Low temperatures are associated with slower decomposition rates, in part because of the effect temperature has on insect activity and survival rates of larvae. Diptera flies remain active in winter until the temperature reaches 5 to 13°C

(Mann et al., 1990). One study performed with *Calliphora varifrons* found that the flies successfully developed between 12 and 27°C; a linear estimate of the lower developmental threshold showed a minimum temperature of 4.20°C for development (Voss, Cook, & Dadour, 2014). Below this temperature, fly eggs will die, and maggot masses will only survive inside body cavities, where they are present in large numbers and produce their own heat (Mann et al., 1990). Alternatively, high temperatures have been linked to increased insect activity and accelerated decomposition rates. However, temperatures exceeding 30°C are also fatal to *C. varifrons* larvae and limit the effects insect activity has on decomposition (Voss et al., 2014).

Bacteria can only survive and function within specific temperature ranges, and low temperatures inhibit bacterial activity (Gill-King, 1997). Autolysis and other chemical processes involved in decomposition are also decelerated in cold temperatures, thus slowing decomposition. Chemical reactions follow Van't Hoff's rule, which states that the rate of a chemical reaction doubles with each 10°C rise in temperature. Conversely, a 10°C drop in temperature will halve the rate of a reaction. Normal human body temperature is about 37°C, and enzymes operate optimally at this temperature, accelerating reactions in cells to 10^8 to 10^{10} times uncatalyzed rates (Gill-King, 1997). With the onset of algor mortis after death, enzymatic reactions are slowed, and autolysis can be essentially halted at sufficiently low temperatures. Alternatively, elevated temperatures such as those experienced when bodies are deposited in hot, sunny regions accelerate autolysis.

1.3.2 Entomological Activity

When temperature differences are accounted for with accumulated degree days (ADD), insects have the greatest impact on decomposition (Simmons, Adlam, & Moffatt, 2010). Necrophagous insects, especially flies, are attracted to body cavities and wounds, which offer ideal environments for egg and larval deposition (Goff, 1993). The feeding of insect larvae on carcasses destroys soft tissue and greatly accelerates decomposition (Mann et al., 1990). In some instances, animal carcasses have been skeletonized within four days of death solely from the activity of fly larvae (Haskell, Hall, Cervenka, & Clark, 1997). Maggot masses (Figure 1.4) also generate heat, which increases carcass temperature and can accelerate chemical decomposition processes (Goff, 1993). When insects are prevented from accessing a carcass (such as underwater submersion or sealed in a plastic bag), decomposition processes can progress more slowly.



Figure 1.4. A maggot mass (photograph credit: Megan Descalzi).

There are four main categories of insects associated with decomposing remains: necrophagous species, predators or parasites of necrophagous species, omnivorous species, and adventitious species (Campobasso, Di Vella, & Introna, 2001). Necrophagous species feed exclusively on the decomposing tissues of remains and have the greatest forensic implications. The most notable necrophagous species are the larvae of a number of flies in the order Diptera, especially *Calliphoridae* and *Sarcophagidae*, although adults of these species are not necrophagous (Figure 1.5 a) (Campobasso et al., 2001). Flies in these species are typically fast to arrive at remains and have been observed within minutes of body deposition (Archer & Elgar, 2003; Campobasso et al., 2001; Goff, 2010; Payne, 1965). Flies are also attracted to carcasses as sites for oviposition and larviposition because of the moist and protein-rich environments that they offer (Archer & Elgar, 2003). Some beetles in the order Coleoptera, especially *Silphidae* and *Dermestidae*, are also necrophagous species (Figure 1.5 b) (Campobasso et al., 2001). Their succession patterns are predictable and can be used in forensic cases involving late stages of decomposition for PMI estimations when flies are no longer present (Kulshrestha & Satpathy, 2001; Zanetti, Visciarelli, & Centeno, 2015).

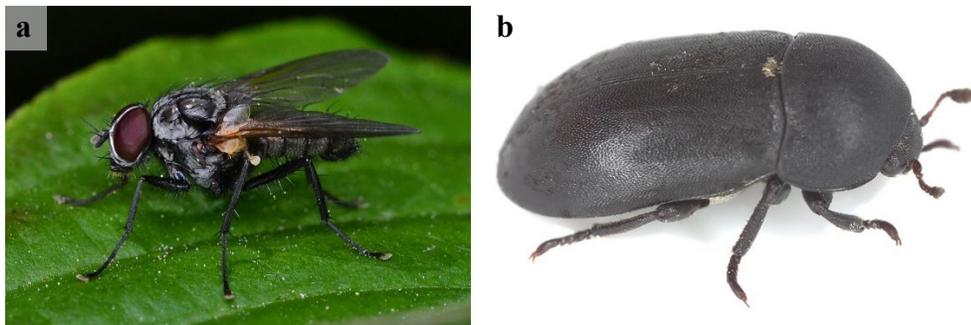


Figure 1.5 a-b. Common necrophagous species of insects. **(a)** Diptera (Hodnett, 2017). **(b)** *Dermestidae* (“Dermestidae Beetle,” n.d.).

Predators or parasites of necrophagous species are also forensically important, although less so than necrophagous species; predators include some species of the orders Diptera and Coleoptera, and parasites include some species of the order Hymenoptera (Campobasso et al., 2001). While some Diptera and Coleoptera species are necrophagous, not all fit in this category, and others feed on necrophagous species. Other species are both necrophages and predators at different points of their life cycle; for example, the larvae of some Diptera species, notably the *Calliphoridae* (Figure 1.6 a), feed on carcasses but prey on other insects in the late stages of their development (Campobasso et al., 2001). Some Hymenoptera species, especially wasps (Figure 1.6 b), also prey on Diptera larvae and pupae and reduce the size of their populations (Campobasso et al., 2001).

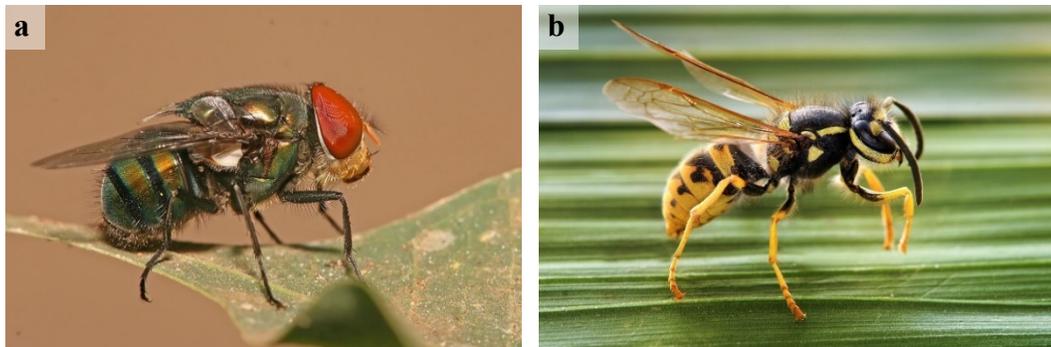


Figure 1.6 a-b. Common predators or parasites of necrophagous species of insects. **(a)** Diptera: *Calliphoridae* (Karim, 2009). **(b)** Hymenoptera: *Vespidae* (Bartz, 2007).

Omnivorous species feed on both decomposing remains and the arthropods that are attracted to the remains (Campobasso et al., 2001). Large populations of these species, which include wasps, ants, and some beetles, can diminish the populations of necrophagous insects, which in turn reduces the impact on decomposition rates. Early

and Goff (1986) found that the removal of Diptera larvae by ants (Figure 1.7) slows the rate of decomposition by reducing the amount of flesh the larvae consume (Early & Goff, 1986). Graphs of removal rates in these cases (Figure 1.8) resemble those obtained in Payne's (1965) experiments (Figure 1.9 a-b) that excluded entomological activity (Early & Goff, 1986).



Figure 1.7. Hymenoptera carrying a larva (Darras, n.d.).

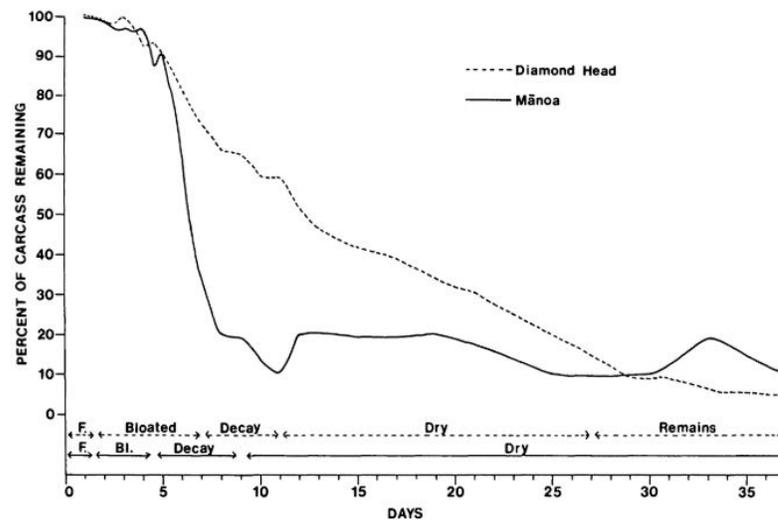


Figure 1.8. Rate of carcass removal at Diamond Head and Manoa by weight (Early and Goff, 1986).

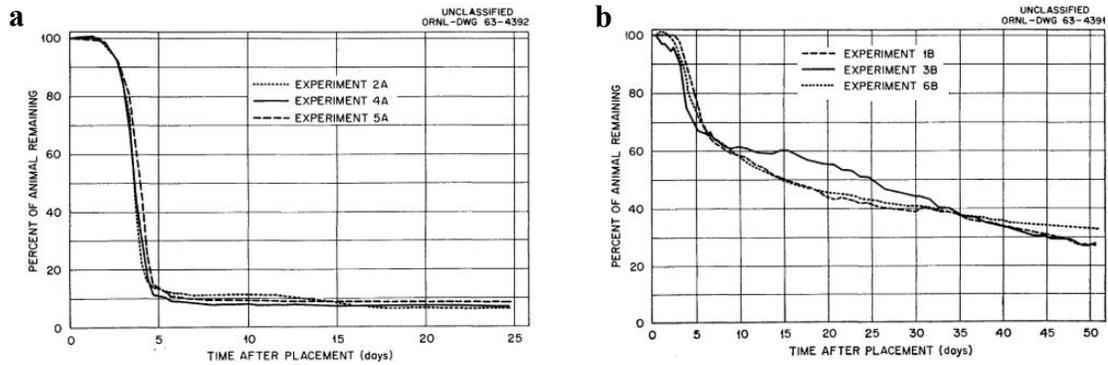


Figure 1.9 a-b. Rate of carcass removal by weight (a) with insect activity and (b) without insect activity (Payne, 1965).

Adventitious species use a carcass and incorporate it into their environment (Campobasso et al., 2001). These species live in vegetation or subsoil but emerge when a carcass is present to use it as a new habitat either permanently or sporadically; some also prey on necrophagous insects (Campobasso et al., 2001). For example, many *Staphylinidae* species of beetles (Figure 1.10) arrive at a body within days of death and remain there until insect activity ceases (Smith, 1986). Adults of these species also prey on Diptera larvae and have been observed to follow these larvae into the soil as they moved away from the carcass (Smith, 1986).



Figure 1.10. *Staphylinidae* (Villers-Golde, 2013).

1.3.3 Carcass Size

Carcass size can also influence decomposition rates (Simmons, Adlam, et al., 2010). Studies on the effect of carcass size on decomposition rates have yielded conflicting results, possibly due to different methods of measuring decomposition rates. Some studies have found that small carcasses decay and become skeletonized faster, likely because larval masses have a proportionally larger volume on smaller carcasses than on larger ones, so flesh consumption is proportionally faster. Conversely, large carcasses were found to decay slower because of the higher flesh content for insects to consume. When insects are not present, no change in decomposition rates were observed when carcass size varied (Simmons, Adlam, et al., 2010). Differences in decomposition rates are most obvious when comparing bodies of drastically different masses, such as an infant and an adult (Komar & Beattie, 1998). One study found that an infant was skeletonized in five days, while an adult human and a pig analog were skeletonized in 15 to 25 days (Catts & Goff, 1992).

Hewadikaram and Goff (1991) compared arthropod activity and decomposition rates of two pig carcasses, one 8.4 kg and one 15.1 kg (Figure 1.11). The study found that both carcasses attracted the same arthropod species and succession patterns, but the larger carcass attracted larger numbers of insects and decomposed more rapidly (Hewadikaram & Goff, 1991). This month-long study measured decomposition rates with percent of carcass remaining per day and concluded that the larger carcass lost a greater percentage of mass per day during the active decay stages, largely due to the higher consumption of flesh by insects. However, the smaller carcass was skeletonized about a week earlier than the larger carcass. Although larger carcasses lose greater

amounts of flesh to insects faster, they still require more time to skeletonize than smaller ones (Hewadikaram & Goff, 1991).

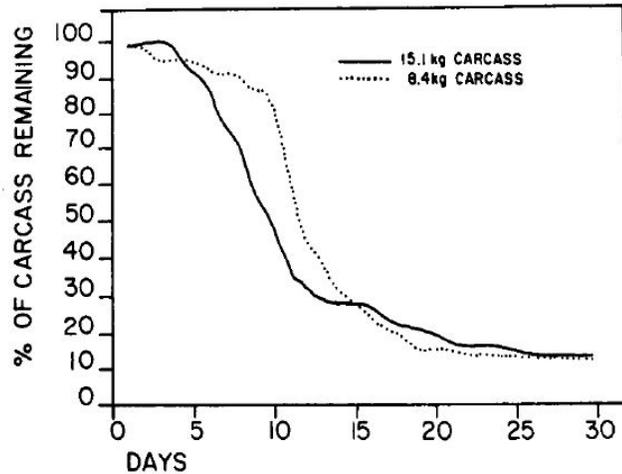


Figure 1.11. Rates of body mass removal over time, represented as percent of carcass remaining (Hewadikaram & Goff, 1991).

1.3.4 Burial

Carcasses that are buried decompose slower than those deposited on the surface of the ground (Mann et al., 1990; Rodriguez, 1997). This phenomenon can be attributed to the physical barrier to insect activity, animal scavenging, and solar radiation that soil can provide; depending on burial depth, soil can either limit or prevent the effects these factors from reaching a body (Rodriguez, 1997). At depths of less than one foot, the odors of decomposition that a body produces can penetrate the shallow soil and attract insects and animals. Some insect species, such as blowflies, migrate through the soil to lay eggs on the carcass; carnivores will also dig up parts of or entire bodies for food (Rodriguez, 1997). Soil is also a barrier to solar radiation, and temperatures and temperature changes decrease as depth increases. Carcasses buried at depths of less than

a foot experience temperatures similar to those above the surface, while those buried at depths greater than two feet are temperature-protected (Rodriguez, 1997). Some experts argue that the greatest influence for decreased decomposition of buried remains is the prevention of insect access (Simmons, Cross, Adlam, & Moffatt, 2010). Simmons, Cross, et al. (2010) propose that accumulated degree days can be used to estimate post-mortem interval in these cases in the same way as surface deposition estimates, as long as an insect-exclusion model is used (Simmons, Adlam, et al., 2010).

Bodies that are buried one to two feet below the surface may reach skeletonization within a few months to a year, but those buried at three to four feet can take years to reach the same level of skeletonization (Mann et al., 1990). The complete degradation of the resulting skeletal remains requires several more years; the survival of numerous archaeological specimens demonstrates how lengthy this process can be and that it is possible skeletal remains to remain intact for centuries (Rodriguez, 1997). Soil pH and moisture are factors that influence skeleton degradation rates. Skeletons in wet, alkaline, or acidic environments decay the most rapidly and can be completely degraded in a few years (Rodriguez, 1997). Alternatively, mummification is another possible fate for buried bodies when environmental conditions are not favorable for decomposition. It is most often seen in carcasses that are buried in shallow graves during the winter and are found in the spring or summer because the shift from freezing winter temperatures to warm weather creates a freeze-drying effect that desiccates the carcass and mummifies it (Rodriguez, 1997).

The burial of a carcass can affect the vegetation surrounding the gravesite, and this can aid in locating clandestine graves. Buried carcasses release nutrients into the

surrounding soil as they decompose, and plant roots grow towards the rich source of nutrients when the carcass is buried at sufficiently shallow depths. This results in increased vegetation growth around a shallow grave, which can make the grave easier to locate (Rodriguez, 1997). The roots of these plants can also grow into skeletal remains and clothing, and root growth can assist with PMI estimations in cases of burials greater than one year (Willey & Heilman, 1987). Alternatively, deep burials result in decreased vegetation growth because digging the grave harms plant roots, and the carcass is too deep to replenish soil nutrients to help plants recover (Rodriguez, 1997). An outlined soil depression is also seen in these cases because the soil resettles over time, making a “primary grave depression”; greater burial depths result in more pronounced soil depressions. When a body is buried and bloats below ground, soil is pushed upwards; the resettling of the soil into the chest cavity as the flesh subsequently decomposes creates a “secondary grave depression” (Rodriguez, 1997).

1.3.5 Scavenging

There are three main classes of scavengers: omnivores, insectivores, and carnivores. Omnivores can best exploit both the flesh and insects on a carcass and can accelerate decay rates. Insectivores, which include birds and mammals, feed on insects on and around remains, including maggots, larvae, and adult insects (O’Brien, 2008). Insectivore activity is greatest when insects are most active, and their feeding can alter the effect insects have on decomposition if they remove high numbers of larvae. Carnivores will eat the flesh from carcasses, which can greatly increase the mass loss and decay rate (Mann et al., 1990).

1.3.5.1 Terrestrial Scavengers

Small omnivore scavengers, such as rodents, can feed extensively on the face, extremities, and abdomen. Rodent scavenging can progress quickly, obscure bone features, and alter perimortem trauma sites (Pokines et al., 2016). Rodent scavenging is usually evident in bone gnawing, and different species exhibit different scavenging patterns (Figure 1.12). For example, rats have been found to gnaw on fat-laden cancellous bone to consume nutrients, while squirrels were observed to gnaw on thicker parts of bones to consume minerals (Klippel & Synsteliën, 2007). Some instances of rodents nesting within human remains have also been observed (Haglund, 1992).



Figure 1.12. Grooves created by gnawing on bone from rodent scavenging (Abel, 2011).

Canids are some of the most common carnivorous scavengers of human remains, especially dogs and coyotes (Haglund, 1997). Canid scavenging peaks when human population density is low (less than 201 people per 2.56 km²); increasing human population densities is linked with decreased canid scavenging rates (Haglund, Reay, & Swindler, 1989). Scavenging by these species leads to modification and consumption of

flesh, disarticulation, skeletal artefacts, and transport of bones away from the body (Haglund, 1997). In forensic cases, carnivore scavenging can complicate determinations of cause and manner of death by modifying or destroying perimortem wounds, clothing, and other evidence. Canid scavenging begins with the removal of skin and flesh from the face and neck. Damage to bones at this stage is minimal, with possible minor damage to the thin bone surrounding eye sockets and consumption of the hyoid and other small bones in the neck. Scavenging then typically progresses to the abdomen, pelvic region, and thighs, which is either followed or accompanied by the disarticulation of upper extremities (Haglund, 1997). Disarticulated extremities and other bones are typically extensively gnawed and scattered up to a quarter of a mile away from the body (Haglund, 1997; Mann et al., 1990). Skeletal artefacts left by carnivore scavenging can be assigned to three categories: pits (including punctures), striations, and furrows (Figure 1.13 a-c) (Horwitz & Smith, 1988). Canine punctures leave characteristic V-shaped marks on bone (Figure 1.14) (Haglund, 1997).

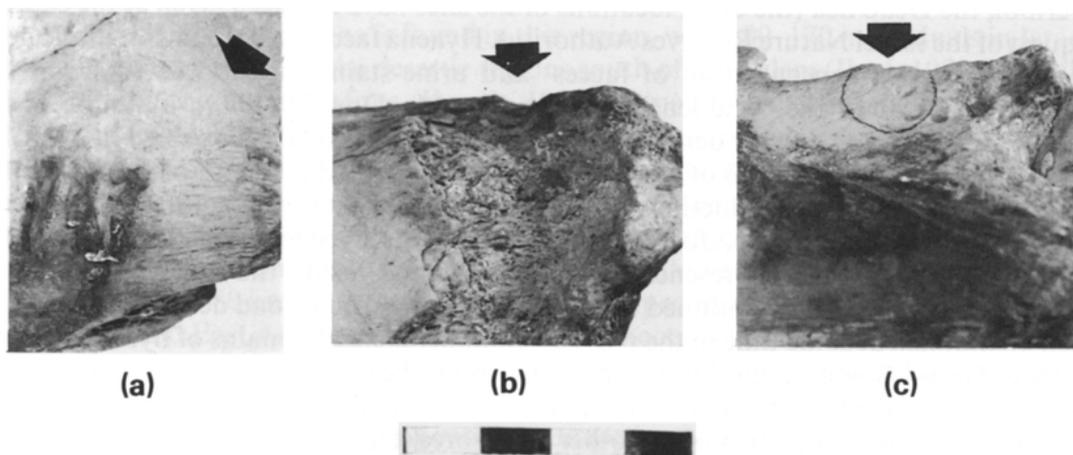


Figure 1.13 a-c. Skeletal artefacts from carnivore scavenging: **(a)** furrows, **(b)** striations, and **(c)** pits (Horwitz & Smith, 1988).

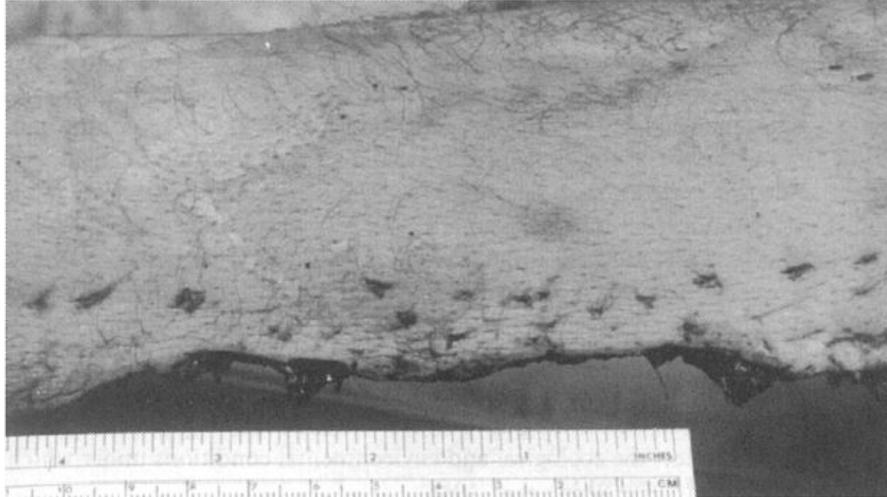


Figure 1.14. V-shaped punctures from canine scavenging (Haglund, 1997).

Some bird species are voracious scavengers and are known for their consumption of remains, such as vultures and condors. In Australia, the Australian Raven (*Corvus coronoides*) is an abundant avian scavenger commonly associated with predation of livestock and consumption of refuse (O'Brien, Larcombe, Meyer, Forbes, & Dadour, 2010). It is an omnivore, though its diet is largely made up of decomposing remains, and the birds are capable of completely consuming bodies. Extensive study of its scavenging patterns has shown that the Australian Raven is diurnal and is most active in autumn and winter. The most intense Australian Raven scavenging occurred in the fourth and final stage of the breeding cycle, after eggs hatched but before juveniles became independent (Figure 1.15 a-b). The birds were observed dispersing small bones, but larger pieces were shifted only small distances (O'Brien et al., 2010).

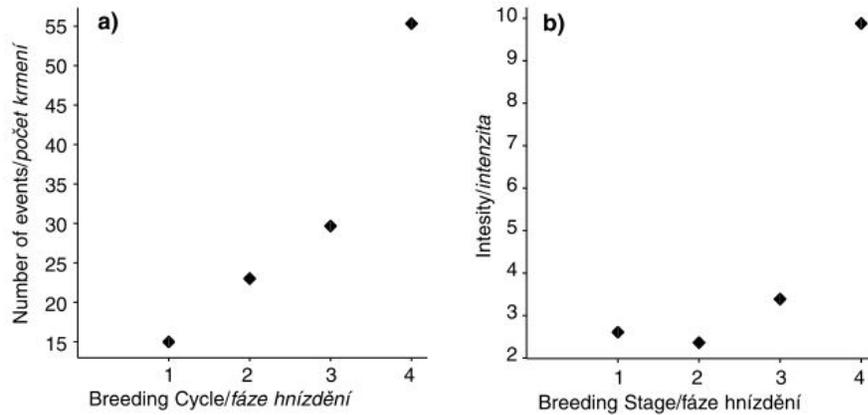


Figure 1.15 a-b. Mean daily intensity of Australian Raven scavenging in terms of (a) mean number of events and (b) mean intensity (mean number of feeding events by day) by breeding cycle phase (O'Brien et al., 2010).

1.3.5.2 Marine Scavengers

Sharks have been known to both attack living people and scavenge on remains, although the former is more common and better-studied (Stock, Winburn, & Burgess, 2017). However, it is important to note that shark attacks on live people are not as common as sensationalized media coverage and portrayal in popular culture have led the public to believe. The three most common shark species involved in attacks and scavenging are the white shark (*Carcharodon carcharias*), tiger shark (*Galeocerdo cuvier*), and bull shark (*Carcharhinus leucas*) (Burgess & Callahan, 1996; Clua, Bescond, & Reid, 2014; Iscan & McCabe, 1995; Rathbun & Rathbun, 1984). Less-severe injuries can also sometimes be attributed to smaller species like the blacktip shark (*Carcharhinus limbatus*) and the spinner shark (*Carcharhinus brevipinna*) (Lentz et al., 2010). Sharks typically attack the limbs because they are deeper in the water and move more actively than the torso and head (Stock et al., 2017). When eyewitness accounts are unavailable, the species of shark responsible for an attack or scavenging event can be

determined from shark teeth evidence, both in the form of bite marks and the teeth themselves, on the rare occasions that they are present (Figure 1.16) (Iskan & McCabe, 1995; Stock et al., 2017). Shark artefacts on bones can be grouped into five categories: puncture without associated fractures, punctures with associated fractures, incised bone gouges, striations with bone shaving, and overlapping striations (Stock et al., 2017). Tooth marks and other postmortem modification on human remains can be obscured by sand, waves, and extended postmortem intervals (Pokines & Higgs, 2015; Stock et al., 2017). Although sharks do not typically eat drowning victims, cases with human remains in the stomachs of tiger sharks (*Galeocerdo cuvier*) have been recorded (Boyle, Galloway, & Mason, 1997; Rathbun & Rathbun, 1984). In these cases, artefacts on bones are generally obscured through gradual digestion and decalcification of bone from the digestive tract.

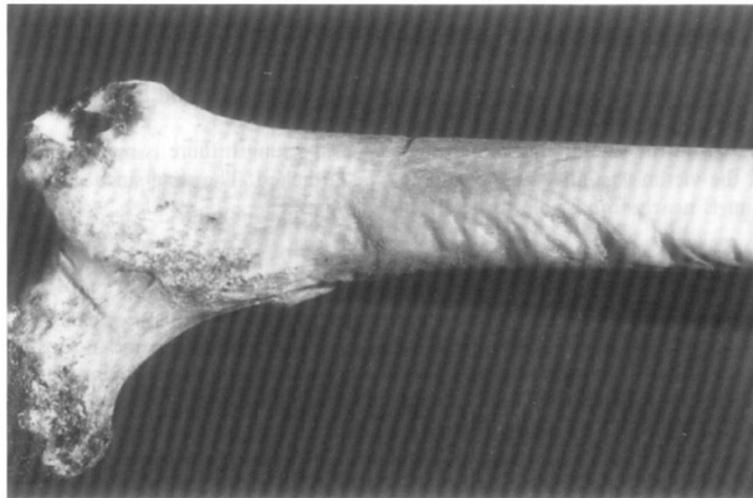


Figure 1.16. Deep gouges without fractures from shark scavenging on a human femur (Iskan & McCabe, 1995).

Fish scavenging activity can cause extensive damage to a body, and the response time for fish to begin scavenging on newly deposited bodies can be rapid (Boyle et al., 1997; Sorg et al., 1997). A wide variety of fish species have been observed scavenging on remains, including sunfish, dace, sculpin, dogfish, parrotfish, dogfish, and wrasse (Byrd & Castner, 2001; Sorg et al., 1997; O'Brien pers comm, 2018). No data has yet provided insight to any feeding preferences by species to specific regions of the body, and the extent of scavenging behavior is difficult to predict (Sorg et al., 1997). However, fish typically gnaw at the ears, lips, and soft regions of the face, which can obscure facial or obliterate characteristics and complicate body identification when remains are recovered (Boyle et al., 1997). In cases of heavy scavenging, fish can skeletonize a body in as little as two weeks (Boyle et al., 1997). Parrotfish, among others, have also been observed to feed on algae adhering to the surface of bodies and bones (Pokines & Higgs, 2015).

Scavenging by arthropods, including barnacles, crabs, shrimp, and lobster, can cause the most commonly seen damage in marine taphonomic investigations (Boyle et al., 1997; Pokines & Higgs, 2015). Marine crustaceans can be divided into two groups for forensic purposes: large macroscavengers (including crabs, large shrimps, and lobsters) and small microscavengers (including small shrimps, sea lice, and beach fleas) (Sorg et al., 1997). Macroscavengers are important for decomposition because feeding by these species open bodies that have settled on the ocean floor (Sorg et al., 1997). Anderson and Bell (2014) conducted a study in the Saanich Inlet, British Columbia, which is hypoxic (low dissolved oxygen levels) or anoxic (no dissolved oxygen) depending on the season. Pig remains that were deposited during the hypoxic time period

were scavenged by large crustaceans and skeletonized in three weeks (Figure 1.17), while remains that were deposited in the anoxic season were scavenged only by microscavengers and required 90 days for complete skeletonization (Anderson & Bell, 2014). Extensive feeding by macroscavenger species leaves artefacts on remains, and it has been suggested that the size of crustacean colonies can be used to determine length of submersion time (Byrd & Castner, 2001; Smith, 1986). Crabs scavenge preferentially around eyes, facial flesh, and soft internal organs; the extent of flesh loss in these regions can aid in postmortem interval determinations when crabs are primary scavengers (Sorg et al., 1997).



Figure 1.17. Scavenging by crabs on pig remains (Anderson & Bell, 2014).

1.3.6 Sun-Exposed vs. Shaded

The long-term exposure of a carcass to sun can also influence the rate of decomposition. Carcasses deposited in locations exposed to sunlight reportedly have accelerated rates of decomposition compared to carcasses deposited in the shade nearby (Shean, Messinger, & Papworth, 1993). In Shean, Messinger, and Papworth's (1993)

study, a sun-exposed carcass reached a minimal stable weight two weeks before a carcass deposited in the shade. This observation was attributed to differences in maggot development, which was affected by the surface temperatures of the carcasses at the two sites (Shean et al., 1993). Another study found that full and partial shade delayed insect colonization, thereby slowing decomposition rates (Komar & Beattie, 1998).

1.4 Location

Decomposition on large land masses has been widely studied and is well-documented. The stages and rates of decomposition, entomological influences, and scavengers have been extensively studied in a wide range of mainland locations and environments (Bass, 1997; Galloway, 1997; Haglund, 1997; O'Brien, 2008; Payne, 1965). The research in this area has established a robust method for PMI estimations and is commonly used in criminal investigations and forensic cases. Decomposition in marine and small island environments follows the same general patterns as that on large masses, but the unique environmental factors and scavenging guilds that each of these environments present can greatly alter decomposition patterns.

1.4.1 Marine Taphonomy

The two major categories of water where bodies can be found are freshwater and seawater, which both affect submerged bodies differently (Davis, 1986). Submersion in freshwater, which includes pools, bath tubs, and lakes, results in the absorption of up to six pints of water into blood, abruptly increasing blood volume and tearing lungs and other tissues (Boyle et al., 1997; Davis, 1986). Alternatively, seawater is highly saline

and draws water from the blood to the lungs. The differences between these two circumstances, combined with water temperature differences and other factors, results in variations of autolysis rates and bacterial distributions (Davis, 1986).

The investigation of freshwater deaths is typically more straightforward than that of marine remains, in part because freshwater locations are more easily accessible and the bodies found within them are recovered more rapidly (Boyle et al., 1997). Alternatively, marine decomposition is more difficult to study and reconstruct than that on land; bodies found in the ocean are often discovered accidentally, and they can sometimes only be recovered from shallow waters or with the help of divers (Sorg et al., 1997). It is often difficult or impossible to visit and correctly identify underwater scenes, so reconstructing them to estimate post-mortem interval presents logistical challenges for marine taphonomists, and such reconstructions are usually indirect (Sorg et al., 1997).

The most common cause of death in marine forensic cases is drowning (Boyle et al., 1997). Drowning introduces water and microorganisms into the lungs and increases blood pressure. This change in blood pressure often causes hemorrhaging in the lungs, middle ears, and mastoid air cells, which accelerates the autolysis within these tissues. Perimortem injuries to soft tissue, when present, provide access points for scavengers and accelerate decomposition (Boyle et al., 1997). Bodies submerged in the ocean may decompose slowly or rapidly, depending on a number of variables, including temperature, depth, currents, salinity, and the number and type of scavengers present (Sorg et al., 1997). Generally, cold waters slow decomposition processes, while warmer and more tropical seas accelerate them, although both cases are still slower than that of terrestrial

remains. Greater access to the water's surface, biodiversity, and water movement have also been linked to accelerated decay (Sorg et al., 1997).

A body generally sinks immediately upon entering the but can sometimes remain afloat if air is trapped in clothing (Boyle et al., 1997). The appearance of deep grooves in the skin, known as washerwoman's hands, is one of the first changes that occurs after submersion and can be seen as early as half an hour after submersion in 50°C water (Figure 1.18). The body will resurface when putrefaction begins and makes the body buoyant. However, the rate of this process is temperature-dependent and is slow in salt water because the salt hinders bacterial activity (Boyle et al., 1997). In addition to buoyancy, skin slippage also commonly accompanies the putrefaction stage.



Figure 1.18. An example of washerwoman's hands ("Washerwoman's skin," n.d.).

After a body resurfaces, the portions of the body that remain submerged continue to experience skin slippage, while the exposed portions of the body become available to birds and insects (Boyle et al., 1997). During this stage, the head, arms, and legs can become separated from the abdomen; the remains continue to float until the gases formed from putrefaction are released, then sink again. Soft tissue is usually removed from the

head, hands, feet, and lower legs before the rest of the body because they are most vulnerable and can brush against sand, rocks, and other objects in the water. Postmortem injuries, including those caused by scavengers boat propellers, and fishing equipment, can also accelerate soft tissue destruction (Boyle et al., 1997).

Adipocere is an odorless, gray-white mixture of decomposing fatty acids and mummified muscles and tissues that can form on submerged remains (Boyle et al., 1997). This process may take weeks, months, or years to form and is typically seen in late stages of decomposition when present. Adipocere formation is dependent on the presence of excess moisture, warmth, skin, subcutaneous tissue, and fat. Because moisture is necessary for its formation, adipocere is primarily seen with marine decomposition, but it is also not uncommon on terrestrial remains as long as the body retains moisture (Boyle et al., 1997).

1.4.2 Small Island Taphonomy

Small island taphonomy is a lesser studied branch within the broad realm of taphonomic research and involves the fate of both terrestrial and marine remains. Preliminary research has revealed that decomposition and scavenging of remains on small islands is different than those on large land masses (O'Brien pers comm, 2018). Fewer large species live on islands than on large land masses, and the number of species tends to be lower on islands as well (O'Brien pers comm, 2018). Additionally, the species present in both locations can vary greatly because of the different traits necessary to survive in the different environmental and climatic conditions. Small island marine taphonomy can also be different from that in the open ocean, which is more well-studied.

Environmental factors (e.g. wave action and water temperature) and scavenging guilds differ between the two environments; however, further study is required to uncover the full extent of these differences and the impact on taphonomic processes. O'Brien's global exploration of small island taphonomy has also revealed inter-island differences in scavenging patterns that require further study to understand the true scope of small island taphonomy (O'Brien pers comm, 2019).

1.5 Australia

As of June 2019, Australia (Figure 1.19) has a population of just under 25.4 million people and a surface area just over 7.5 million km² (Australian Bureau of Statistics, 2019). This calculates to a population density of approximately 3.38 people/km². Western Australia has a population of 2.62 million people and a surface area of just over 2 million km², which calculates to a population density of approximately 1.31 people/km² (Australian Bureau of Statistics, 2019).



Figure 1.19. Map of Australia. Rottneest Island is marked with a yellow star (Google Maps).

1.5.1 Rottnest Island

Rottnest Island is located on the west coast of Western Australia, approximately 19 km west of Fremantle (Figure 1.20). As of 2016, Rottnest Island (colloquially called Rotto) has a population of 334 and a surface area of 19 km², which calculates to a population density of 17.6 people/km² (Van Noort, 2006). Tourism on the island fluctuates seasonally, and tourists can increase the island population by 1,000 people during slow months to 15,000 people during the peak season (Van Noort, 2006). Tourists increase the population density to between 70.2 and 807 people/km².

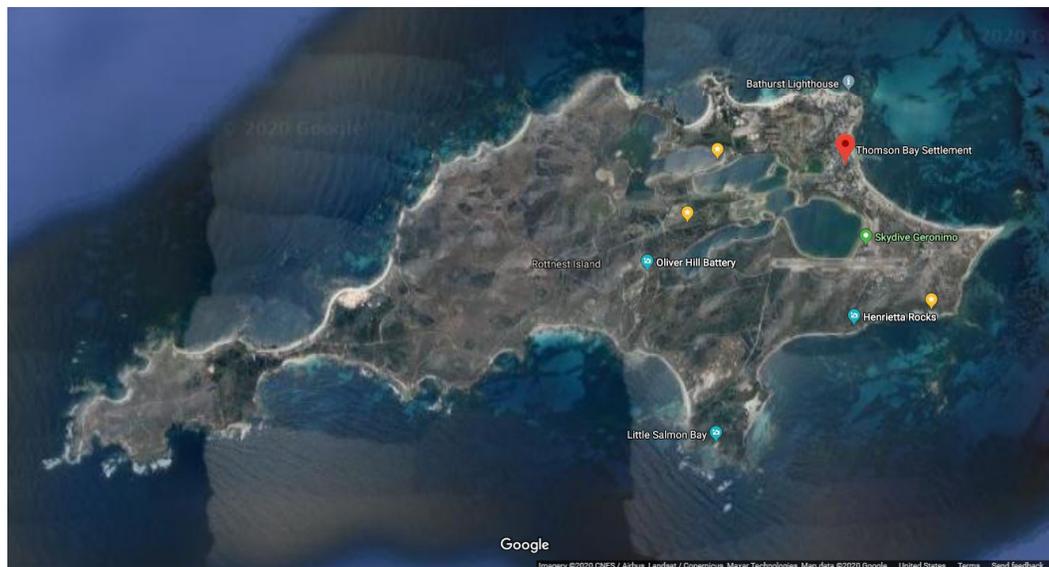


Figure 1.20. Map of Rottnest Island (Google Maps).

Rottnest Island is perhaps best known for its quokkas (*Setonix brachyurus*), a native rodent species that is found exclusively on the island (Rippey & Hobbs, 2003). Settlers arrived on Rottnest in 1831 and began to develop the land and kill quokkas for food, which nearly eradicated the species. Legislation to prohibit shooting and protect quokka populations was first passed in 1917; by 1932, quokka populations had recovered

and were reportedly so numerous that the crops they grazed on began to suffer (Rippey & Hobbs, 2003). Today, quokka populations are still protected, since they are considered a threatened species (Rippey & Hobbs, 2003). The island is an A class reserve, which is the highest protection public land can receive (Rippey & Hobbs, 2003). Although Rottnest Island is a popular tourist destination, most tourists tend to populate the major beaches, and many bays along the southern and western ends of the island remain free from extensive human activity because of difficult access points. Furthermore, several reserves remain on the interior of the island to protect vegetation and wildlife.

1.6 Forensic Implications

Decomposition and scavenging vary by location and environment, among other factors, so determining the impact of these factors on the taphonomic process is essential to forensic investigations. Postmortem interval estimations are complex and require interpretation by forensic pathologists; accurate determination of PMI are key to solving cases (Henssge, 1988). Decomposition rates and scavenging guilds on small islands are poorly studied, and further research in this area is necessary to properly evaluate forensic cases in these locations. Fishing is a common island pastime but can become fatal unexpectedly (7NEWS Perth, 2019; Hickey, 2019). Additionally, large numbers of bodies or body parts may be found in the ocean or washed ashore on islands following disasters at sea, including airplane crashes and shipwrecks. (Pokines & Higgs, 2015; Sorg et al., 1997).

1.7 Aims and Objectives

This research aims to understand the major taphonomic influences on Rottnest Island, Western Australia. The aims include the following:

- Identification of animals imaged at experimental sites,
- Establishment of a preliminary catalogue of terrestrial, hypersaline, and marine scavenging guilds on Rottnest Island, Western Australia,
- Study of scavenging patterns of the scavenging guilds by experimental location,
- Analysis of interactions between scavengers, and
- Determination of early decomposition rates.

The objectives of this research are to:

- Create an underwater camera system that can be operated from shore,
- Establish a standardized definition of a scavenging event,
- Define scavenging intensity, and
- Utilize Behavioral Observation Research Interactive Software (BORIS) to process marine imagery.



Chapter 2: Materials and Methods



University of New Haven

HENRY C. LEE COLLEGE OF
CRIMINAL JUSTICE AND FORENSIC SCIENCES

DEPARTMENT OF FORENSIC SCIENCE



2.1 Animal Model

Domestic pigs (*Sus scrofa*) carcasses are generally accepted proxies for human remains. They have several anatomical similarities, including size, skin thickness, and hair coverage, and they have been shown to attract similar species of scavengers (Dautartas et al., 2018; Schoenly et al., 2007). Pigs also offer logistical advantages over human remains: they are more easily obtainable, are more consistent in size and age, and raise fewer ethical concerns than do human cadavers (Matuszewski et al., 2019).

Two adult pigs weighing approximately 40 kgs were euthanized with a head bolt in accordance with standard industry practices. The carcasses were frozen and transported to Rottnest Island, where the carcasses were disarticulated. Seven of the legs were used for this research, and the rest of the carcasses were buried.

2.2 Overview

The research was conducted on Rottnest Island, Western Australia under accordance with the Rottnest Island Authority (Permit #2019/351333). Three different environments were selected for the study: marine, terrestrial, and hypersaline (Figure 2.1). Bickley Point, located on the southeast tip of the island, was the marine experiment site. Forbes Hill, located in the central region of the island, was the terrestrial experiment site. Lake Baghdad was the hypersaline experiment site.



Figure 2.1. Map of Rottneest Island with the three experimental sites (indicated by red stars) (Google Maps).

2.3 Equipment

2.3.1 Imaging

One SplashCam™ Delta Vision HD and two homemade cameras were used at Bickley Point. The latter were repurposed security system cameras that were fitted into generic underwater camera cases and sealed with super glue. One Browning™ (Model BTC-8FHD-PX), two Moultrie® (Model MCG-12596), one Moultrie® panoramic (Model MCG-12597), and two Toguard™ (Model H70) trail cameras were used at Forbes Hill and Lake Baghdad. A Nikon™ DX (Model D5100) camera was used to photograph the legs daily to document stage of decomposition and insect activity at each site.

2.3.2 Data Loggers

All data loggers took readings every 5 minutes and were downloaded at the conclusion of each experiment.

2.3.2.1 Temperature and Humidity

Gemini TinyTag™ data loggers (Model Aquatic 2 - TG-4100) were used to record water temperature at Bickley Point and Lake Baghdad. At Forbes Hill, a TinyTag™ Plus 2 Internal/External Temperature data logger (Model TGP-4510) was used to record ambient temperature. At Lake Baghdad, a Gemini TinyTag™ Plus 2 Dual External Temperature data logger (Model TGP-4520) was used to record the temperature of the leg and water temperature. A TinyTag™ Plus 2 Internal Temperature and Relative Humidity data logger (Model TGP-4500) was placed inside a Stevenson screen and recorded ambient temperature and humidity. Temperatures were recorded in degrees Celsius (°C), and humidity was recorded as relative humidity (% RH).

2.3.2.2 Light Intensity

Onset Hobo™ light intensity data loggers (Part Number UA-002-08) were used to record light intensity at all experimental sites. Light intensity was recorded in lux, which is the SI unit of illuminance. One lux is equal to one lumen per square meter and measures the intensity of light as perceived by the human eye. For reference, a bedroom is typically 300 lux, and a well-lit workshop is typically 800 lux (Adams, 2017).

Datalogger data were downloaded at the end of the experiment.

2.3.2.3 Depth

Two Onset Hobo™ Water Level Loggers (Part Numbers U20L-01 and U20L-02) were deployed to indirectly measure water depth: one on shore and one secured to the Silver Bullet camera rig. The pressure data was recorded in kilopascals (kPa) and

computed with Hobo™ Software. The difference between the pressures was used to calculate water depth in meters (m).

2.4 Marine Experiment

2.4.1 Site

The marine experiment was conducted at Bickley Point on Rottnest Island, Western Australia over two days (Figure 2.2). Bickley Point is located at 32° 0' 41" S and 115° 33' 1" E. Two legs were used each day, located approximately 6 m apart but with slightly different environments (Figure 2.3). On each day, one leg was located in an open sandy bottom area in line with the beach (Marine 1 and Marine 3), while the other was in a sandy area close to Jubilee Rock and out of sight from the beach (Marine 2 and Marine 4). The onshore equipment was set up on Jubilee Rock.



Figure 2.2. Bickley Point. Note Jubilee Rock at the right (photograph credit: Courtney Newberry).

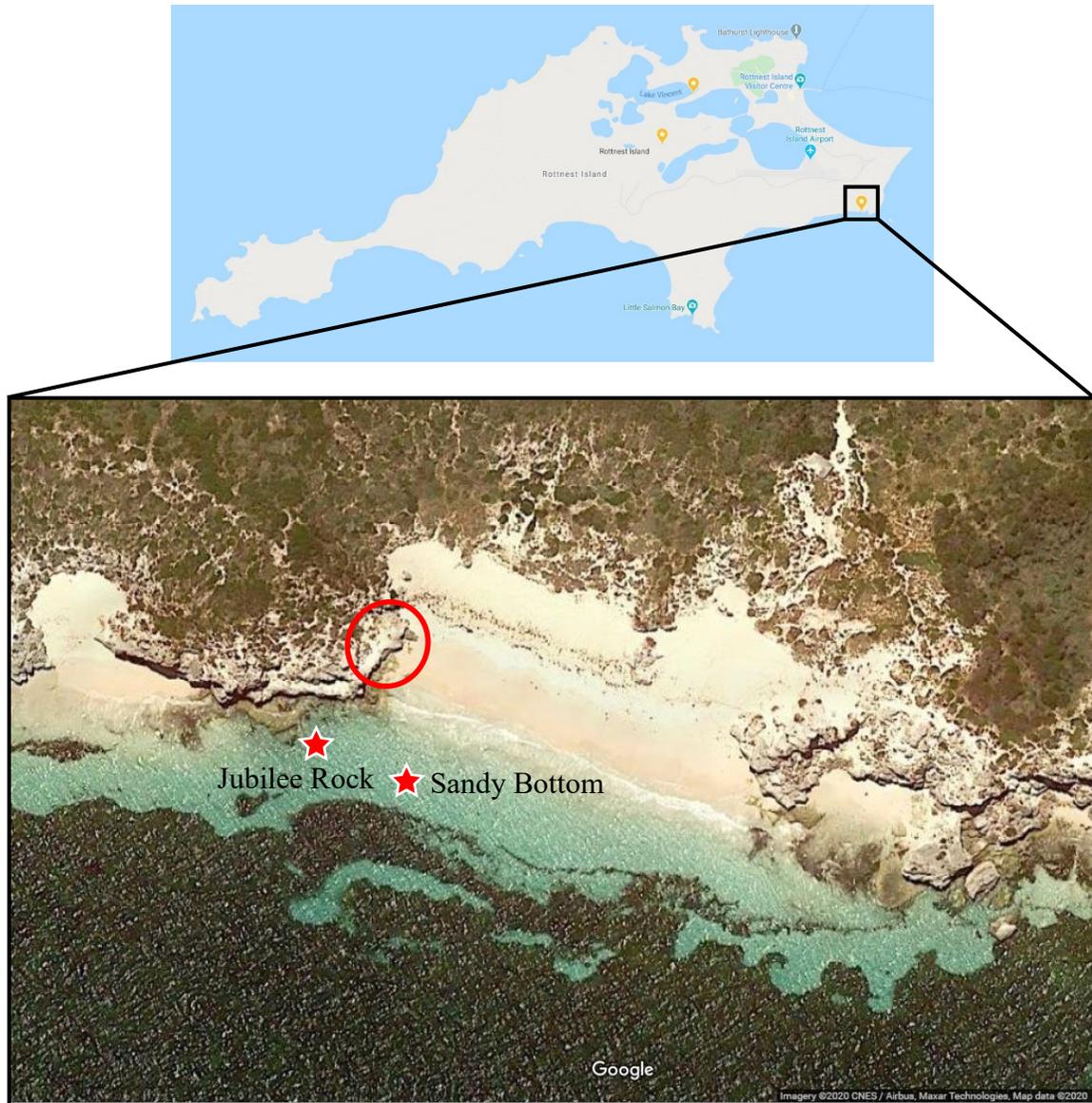


Figure 2.3. Approximate locations of the marine legs (starred) at Bickley Point and equipment setup (circled) on Jubilee Rock (Google Maps).

2.4.2 Equipment

Each leg was secured to $\frac{1}{4}$ " diameter paracord and a six-pound lead dive weight. The free ends of both ropes were tied to a dive weight placed on Jubilee Rock. Five rigs were constructed from $\frac{1}{2}$ " PVC pipes; three were equipped with cameras and two with flashlights (Figure 2.4). The cameras and flashlights were wired and controlled from an

imaging box on Jubilee Rock. A sixth rig and an additional camera were also deployed, but the camera flooded immediately upon deployment and was removed from the experiment.



Figure 2.4. The underwater camera setup from previous research in Curaçao. A similar setup was used in this Rottneest Island research (photograph credit: Courtney Newberry).

The imaging box was a modified Pelican™ case (Model 1610 Protector Case) that housed the video control box, monitor, power distributor, excess cable, voltmeter, and voltage reducer (Figure 2.5). The case was fitted with waterproof cigarette lighter ports and modified with holes to allow cables to pass through while the case was closed. Power was drawn from two Drypower™ (Model 12SB14C-F2) and one Katana™ (Model YTX14-BS) 12-volt/14-amp hour motorcycle batteries (1) that were connected via alligator clips to a cigarette lighter port. The three batteries were used in rotation: at any given time, two batteries were used in parallel to power the equipment while the third was charging. The batteries were rotated each morning and night. A voltmeter (2) was

connected to the internal terminal of the port and displayed the power input from the batteries. Wires connected the battery port to a four-port distributor (3). All of these ports were used: one each to power the monitor (4), the control box (5), the two homemade cameras (7 and 8) via a 1-to-4 splitter, and the Silver Bullet (10) and lights (11). The power to the Silver Bullet and lights was split: one to the internal terminal of the Silver Bullet cigarette lighter port, and one to a voltage reducer (9) that led to the lights. The voltage reducer was set up to reduce the flashlight voltage to 3.7V. This was equipped with a toggle switch to allow the lights to be turned on in the evening and off in the morning without removing them from the water. A 1-to-2 splitter was plugged into the third cigarette lighter port and powered the lights.

The Silver Bullet had a wire that split from the main line and was plugged into Channel 1 on the control box. Camera M2 was connected to Channel 2, and camera M3 was connected to Channel 3. An internal solid-state drive (6) was connected to the control panel and housed outside of the control box. The control box was connected to the monitor via a short HDMI cord.

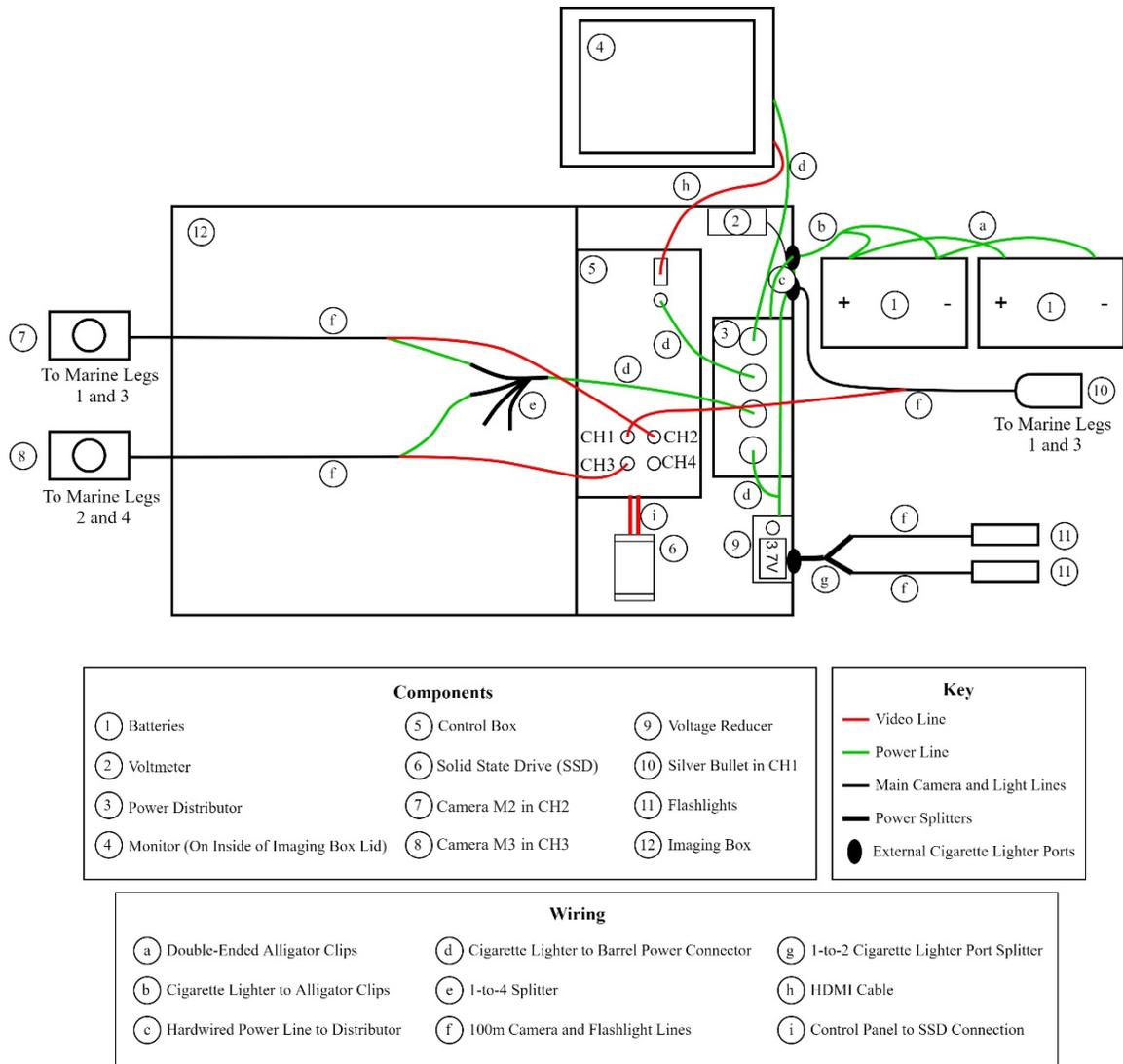


Figure 2.5. Diagram of imaging box setup (<https://www.diagrameditor.com/>).

2.4.3 Video Capture

Three cameras were used to monitor the legs. A fourth camera was initially used, but the waterproof connection failed immediately upon deployment. The Silver Bullet and camera M2 monitored the sandy bottom legs (Marine 1 and Marine 3). Camera M3 monitored the Jubilee Rock legs (Marine 2 and Marine 4).

The videos were recorded on an EverFocus™ recording system (Model ECOR-960-4F2). The control box was modified from its original form to conserve space in the

imaging box. The internal components were removed, and the box was cut to slightly larger than the control panel. The face of the control box was retained. A sheet of the excess metal that was removed was converted into a hinged lid for the new box, and Velcro was applied around the opening to secure it. The control panel contained one USB port, and a second USB port was inserted on the inside of the box to allow simultaneous use of a mouse and imagery downloading. Footage was recorded on a 1TB SanDisk™ X400 internal solid-state drive. A Manhattan® LCD 8.9” High Definition monitor was used to view the video on-site and adjust the camera positions during deployment.

2.4.4 Data Loggers

2.4.4.1 Temperature

An aquatic Gemini TinyTag™ data logger was secured to the camera M2 rig.

2.4.4.2 Depth

Two Onset Hobo™ Water Level Loggers were deployed to indirectly measure water depth: one on Jubilee Rock and one secured to the Silver Bullet camera rig. The pressure data was computed with Hobo™ Software, and the difference between the pressures was used to calculate water depth in meters.

2.4.4.3 Light Intensity

Two Onset Hobo™ light intensity data loggers recorded aquatic and ambient light intensity. The aquatic data logger was secured to the Silver Bullet camera rig, and the ambient data logger was secured to a bush on Jubilee Rock.

2.5 Terrestrial Experiment

2.5.1 Site

The terrestrial experiment was conducted on Forbes Hill on Rottnest Island, Western Australia. Forbes Hill is located at $32^{\circ} 0' 9''$ S and $115^{\circ} 31' 18''$ E. Two replicates were used and were located approximately 4-6 m apart (Figure 2.6).

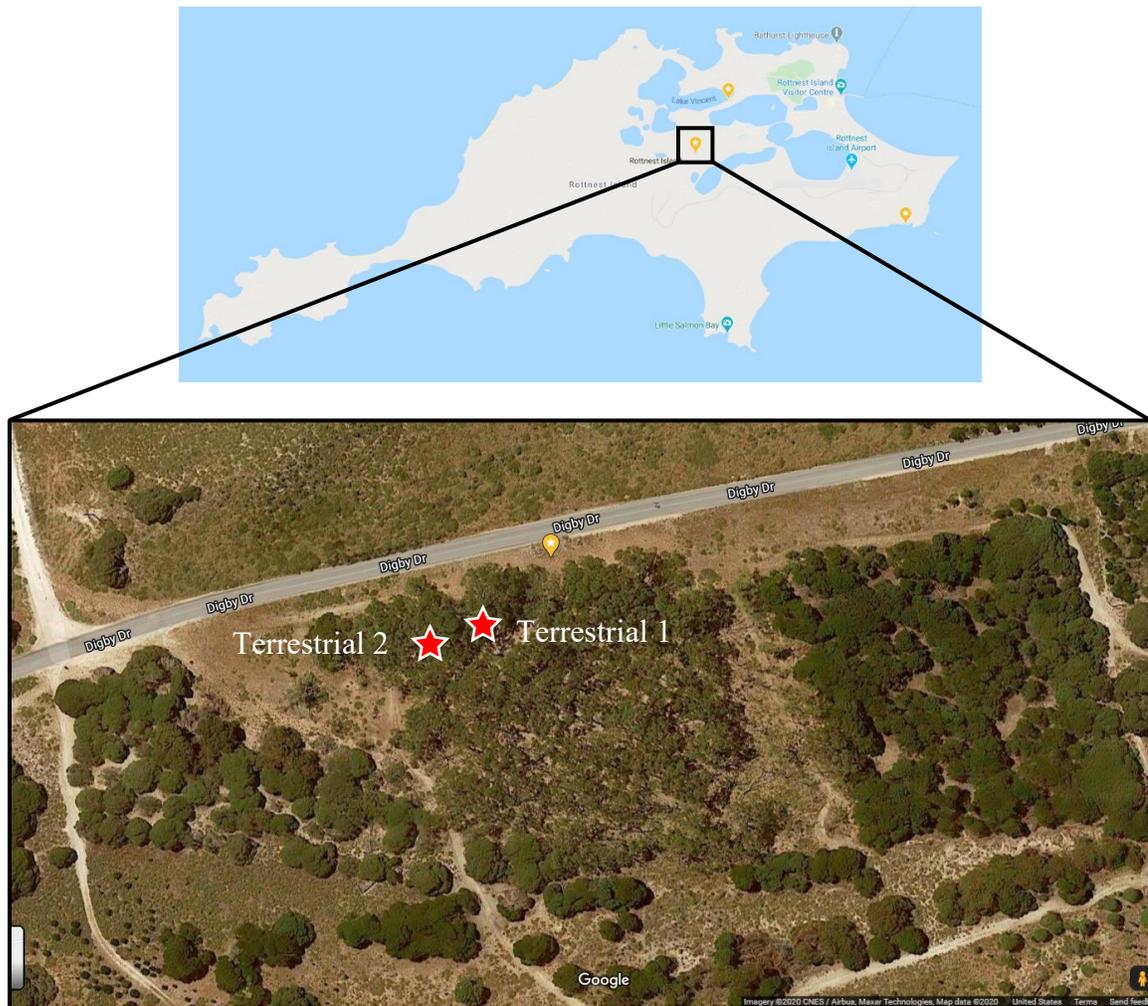


Figure 2.6. Approximate location of the terrestrial legs at Forbes Hill (Google Maps).

2.5.2 Equipment

Each leg was tied to two trees to ensure scavengers did not remove them. Forbes Hill is part of an ongoing conservation project on the island; trees have been planted in the area to reclaim land for natural habitats, so the trees are in somewhat organized rows. Each leg was placed in the center of a group of four trees, and trail cameras were tied to two neighboring trees such that the two cameras and the leg formed a triangle (Figure 2.7). One Browning™, one Moultrie®, and Two Toguard™ trail cameras were used. A Nikon™ camera was used to photograph the legs daily to document stage of decomposition and insect activity.



Figure 2.7. Experimental setup at Forbes Hill (trail cameras are indicated by red arrows) (photograph credit: Courtney Newberry).

2.5.3 Data Loggers

2.5.3.1 Temperature

A TinyTag™ Plus 2 Internal/External Temperature data logger was hung in a tree and recorded ambient temperature and humidity.

2.5.3.2 Light Intensity

An Onset Hobo™ light intensity data logger was hung in a tree and recorded ambient light intensity.

2.6 Hypersaline Experiment

2.6.1 Site

The hypersaline experiment was conducted the south-eastern coast of Lake Baghdad on Rottneest Island, Western Australia. The experimental site is located at $32^{\circ} 59' 46''$ S and $115^{\circ} 31' 31''$ E (Figure 2.8).

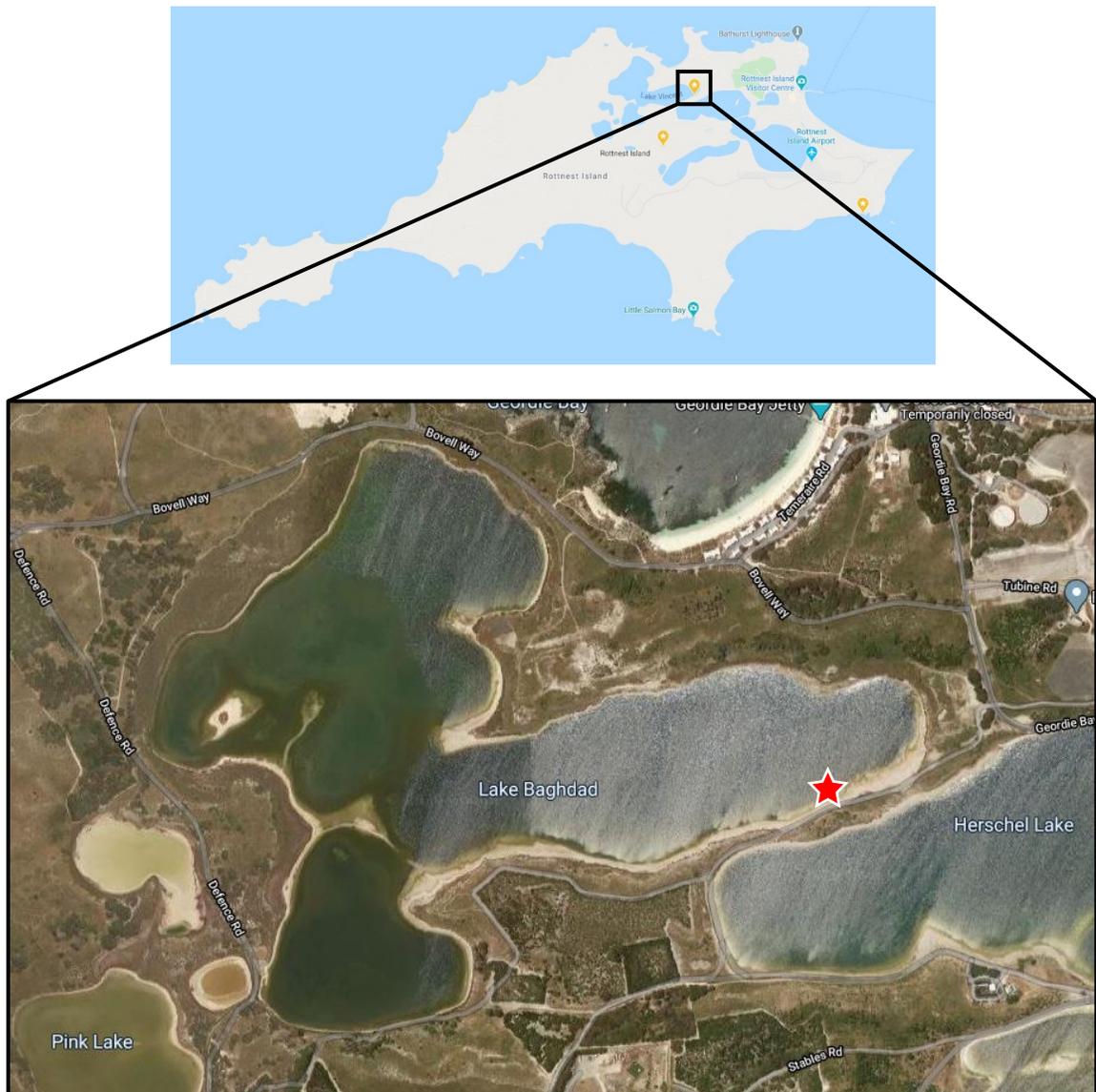


Figure 2.8. Approximate location of the hypersaline leg at Lake Baghdad (Google Maps).

2.6.2 Equipment

The leg was secured with rope, and the free end was tied to a dive weight to ensure scavengers did not remove it. Two motion-sensor Moultrie® trail cameras were set up on tripods, one to take pictures and one to take panoramas (Figure 2.9). Water salinity readings were taken daily with a handheld refractometer (TRZ). A Nikon™ camera was used to photograph the legs daily to document stage of decomposition.



Figure 2.9. Experimental setup at Lake Baghdad (water data logger location indicated by a red arrow) (photograph credit: Courtney Newberry).

2.6.3 Data Loggers

2.6.3.1 Temperature

A Gemini TinyTag™ Plus 2 Dual External Temperature data logger was used to record temperature. One probe was placed in the water, and the other inside the center of the leg.

An aquatic Gemini TinyTag™ data logger was tied to a rope and secured to a dive weight onshore. The data logger was placed approximately two meters away from the leg, where it was fully submerged.

A TinyTag™ Plus 2 Internal Temperature and Relative Humidity data logger was placed inside a Stevenson screen and hung from a rock (Figure 2.10). The Stevenson screen helps prevent heat loading on the data logger, which would result in elevated temperature readings.



Figure 2.10. A Stevenson screen (photograph credit: Courtney Newberry).

2.6.3.2 Light Intensity

An Onset Hobo™ light intensity data logger was secured to a tripod and recorded ambient light intensity.

2.7 Accumulated Degree Days (ADD)

The mean daily temperature at each site was calculated, and accumulated degree days (ADD) were calculated from these values. The ADD was calculated as the running sum of the mean daily temperatures as time progressed, i.e. the ADD of Experimental Day 4 is the sum of the mean daily temperatures from Experimental Days 0-3.

2.8 Data Collection

The images and videos captured were processed, and data was collected regarding the environment of the experimental sites, the experimental days, the time of day, and the stage of decomposition. The experiment began on experimental Day 0 with the deployment of the pig legs, and subsequent days were counted from midnight to midnight. Both days of the marine experiment were Day 0 because a unique set of pig legs was deployed on each day.

The stages of decomposition were evaluated visually based on the definitions of Galloway (1997). The “fresh” stage of decomposition began at the point of deployment and ended when brown shades of discoloration appeared. The “bloat” stage was marked by bloating of the flesh. The “active decay” stage began with brown shades of discoloration and ended with sagging flesh. The “advanced decay” stage began with sagging flesh and ended with mummification of the remains. The “skeletonization” stage began when more than half the bone was exposed and ended when the entire bone was dry. The advanced decay and skeletonization stages were not reached during this experiment.

2.9 Feeding Events

The videos captured from the marine experiment were first visually scanned, and each species of scavenger was identified from the recordings. Screen captures were taken of each species to create a reference identification guide. Note that the control box date and time were set incorrectly, so timestamps on screen captures are one day behind and eleven minutes ahead. When all possible species identifications were made, the videos were processed with Behavioral Observation Research Interactive Software (BORIS). When feeding was observed on the video imagery, the start and end time of each event was recorded. The duration of each event was calculated from these times. A feeding event was classified as one event if less than one minute elapsed between the time a species had left and returned to the leg. If more than one minute had elapsed, the events were classified as unique and were recorded separately. Start and end times of each feeding event were recorded to the second. Event durations were calculated to the second, then converted to decimals and recorded to the hundredth of a minute.

The videos and images captured from the terrestrial and hypersaline experiments were processed visually. When feeding was observed on the imagery, the start and end time of each event was recorded, and the duration of each event was calculated from these times. A feeding event was classified as one event if less than ten minutes elapsed between the time a species had left and returned to the leg (O'Brien, 2008). If more than ten minutes had elapsed, the events were classified as unique and were recorded separately. The start time, end time, and duration of each feeding event were recorded to the minute.

2.10 Data Entry

2.10.1 Environmental Data

All datalogger data were compiled in a master climate data Microsoft Excel spreadsheet. The datalogger data were then divided into individual spreadsheets by site. For the marine experiment, water temperature, water depth, and light intensity were plotted against time in Microsoft Excel 2019. Data collected prior to datalogger deployment (09:10 on 07 Jan 2020) were removed because the dataloggers were not submerged during this time. Data collected between the disappearance of Marine 4 and midnight of that day (08 Jan 2020) were included in the graphs to better show environmental trends.

For the terrestrial experiment, ambient air temperature, relative humidity, and light intensity were plotted against time in Excel. Only data between the deployment time (14:45 on 06 Jan 2020) and collection (15:25 on 11 Jan 2020) were included in the graphs.

For the hypersaline experiment, ambient air temperature, relative humidity, light intensity, water temperature, and leg temperature were plotted against time in Excel. Only data between the deployment time (15:05 on 06 Jan 2020) and collection (09:44 on 11 Jan 2020) were included in the graphs.

2.10.2 Scavenging Data

All scavenging data were compiled in a master scavenging spreadsheet. The scavenging data were then divided into individual spreadsheets for the marine and terrestrial experiments. The hypersaline experiment did not have any scavenging data and did not need a spreadsheet. For each event, data were recorded regarding the following:

- The timing of the event (date, start and end times, experimental day, time of day, duration, stage of decomposition, and ADD),
- The experimental site (name of the site, specific location, state, and country),
- The substrate (anatomy and method of securing the remains),
- The environment (type, datalogger data, tide, and moon phase),
- The replicate (name and camera), and
- The scavenger present (common name, family, genus, and species).

Some of these data were the same for all sites and replicates and were not investigated in the present research. These factors were recorded as part of a continuous research project on small island taphonomy led by Dr. R. Christopher O'Brien and will be analyzed to compare taphonomy on multiple small islands worldwide.

The compiled raw scavenging data were sorted by site, species, replicate, date, and time of day. Scavenging events/hour and time/hour were calculated by species and date for each replicate. Scavenging events/day and time/day were also calculated by species for each replicate from these data. Each of these hourly and daily data were then divided into individual spreadsheets for each site. A total of nine scavenging spreadsheets were used for data analysis.

2.10.3 Data Storage

All imagery and data logger spreadsheets were downloaded to an external hard drive. When all imagery and data were compiled, the files were backed up on a second external hard drive. For image processing, imagery was downloaded to a personal flash drive as needed.

2.11 Statistical Analysis

Statistical analysis was conducted using VSN International Genstat[®] 19th edition statistical package. ANOVA analysis was used to determine differences between factors. The maximum standard error of differences was used to evaluate the results. Marine and terrestrial scavenging were first analyzed separately to determine site-specific differences between species, then analyzed together to determine differences between each site.



Chapter 3: Results



University of New Haven

HENRY C. LEE COLLEGE OF
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3.1 Marine Results

The mass and size of the first two legs (Marine 1 and Marine 2) were measured and recorded prior to deployment at Bickley Point. After setting up all underwater cameras and lights, Marine 1 and Marine 2 were deployed. The cameras were then adjusted for optimal imaging of each leg, and the deployment time was recorded following the last camera adjustment when human activity at each location ceased (Table 3.1).

The experiment was monitored at dusk to turn on the underwater lights. However, both Marine 1 and Marine 2 were gone upon arrival to the site. Later review of the footage from this day revealed Marine 1 had been taken by a tiger shark around 19:07 that evening. Camera M3, which was monitoring Marine 2, had been turned by an octopus at about 13:30 that afternoon, and the leg was out of view for the rest of the day, so no scavenging data were collected after this time. However, it also showed a shark circling the area at around the same time Marine 1 was taken.

The experiment was relaunched the morning of the following day, 08 Jan 2020, with the deployment of Marine 3 and Marine 4. Marine 3 floated away soon after, so this replicate was removed from the experiment. Marine 4 also floated away in the evening, but enough imagery was recorded for image processing.

Table 3.1. Summary of marine replicate information.

Replicate	Location	Mass (kg)	Proximal-Distal Length (cm)	Caudal-Cephalic Width (cm)	Date	Start Time	End Time
Marine 1	Sandy Bottom	2.695	46	23	07 Jan 2020	09:21	19:07
Marine 2	Jubilee Rock	2.450	46	18	07 Jan 2020	09:26	13:08
Marine 3	Sandy Bottom	*	*	*	08 Jan 2020	10:48	10:50
Marine 4	Jubilee Rock	*	*	*	08 Jan 2020	10:37	17:06

* No data recorded.

3.1.1 Environmental Data

Environmental data were collected to track water temperature, depth, and light intensity over the course of the experiment. Each set of data was plotted against time between initial data logger deployment at 09:10 on 07 Jan 2020 and midnight on 08 Jan 2020. The red line at the bottom of each graph indicates the time at which at least one replicate was present on each day.

The lowest water temperature recorded was 22.581°C, and the highest was 24.592°C (Figure 3.1). Water temperature was lowest at dawn and highest in the mid-afternoon.

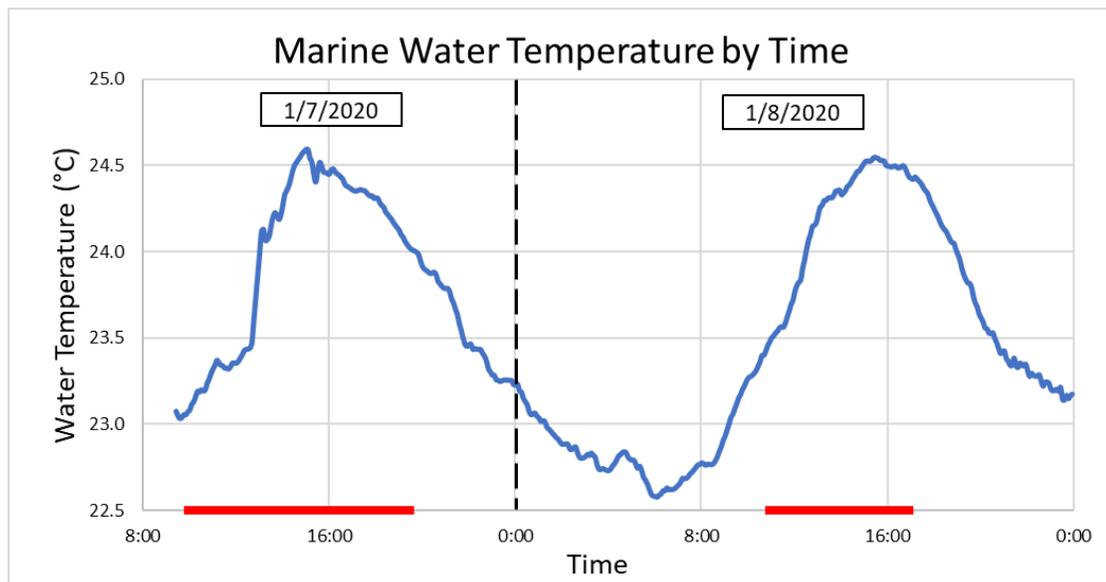


Figure 3.1. Water temperature at Bickley Point during the experiment. The red line at the bottom of the graph indicates the time at which at least one leg was present.

The lowest depth recorded was 1.550 m, and the highest was 2.406 m (Figure 3.2). Although water depth fluctuated with waves, low tide occurred between 05:00 and 06:00, and high tide occurred between 19:00 and 20:00.

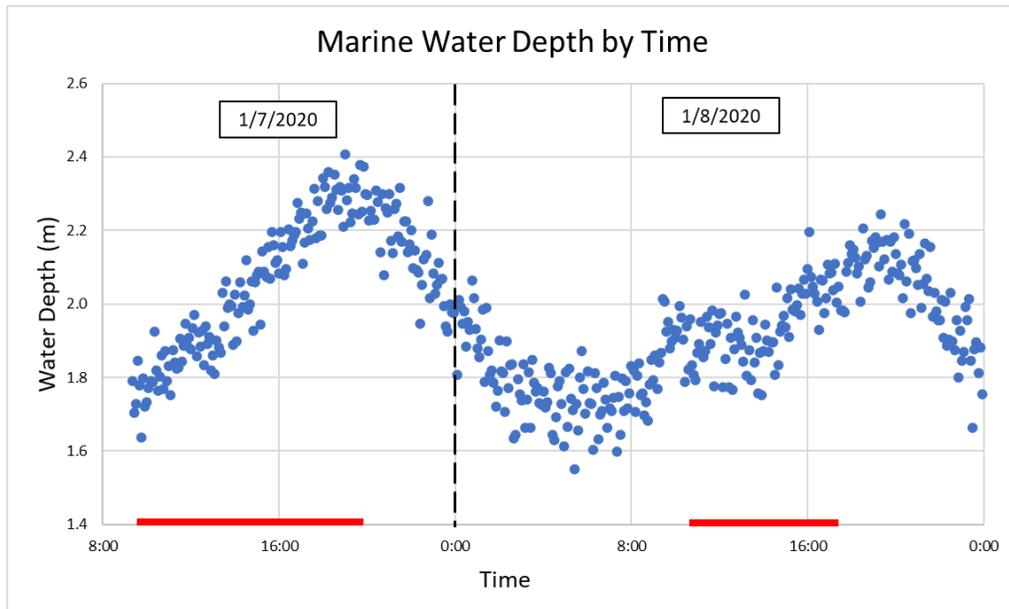


Figure 3.2. Water depth at the Sandy Bottom location at Bickley Point during the experiment. The red line at the bottom of the graph indicates the time at which at least one leg was present.

The lowest light intensity recorded was 0 lux, and the highest was 49,600.3 lux (Figure 3.3). The light intensity peaked in the middle of the day and was 0 lux during the night. Light intensity fluctuated during the day.

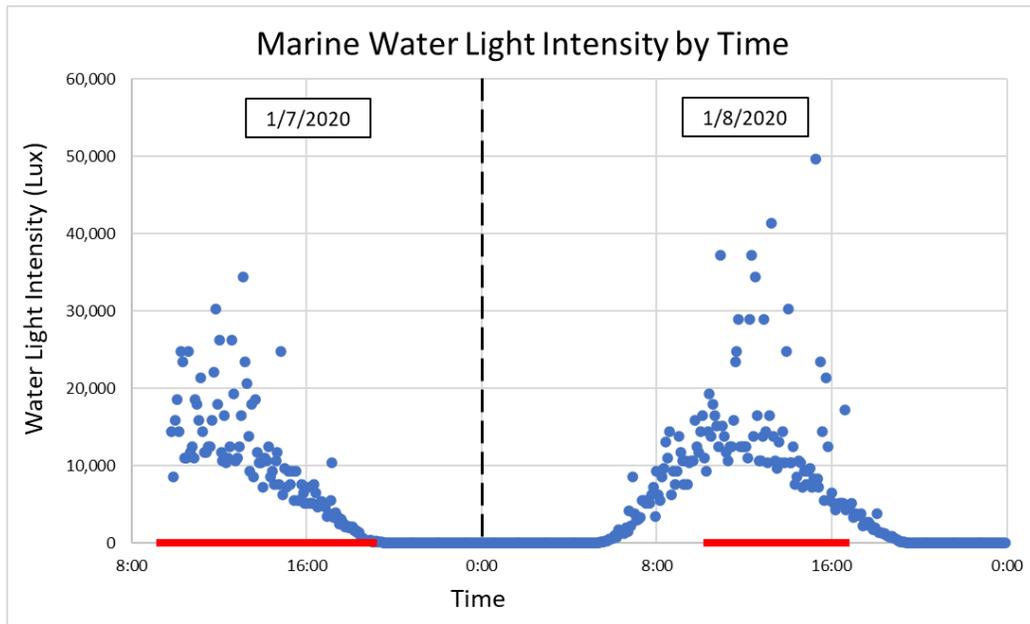


Figure 3.3. Water light intensity at Bickley Point during the experiment. The red line at the bottom of the graph shows the time at which at least one leg was present.

3.1.2 Scavengers

Seven marine species were imaged scavenging on at least one replicate. These species include the Australian herring (*Arripis georgianus*), Banded Sweep (*Scorpiis georgiana*), Brownspotted Wrasse (*Notolabrus parilus*), Weeping Toadfish (*Torquigener pleurogramma*), common octopus (*Octopus sp.*), tiger shark (*Galeocerdo cuvier*), and an unknown crab. The first four of these species repeatedly scavenged throughout the day, and the scavenging events of these species were analyzed in depth. The latter three species were only imaged once and did not return; the scavenging behavior of these species was also recorded, but statistical analysis was not possible. Note that the imagery obtained in this experiment was motion-based, so species identifications, when possible, were made from the original video because pausing the video obscured some of the details present.

3.1.2.1 Australian Herring

The Australian herring (*Arripis georgianus*) is a silver-gray fish with bands of yellowish spots along the sides (Figure 3.4 a-b). These fish have forked, pointed tails with distinctive black tips. Australian herrings can grow to a maximum of 41 cm and are sometimes observed in large schools (Whisson & Hoschke, 2017).

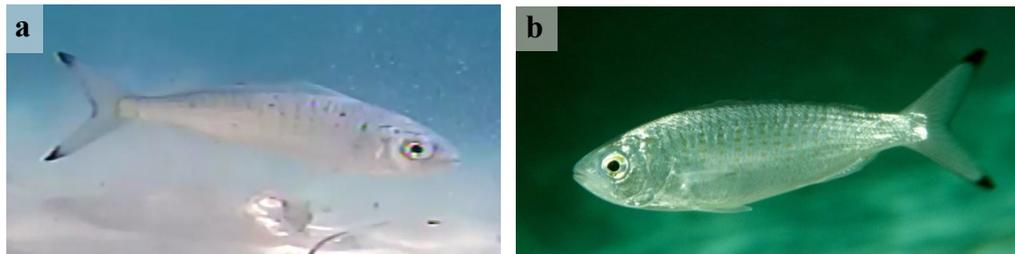


Figure 3.4 a-b. An Australian herring (a) at Bickley Point (photograph credit: Courtney Newberry) and (b) reference picture (Kuiter, n.d.).

The Australian herring scavenging habits were assessed visually during image-processing. The Australian herring was observed scavenging on Marine 1 only. The fish were generally observed scavenging in schools of four to twelve or more, although individuals were also infrequently observed alone. The small schools of fish slowly swam near the leg, and one individual fed at a time. Larger groups looked like swarms and were difficult to count accurately. The fish in these schools behaved as a singular unit, although individual fish did not move in unison. The fish sometimes circled around the leg without feeding for extended periods of time, but the fish fed in a swarm when scavenging did occur, with one or two individuals biting the leg at a time before rejoining the group. The schools also moved en masse and were observed quickly swimming to and away from Marine 1 at the same time.

During image processing, the Australian herring appeared to be most active during the afternoon hours and rarely scavenged in the mornings and evenings. Individual fish were observed swimming past the leg in the morning and evening hours, usually without scavenging. During peak scavenging times, the Australian herring was only observed in groups of varying sizes. The largest, most active groups were observed between during the 15:00 hour.

This observation was reflected in a graph of average scavenging time/hour by time of day (Figure 3.5). From the graph, the Australian herring had heightened scavenging activity between 13:00 and 16:00, which is consistent with initial observations from image processing.

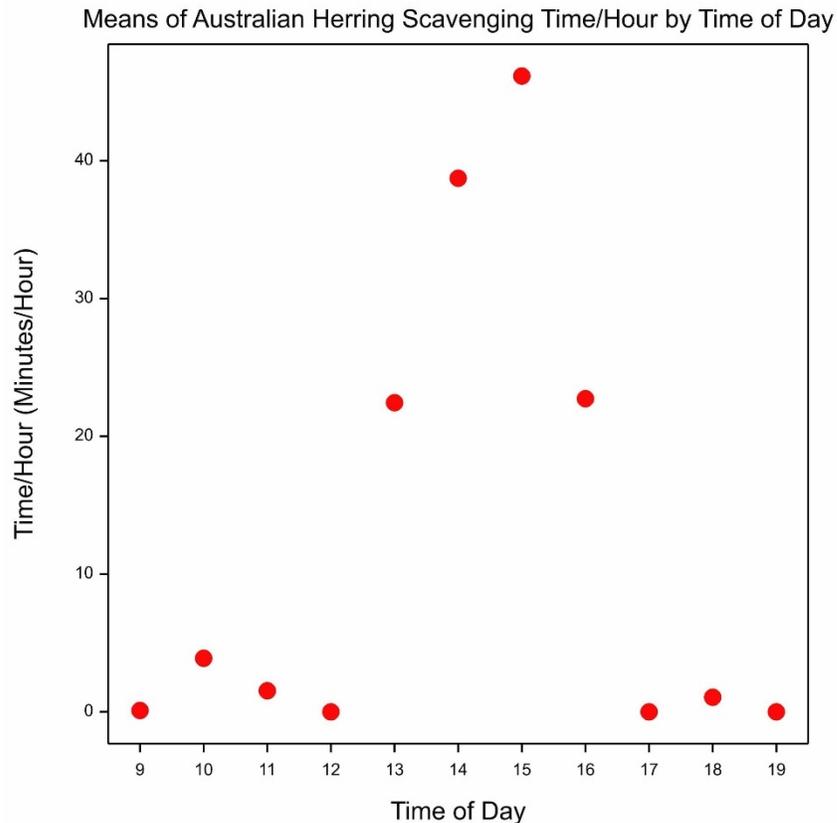


Figure 3.5. Means of Australian Herring Scavenging Time/Hour by Time of Day.

3.1.2.2 Banded Sweep

The Banded Sweep (*Scorpis georgiana*) is silver-gray with two prominent black bands on the sides and yellow pectoral fins (Figure 3.6 a-b). The dorsal and anal fins give the fish a distinctive shape. The Banded Sweep can grow to a maximum of 46 cm and are common near macroalgae-covered reefs (Whisson & Hoschke, 2017).

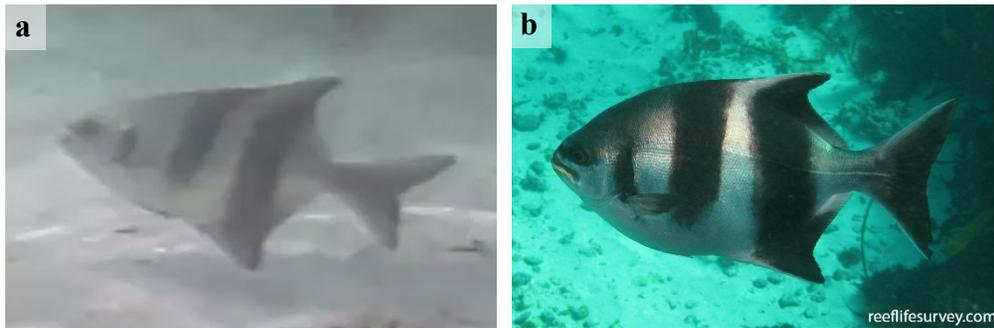


Figure 3.6 a-b. A Banded Sweep (a) at Bickley Point (photograph credit: Courtney Newberry) and (b) reference picture (Green, n.d.).

The Banded Sweep was observed scavenging on Marine 2 and Marine 4. For most scavenging events, only one fish of this species was present, although two Banded Sweep were present simultaneously on rare occasions. Waves frequently buffeted the fish away from the leg, sometimes occurring every few minutes for several hours. During these instances, the fish remained at a short distance from the remains, repositioned constantly as the current changed in order to remain approximately 1-2 meters away from the leg and waited until the waves subsided before returning to feed. Even when the waters remained calm, the fish spent extended periods of time hovering near the remains between scavenging events. The scavenging intensity of the Banded Sweep did not appear to change drastically throughout the day.

This observation was reflected in the statistical analysis of scavenging time/hour by time of day (Figure 3.7). These data appear to show that average scavenging time/hour increases as the day progresses, but ANOVA results do not support this notion. Hourly comparisons of scavenging time/hour show that the Banded Sweep spent the most time feeding during the 15:00 hour, and that this time was greater than the hourly feeding times from 09:00 to 14:00. The Banded Sweep spent the least amount of time/hour feeding during the 09:00 hour, and this time was less than that of 11:00, 15:00, and 16:00, but was not different from the remaining hours.

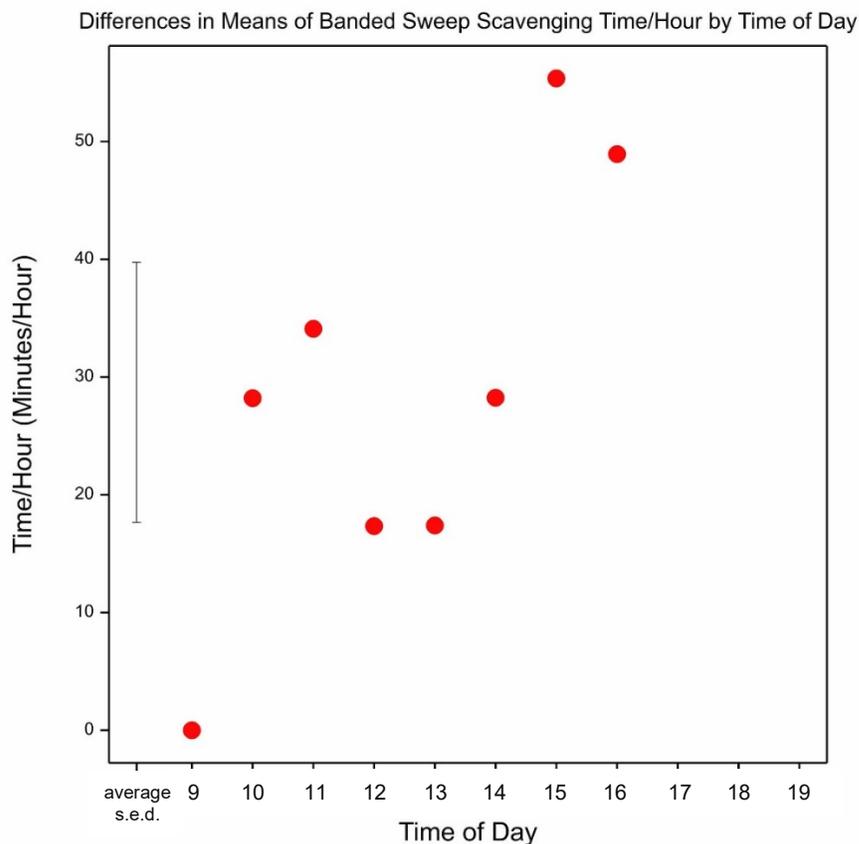


Figure 3.7. Differences in Means of Banded Sweep Scavenging Time/Hour by Time of Day. (ANOVA $F_{(7,4)} = 1.08$, $p = 0.500$, s.e.d. = standard error of differences).

3.1.2.3 Brownspeckled Wrasse

The Brownspeckled Wrasse (*Notolabrus parilus*) can be a variety of colors, from brown to green and white and can grow to a maximum of 50 cm (Whisson & Hoschke, 2017). Regardless of color, fish of this species have a distinctive scale pattern of dark vertical stripes overlaid on alternating light and dark horizontal stripes (Figure 3.8 a-b). This species is common around Rottneest Island and can be observed lying on their sides in the sand (Whisson & Hoschke, 2017).

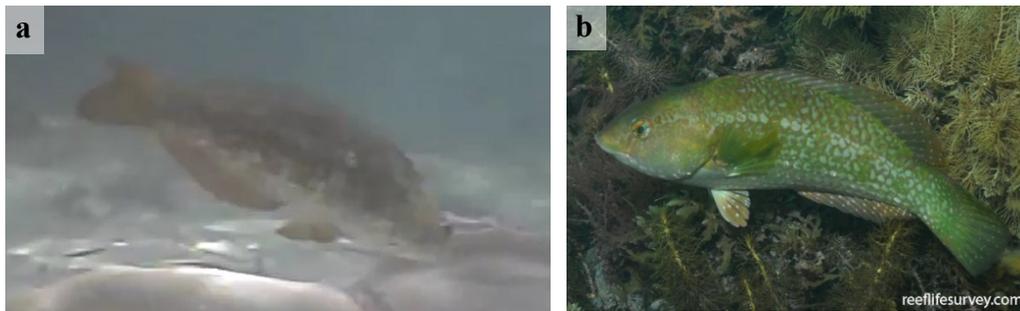


Figure 3.8 a-b. A Brownspeckled Wrasse (a) at Bickley Point (photograph credit: Courtney Newberry) and (b) reference picture (Stuart-Smith, n.d.).

On 07 Jan 2020, two varieties of Brownspeckled Wrasses fed on Marine 2. One was long and had dark colors, while the second was shorter and had lighter green-brown coloration (Figure 3.8 a). Both varieties were seen scavenging alone and together at various times. On 08 Jan 2020, only the larger, darker variety was observed. The fish quickly swam directly to the remains and lay on the sand as they scavenged. The Brownspeckled Wrasse typically lingered at the remains momentarily after a feeding event before quickly swimming away, typically in the same direction from whence they came. Currents that were not strong enough to move the leg had minimal effect on the fish, which remained stationary on the sand. Currents that were strong enough to move the leg

sometimes disrupted scavenging events when waves buffeted the remains, and the fish waited out the currents a few feet away from the remains during these instances before resuming scavenging after the currents calmed. The scavenging intensity of the Brownspeckled Wrasse did not appear to change drastically throughout the day.

This observation was reflected in the statistical analysis of scavenging time/hour by time of day (Figure 3.9). Hourly comparisons of scavenging time/hour reveal there are no differences in intensity between any hours of the day.

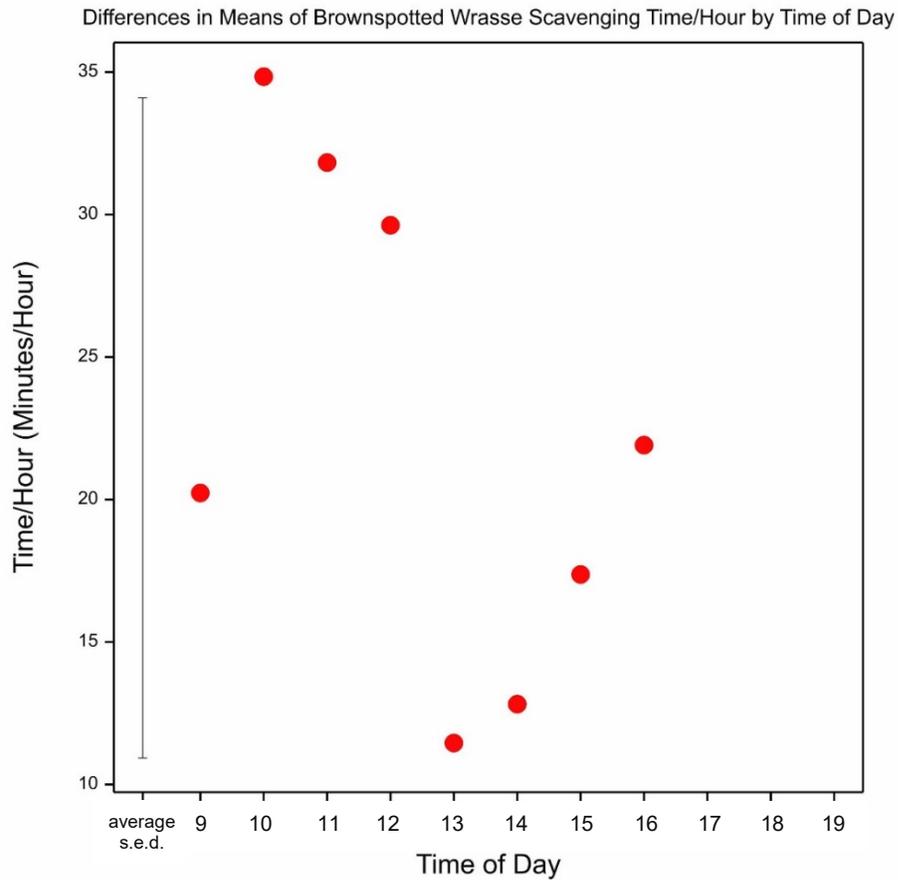


Figure 3.9. Differences in Means of Brownspeckled Wrasse Scavenging Time/Hour by Time of Day. (ANOVA $F_{(7,4)} = 0.36$, $p = 0.885$, s.e.d. = standard error of differences).

3.1.2.4 Weeping Toadfish

The Weeping Toadfish (*Torquigener pleurogramma*) has a dark lateral line dividing the speckled upper half and solid white lower half (Figure 3.10 a-b). There are two broad dark bands across the back and thin dark streaks below the eyes. Fish of this species can reach a maximum of 21 cm in length, are poisonous, and inflate the body cavity when threatened (Whisson & Hoschke, 2017).

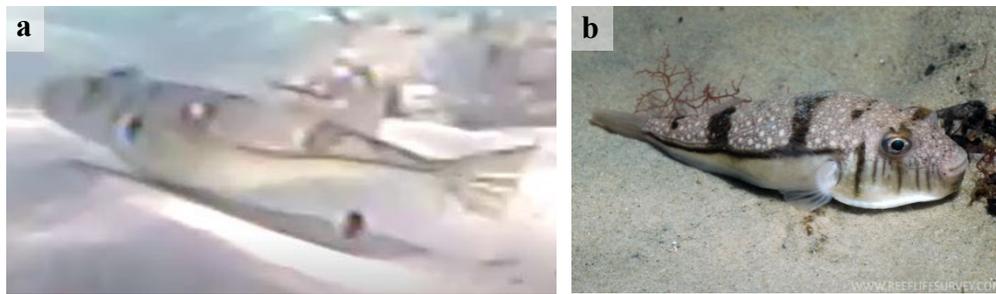


Figure 3.10 a-b. A Weeping Toadfish (a) at Bickley Point (photograph credit: Courtney Newberry) and (b) reference picture (Edgar, n.d.).

Fish of this species were observed scavenging individually and in small groups of two or three. The Weeping Toadfish was the only repeat scavenger that was observed feeding on all three legs. The fish often spent extended periods of time feeding (at one point for more than two hours) and remained in close proximity to the remains between bites. The constant ebb and flow of the water kept the leg in constant motion, and the fish followed the legs' movements closely. When strong currents interrupted a scavenging event, the fish waited out the waves several feet away from the leg and resumed scavenging once the waters calmed. The Weeping Toadfish was observed only in its deflated state throughout both days of the experiment. The scavenging intensity of the Weeping Toadfish did not appear to change drastically throughout the day.

This observation was reflected in the statistical analysis of scavenging time/hour by time of day (Figure 3.11). The Weeping Toadfish was only active before 17:00, and no scavenging events were observed between 17:00 and 19:00. Hourly comparisons of scavenging time/hour reveal there are no differences in intensity between any hours of the day.

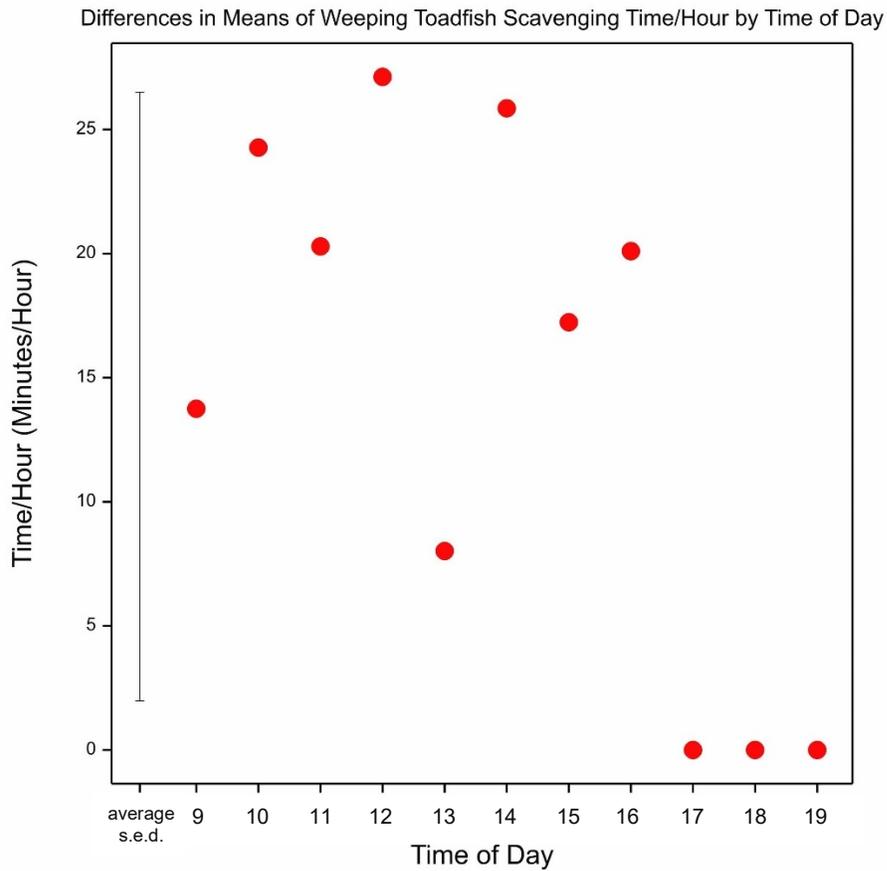


Figure 3.11. Differences in Means of Weeping Toadfish Scavenging Time/Hour by Time of Day. (ANOVA $F_{(10, 12)} = 0.34$, $p = 0.953$, s.e.d. = standard error of differences).

3.1.2.5 Other Scavengers

The common octopus (*Octopus sp.*) has a distinctive anatomy consisting of a large saccular mantle and eight legs lined with two rows of fleshy suckers (“Common Octopus,” n.d.). The mouth contains horny beaks capable of drilling shells and tearing flesh. Octopuses typically move by crawling along the ocean floor; however, individuals of this species can quickly repel backwards when alarmed and eject ink as a shield against attackers when threatened (“Common Octopus,” n.d.). The common octopus is a reclusive species and lives in holes or crevices in rocks. The species primarily feeds on crabs and other crustaceans at night (“Common Octopus,” n.d.). Chromatophores (pigment-bearing cells) in the skin allow the octopus to change colors rapidly; when agitated, the common octopus can become entirely white (“Common Octopus,” n.d.).

One common octopus was observed interacting with Marine 1 on the first day of the experiment. The octopus could not be identified because many species of octopus are indistinguishable to the untrained eye. Identifications are based in part on mantle to arm ratios, which were not available from videos. The video recordings also did not offer optimal image quality to visualize details necessary for identification. The octopus was initially imaged crawling along the sand at a leisurely pace before seeing the leg approximately half a meter away and flinching. After a brief pause, the octopus moved closer to the leg for a few seconds before suddenly turning white, ejecting ink, and repelling backwards a few feet. The octopus’ skin changed from white and smooth to red-orange and textured within two seconds of ejecting ink (Figure 3.12 a-b).



Figure 3.12 a-b. Octopus ink ejection and color change when backing away from Marine 1. Note that only two seconds elapsed between each picture (photograph credit: Courtney Newberry).

The octopus returned four more times in a similar manner but extended one tentacle and shifted between pale and dark coloration as it approached the leg (Figure 3.13). The time spent next to the leg increased slightly with each approach and ranged from six to twenty seconds. By the fifth and final encounter, the octopus first followed the same approach pattern before gradually shifting to be on top of the leg and changing from pale to red. After remaining on the leg for nearly a minute, the octopus backed up slowly, still red, and went out of frame permanently.



Figure 3.13. A common octopus extending a tentacle onto Marine 1 while approaching the leg (photograph credit: Courtney Newberry).

A similar pattern of behavior was observed when the octopus interacted with Marine 2. Over the course of a minute and a half, the octopus approached and left the leg four times, then spent nearly the same time on top of the leg. During this fifth encounter, the octopus appeared to brace itself, grasp the leg with its tentacles, and attempt to repel backwards. After nearly a minute and a half, the octopus left the leg slowly, still red in color, and went out of frame at 12:18. At 13:08, suction cups obscured the camera's view (Figure 3.14), and the camera was facing away from Marine 2 when the suction cups were removed after slightly less than a minute. Unfortunately, this ended further scavenging observations on Marine 2.



Figure 3.14. Octopus suction cups covering camera M3 (indicated by red arrows) (photograph credit: Courtney Newberry).

The tiger shark (*Galeocerdo cuvier*) has a gray top half with darker gray stripes and is pale underneath (Figure 3.15 a-c). These sharks can reach a maximum length in excess of 5 m and are occasionally observed around Rottnest Island (Whisson & Hoschke, 2017). Sharks are most active at dawn, dusk, and night. A tiger shark was recorded scavenging on Marine 1 at 19:07 on 07 Jan 2020 (Figure 3.15 a). At this time, the light intensity was nearly 0 lux, and the water depth was at a maximum. No other fish were present when the shark was near the leg. The shark was determined to be a female approximately 1.5 to 2 m in length. The shark circled the leg about 1 to 2 feet above the leg for 40 seconds before biting the leg. The shark's body moved laterally, kicking up sand as the shark picked the leg up and disappeared from view (Figure 3.15 b). Only the rope attaching the leg to the dive weight was severed; the weight was left in the sand near the cameras, and the rope attaching the weight to Jubilee Rock remained intact. A tiger shark returned briefly twice more at 19:15 and 19:22.



Figure 3.15 a-c. A tiger shark (a) circling and (b) scavenging on Marine 1 (photograph credit: Courtney Newberry) and (c) reference picture (Taylor, V., & Taylor, R., 2007).

Although camera M3 was not aimed at Marine 2 when the shark was at Marine 1, the camera did capture a tiger shark circling the area at 19:22 (Figure 3.16). As with Marine 1, the lead dive weight and rope leading to Jubilee Rock were found near the original location the next morning.



Figure 3.16. A tiger shark captured on video by camera M3 (photograph credit: Courtney Newberry).

An unknown crab was observed once during the experiment, on Marine 1 at around 10:30 on 07 Jan 2020 (Figure 3.17). Visualization of the crab was difficult and prohibited identification, but a catalogue of crustaceans on Rottneest Island identified the crab to the Portunidae family. The crab was light in color and blended in with the sand when stationary; the shell was approximately 12 cm wide. The crab quickly approached the leg in a zig-zag fashion and was then observed holding onto the leg with its front legs; its back legs moved rapidly for a few seconds as if struggling unsuccessfully to find a foothold. For two minutes, the crab remained firmly attached to the leg before leaving. After leaving the frame, the crab was not observed again.



Figure 3.17. An unknown crab on Marine 1 (photograph credit: Courtney Newberry).

3.1.3 Species Comparisons

The scavenging intensity of each species was compared to establish which species, if any, were the primary scavengers. The Australian herring, Banded Sweep, Brownspotted Wrasse, and Weeping Toadfish spent more time per hour scavenging than did the common octopus, tiger shark, and crab (Figure 3.18). These findings are consistent with initial observations from image processing. Among the top four species, the Australian herring had the lowest scavenging intensity. The scavenging intensity of the Weeping Toadfish was higher than that of Brownspotted Wrasse but was not different from that of the Banded Sweep. The Brownspotted Wrasse and Banded Sweep had similar scavenging intensities.

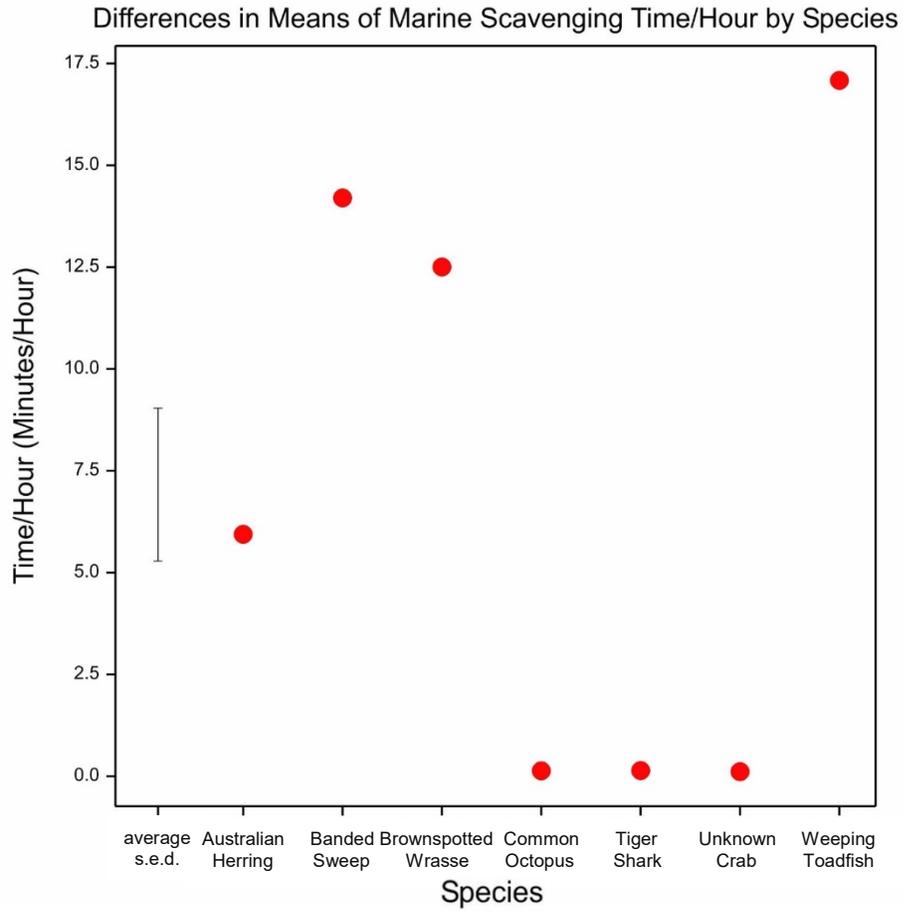


Figure 3.18. Differences in Means of Marine Scavenging Time/Hour by Species. (ANOVA $F_{(6, 155)} = 7.71$, $p < 0.001$, s.e.d. = standard error of differences).

The mean scavenging event duration of each species was compared. There were no differences between the mean feeding duration of any species (Figure 3.19).

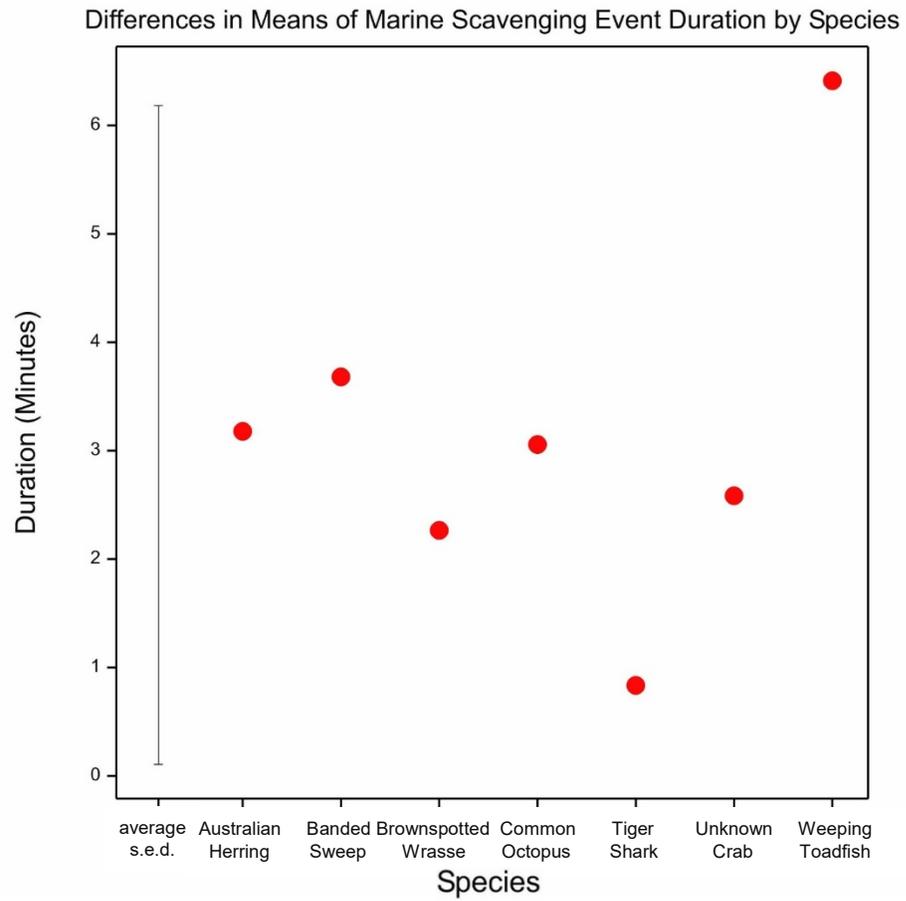


Figure 3.19. Differences in Means of Marine Scavenging Event Duration by Species. (ANOVA $F_{(6, 319)} = 1.67$, $p = 0.127$, s.e.d. = standard error of differences).

3.2 Terrestrial Results

The mass and size of the two terrestrial legs (Terrestrial 1 and Terrestrial 2) were measured and recorded prior to deployment at Forbes Hill on 06 Jan 2020 (Table 3.2).

The deployment time was recorded when all researcher activity at the site ceased.

Table 3.2. Summary of terrestrial pig leg information.

Replicate Name	Mass (kg)	Proximal-Distal Length (cm)	Caudal-Cephalic Width (cm)	Start Date	Start Time	End Date	End Time
Terrestrial 1	3.06	56	19	06 Jan 2020	14:45	11 Jan 2020	15:25
Terrestrial 2	2.66	51	21	06 Jan 2020	14:45	11 Jan 2020	15:25

The experiment was monitored in the morning and afternoon each day beginning on 07 Jan 2020. Camera batteries and SD cards were replaced daily, and observations of the experimental site and replicates were recorded. Additionally, maggots were collected from the legs to contribute to a Master's entomology research project for another university. On Experimental Day 5, the site was monitored in the morning, and the experiment was collected in the afternoon.

3.2.1 Environmental Data

Environmental data were collected to track ambient temperature, humidity, and light intensity over the course of the experiment. Each set of data was plotted against time between experiment deployment at 14:30 on 06 Jan 2020 and experiment breakdown at 15:25 on 11 Jan 2020.

The ambient temperature ranged from 16.685°C to 34.812°C. Humidity ranged from 28.2% RH to 88.8% RH. Ambient temperature and humidity followed inverse

trends: temperature was at a maximum during the day, while humidity was at a maximum at night (Figure 3.20).

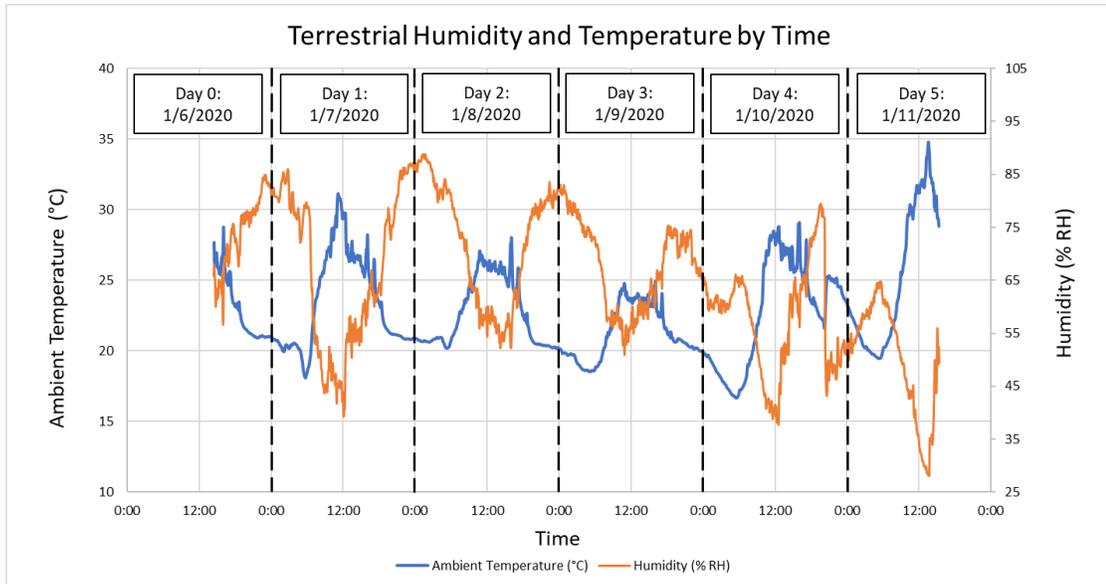


Figure 3.20. Ambient temperature (blue) and humidity (orange) at Forbes Hill during the experiment.

The ambient light intensity was 0 lux at night and reached up to 187,379 lux during the day (Figure 3.21). Light intensity was highest at around 09:00 each day.

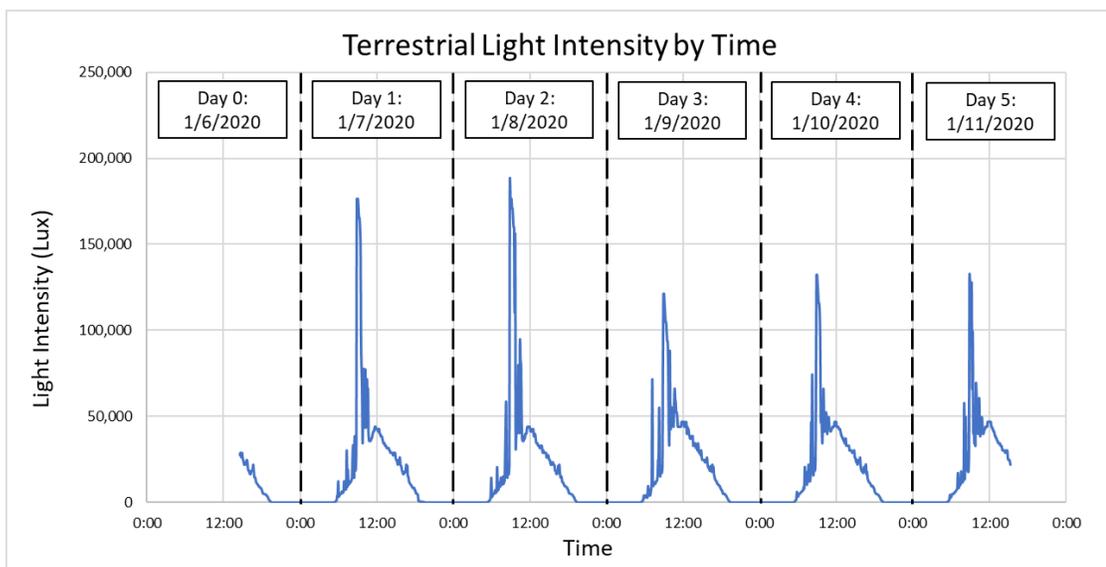


Figure 3.21. Ambient light intensity at Forbes Hill during the experiment.

3.2.2 Stages of Decomposition

The stage of decomposition was assessed visually for each experimental day. Both legs were in the fresh stage on Experimental Days 0 and 1 (06 Jan 2020 and 07 Jan 2020) and were in the active decay stage on Experimental Days 2-5 (08 Jan 2020-11 Jan 2020) (Figure 3.22 a-f). The beginning of the active decay stage was marked by brown discoloration of the flesh and bone. Neither leg went through the bloat stage but instead became desiccated.



Figure 3.22 a-f. The stages of decomposition of Terrestrial 2. **(a)** Day 0: fresh. **(b)** Day 1: fresh. Note that the darkening of the flesh is due to drying blood. **(c)** Day 2: active decay. **(d)** Day 3: active decay. **(e)** Day 4: active decay. **(f)** Day 5: active decay. Note the progression of desiccation (photograph credit: Courtney Newberry).

3.2.3 Observations

Fly and ant activity persisted throughout the experiment, but because this research did not focus on entomology, only select photographs were selected to present an overview of insect activity throughout the experiment. Blow flies (Diptera: *Calliphoridae*) struck the carcass within five minutes of deployment. On Day 1, flies were observed flying around the leg; eggs were present on the exposed flesh of Terrestrial 1, and maggots were present on Terrestrial 2. On Day 3, several flies were inside a hole in Terrestrial 1 (Figure 3.23 a), and maggots were in a pool of blood on Terrestrial 2 (Figure 3.23 b). Both maggots and eggs were found between on Terrestrial 1 on Day 5 (Figure 3.23 c). Larger maggots were found underneath the leg when breaking down the experiment.

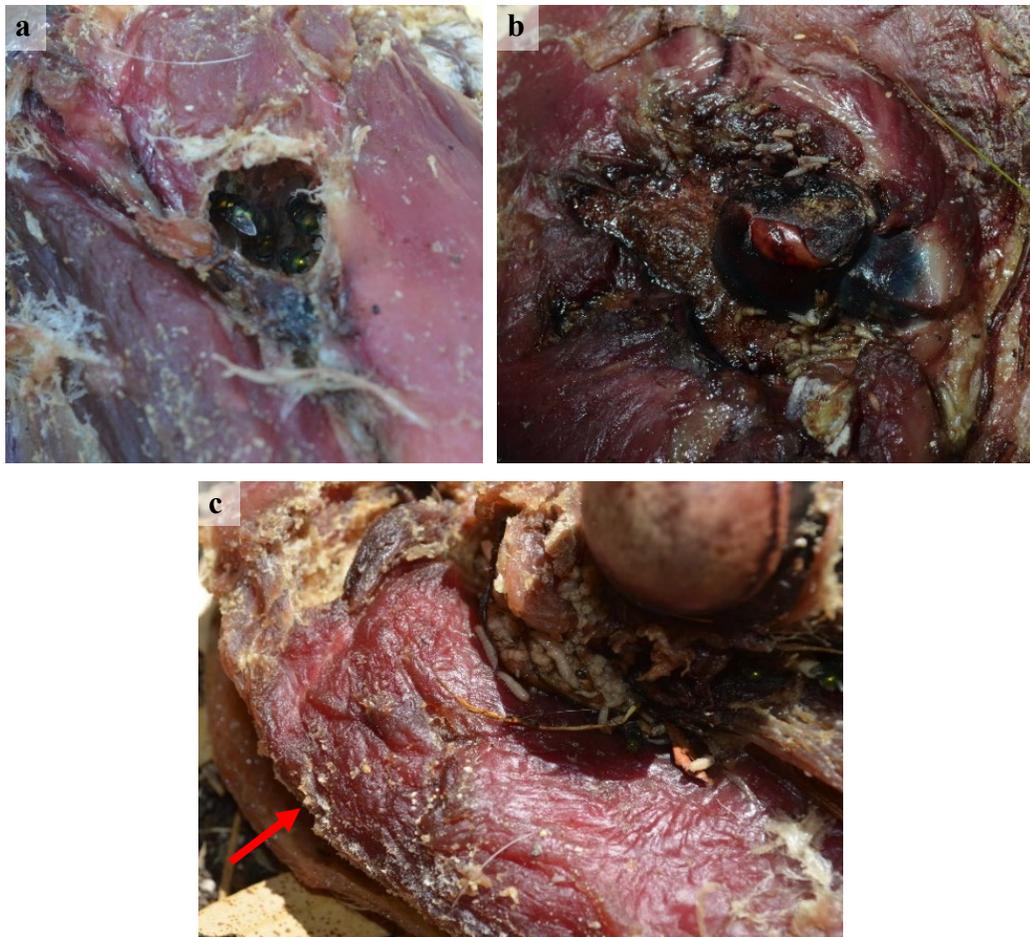


Figure 3.23 a-c. Fly activity on the terrestrial legs. **(a)** Flies inside a hole of Terrestrial 1 on Day 2. **(b)** Maggots in a pool of blood on Terrestrial 2 on Day 2. **(c)** Maggots and eggs (indicated with a red arrow) present on Terrestrial 1 on Day 5 (photograph credit: Courtney Newberry).

Ants were present on both legs throughout the experiment and were observed beginning on Day 1. Lines of ants were seen walking between Terrestrial 2 and a nearby tree beginning on Day 2, using the rope as a bridge (Figure 3.24). On Day 3, the ants on the rope bridge were so numerous that individuals travelled within two centimeters behind each other. Unfortunately, photographs were unable to capture this observation. Trail camera videos also frequently captured ants crawling on King's skinks during scavenging events.



Figure 3.24. Ant activity on Terrestrial 2. Two ants are walking on the rope, and a crowd of ants are present on the leg. Note that ant activity was detected through motion, and individual ants are difficult to visualize in photographs (photograph credit: Courtney Newberry).

Unidentified beetles were observed on and around the leg Terrestrial 2 at approximately 04:30 on Day 2 (Figure 3.25). This observation coincided with a quokka inspecting the leg. Beetles were also present on both legs during experiment breakdown on Day 5.



Figure 3.25. Unidentified beetles on and around Terrestrial 2 (photograph credit: Courtney Newberry).

3.2.4 Scavengers

Three terrestrial species were imaged scavenging on at least one leg. These species include the Australian Raven (*Corvus coronoides*), King's skink (*Egernia kingii*), and quokka (*Setonix brachyurus*).

3.2.4.1 Australian Raven

The Australian Raven (*Corvus coronoides*) is a black bird known for being a voracious scavenger (Figure 3.26 a-b). The birds are abundant in Australia and, although they are omnivores, the birds' diet can consist largely of decomposing remains (O'Brien et al., 2010). The Australian Raven is a diurnal scavenger, with heightened activity in autumn and winter, and is capable of completely consuming a body. In a previous study, the birds were observed dispersing small bones but did not move larger pieces more than a few centimeters (O'Brien et al., 2010).

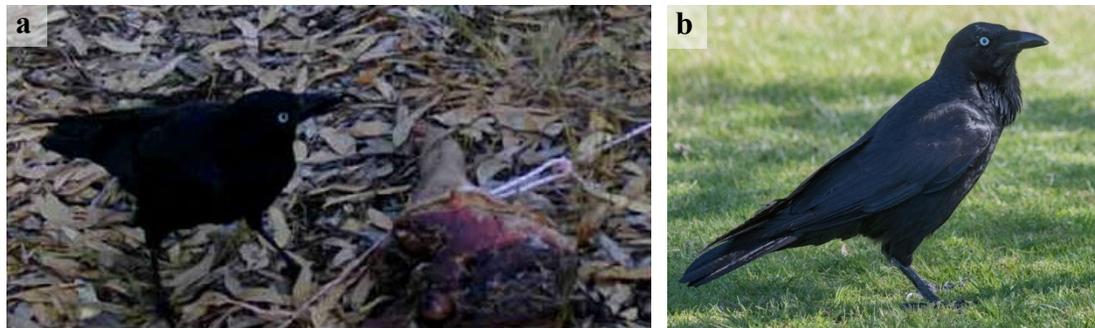


Figure 3.26 a-b. An Australian Raven (a) at Forbes Hill (photograph credit: Courtney Newberry) and (b) reference picture (Alexander, n.d.).

An Australian Raven was observed scavenging on both legs, and only one raven was captured on video at any time. A bird was observed several meters away from the

leg and walked to it in a roundabout manner, rather than flying directly to it. When scavenging, the bird pecked at the exposed flesh and looked around the surrounding area between bites.

The Australian Raven was most active at 11:00, 12:00, and 18:00 (Figure 3.27). Scavenging events were intermittent, with several hours-long breaks throughout the day between each event.

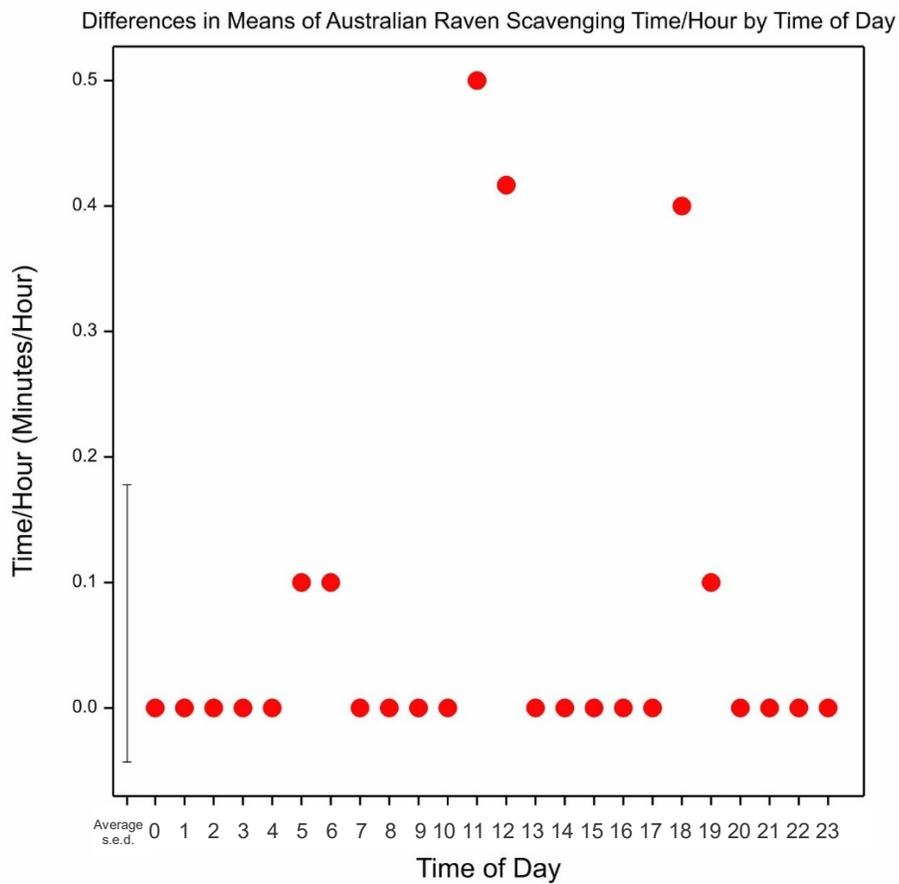


Figure 3.27. Differences in Means of Australian Raven Scavenging Time/Hour by Time of Day. (ANOVA $F_{(23, 230)} = 0.97$, $p = 0.509$, s.e.d. = standard error of differences).

Australian Raven scavenging intensity was plotted by experimental day (Figure 3.28). The Australian Raven scavenged only on Experimental Days 2 and 3, which marked the beginning of the active decay stage of decomposition. No scavenging activity was detected on any other days. However, this was insufficient to establish a pattern of scavenging activity.

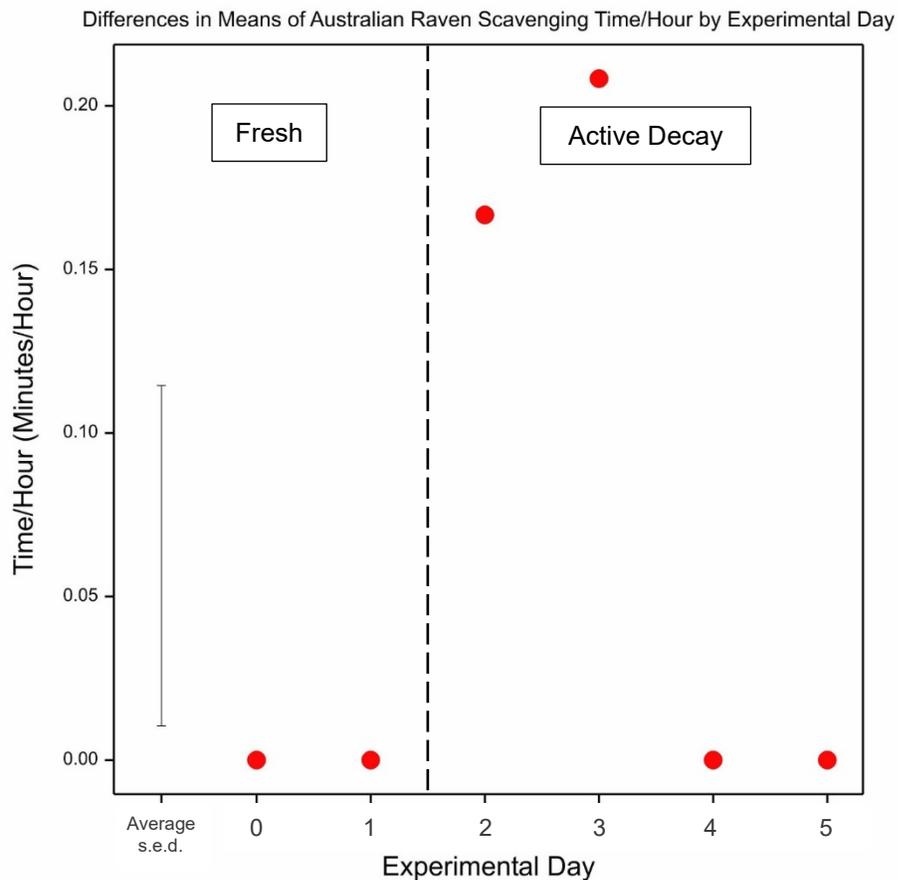


Figure 3.28. Differences in Means of Australian Raven Scavenging Time/Hour by Experimental Day. (ANOVA $F_{(5, 264)} = 1.87$, $p = 0.100$, s.e.d.=standard error of differences). The stages of decomposition are overlaid on the graph.

3.2.4.2 King's Skink

The King's skink (*Egernia kingii*) is a large, uniformly dark-colored skink that is endemic to Western Australia (Figure 3.29 a-b) (Barr, Somaweera, Godfrey, & Bateman, 2019). Individuals can grow up to 55 cm in length and between 220 and 260 g in weight. Like lizards, skinks can lose their tails when attacked as an anti-predation tactic (Barr et al., 2019).



Figure 3.29 a-b. A King's skink (a) at Forbes Hill (photograph credit: Courtney Newberry) and (b) reference picture ("King's Skink," 2017).

The King's skink was only observed scavenging on pig leg Terrestrial 2, either alone or in pairs (Figure 3.30 a). When present in a pair, the skinks occasionally interacted with each other by climbing over and around each other when scoping out the leg; however, the skinks generally kept to themselves and did not interfere with the other's scavenging. The King's skink does not have any evident external sex-defining characteristics, so it was not possible to determine the sex of the skinks on the leg (Barr et al., 2019). The skinks walked around, climbed over, and perched on top of the leg. Skinks fed on exposed flesh, both along the edges of the leg and at the center near the bone. Typical scavenging behavior consisted of biting onto a loosely hanging piece of

flesh and rolling to tear it off (Figure 3.30 b). When unsuccessful, the skink paused briefly before biting and rolling again. When a piece was successfully torn off, the skinks either ate the piece at the leg or walked out of frame to eat elsewhere. Ants were frequently observed walking along the skinks' backs, and flies to a lesser extent, but the skinks did not change their behavior. The King's skink was only observed scavenging during the daytime.



Figure 3.30 a-b. A King's skink scavenging on Terrestrial 2 at Forbes Hill. **(a)** Scavenging in a pair and **(b)** rolling to tear off a piece of flesh (photograph credit: Courtney Newberry).

This observation is consistent with statistical analysis of scavenging data (Figure 3.31). The King's skink was not observed scavenging between 16:00 and 08:00 or at 12:00. Scavenging intensity was highest at 09:00, followed by 10:00 and 11:00.

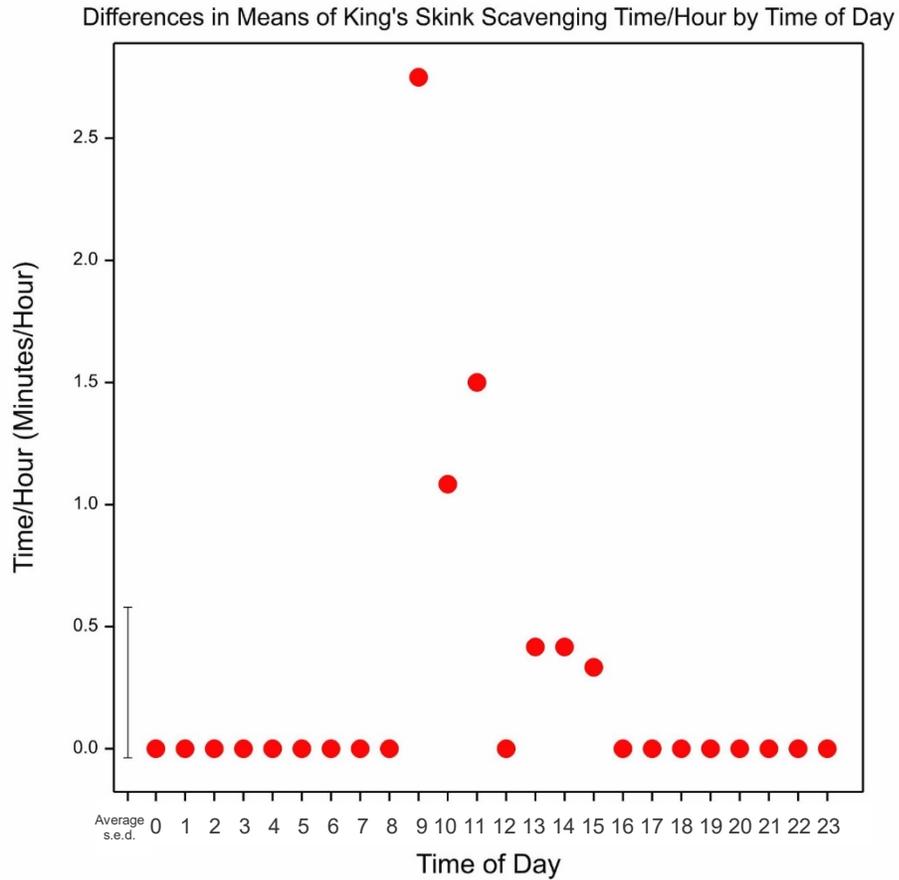


Figure 3.31. Differences in Means of King's Skink Scavenging Time/Hour by Time of Day. (ANOVA $F_{(23, 230)} = 2.46$, $p < 0.001$, s.e.d. = standard error of differences).

King's skink scavenging intensity was plotted by experimental day. The King's skink scavenging intensity varied daily and showed a more complex pattern than that of other species (Figure 3.32). The day with the highest scavenging intensity occurred during the active stage of decomposition (Figure 3.33).

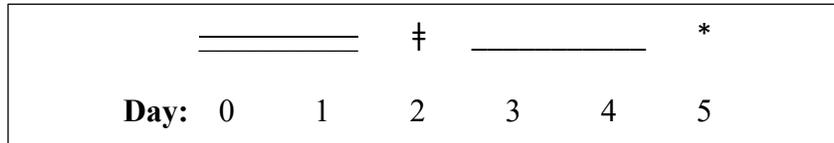


Figure 3.32. Comparisons of King's skink active scavenging days. ‡Day 2 had higher scavenging intensity than double-lined days. *Day 5 had higher scavenging intensity than days with at least one line.

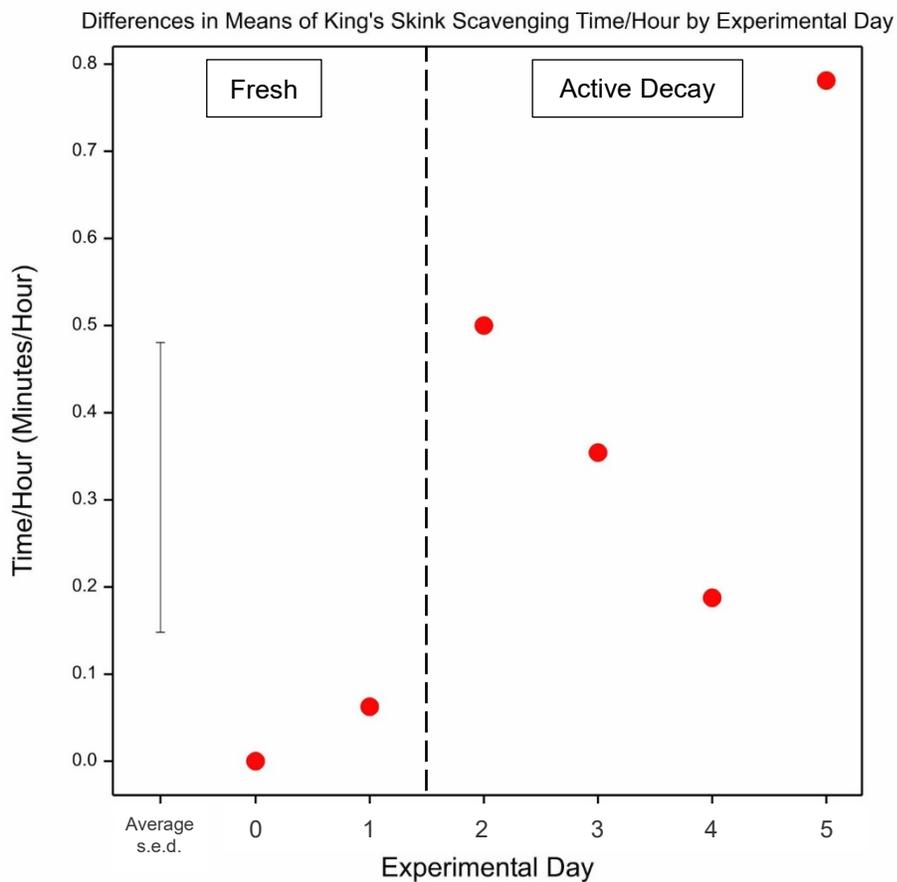


Figure 3.33. Differences in Means of King's Skink Scavenging Time/Hour by Experimental Day. (ANOVA $F_{(5, 248)} = 1.37$, $p = 0.235$, s.e.d. = standard error of differences). The stages of decomposition are overlaid on the graph.

3.2.4.3 Quokka

The quokka (*Setonix brachyurus*) is a nocturnal marsupial endemic to Rottnest Island, Western Australia (Figure 3.34 a-b) (Rippey & Hobbs, 2003). Quokkas are herbivores and were detrimental to shrub and crop growth in the early 1900s (Rippey & Hobbs, 2003). The species has been subject to overhunting in the last century, and quokkas are currently a vulnerable and protected species. The animals have become accustomed to the large influx of tourists and are commonly seen around the island at all hours of the day.

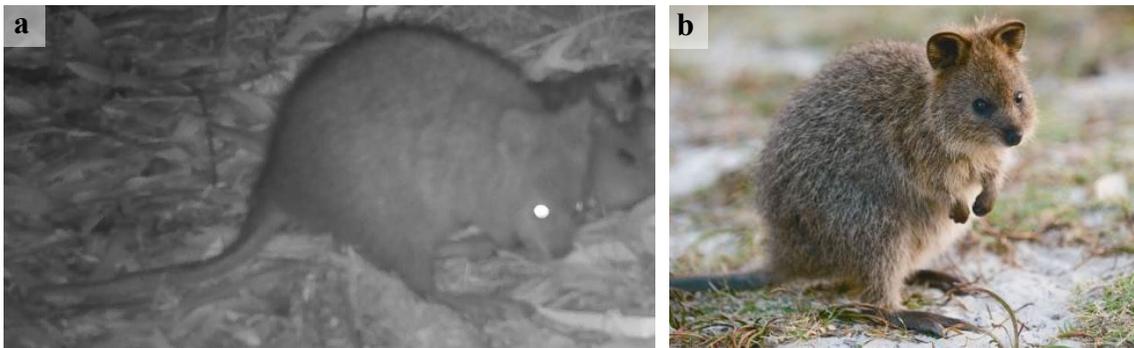


Figure 3.34 a-b. A quokka (a) at Forbes Hill (photograph credit: Courtney Newberry) and (b) reference picture (Barnard, 2018).

A quokka was observed investigating pig leg Terrestrial 2. The animal initially paused approximately 25 cm away from the left side of the leg, then moved closer a few centimeters at a time, sniffing in the direction of the leg with each pause (Figure 3.35 a). The quokka began walking to the other side of the leg, continuing to pause and sniff both the ground and the air in the direction of the leg along the way before going out of frame. Five minutes later, a quokka reappeared on the right side of the leg and slowly approached, sniffing the leaves along the way. Upon arrival at the leg, the quokka sniffed

and then briefly and gently tugged at the exposed flesh (Figure 3.35 b). The quokka remained in the area for another eight minutes, meandering in various directions and sniffing the ground. A quokka was observed on two occasions, once during the night of 07 Jan 2020 and once in the early morning of 08 Jan 2020.



Figure 3.35 a-b. A quokka (a) sniffing and (b) inspecting Terrestrial 2. Note that video of (b) showed the quokka tugging at the leg, which was not captured in the picture (photograph credit: Courtney Newberry).

The observation that the quokka rarely interacted with the legs is consistent with statistical analysis of scavenging data (Figure 3.36). The quokka was active at 20:00 and 04:00 and did not scavenge during any other time. However, this is insufficient to establish a pattern of scavenging behavior, and the results indicate that it is an anomaly.

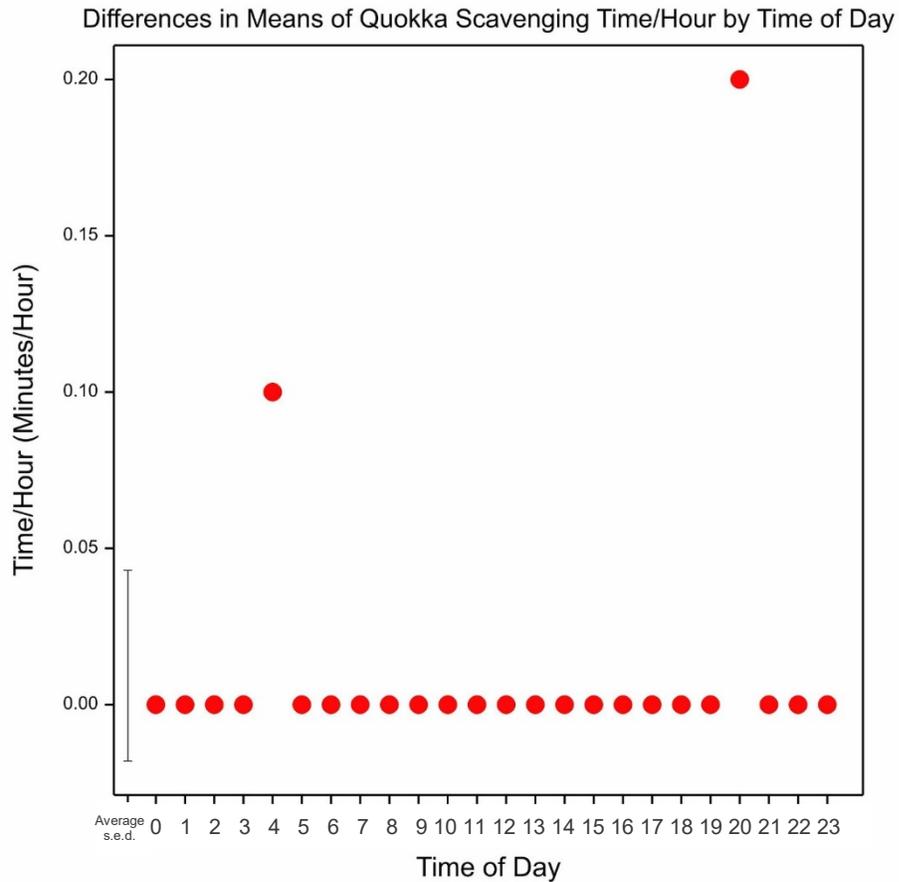


Figure 3.36. Differences in Means of Quokka Scavenging Time/Hour by Time of Day. (ANOVA $F_{(23, 230)} = 1.03$, $p = 0.426$, s.e.d. = standard error of differences).

Quokka scavenging intensity was plotted by experimental day (Figure 3.37). The quokka scavenged only on Experimental Days 1 and 2; however, this was insufficient to establish a pattern of scavenging behavior because only two events were recorded.

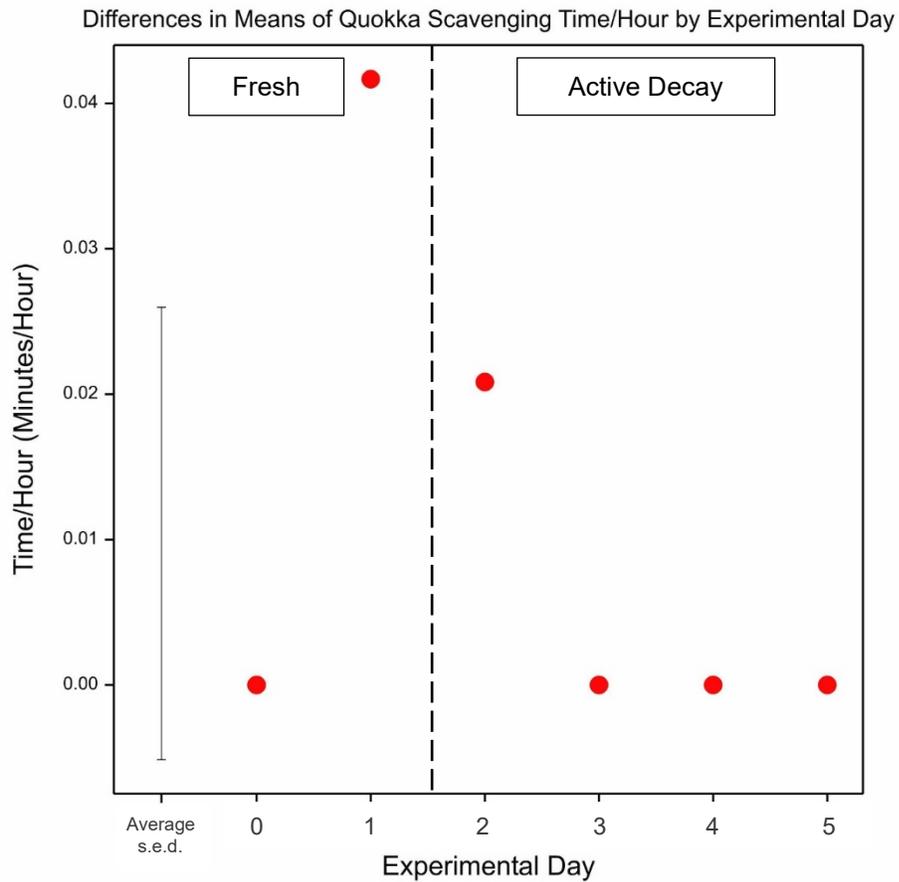


Figure 3.37. Differences in Means of Quokka Scavenging Time/Hour by Experimental Day. (ANOVA $F_{(5, 248)} = 0.70$, $p = 0.627$, s.e.d. = standard error of differences). The stages of decomposition are overlaid on the graph.

3.2.5 Species Comparisons

The scavenging intensity of each species was compared to establish which species, if any, were the primary scavengers. The King's skink was the primary scavenger, and there were no difference in scavenging intensity between the Australian Raven and quokka (Figure 3.38).

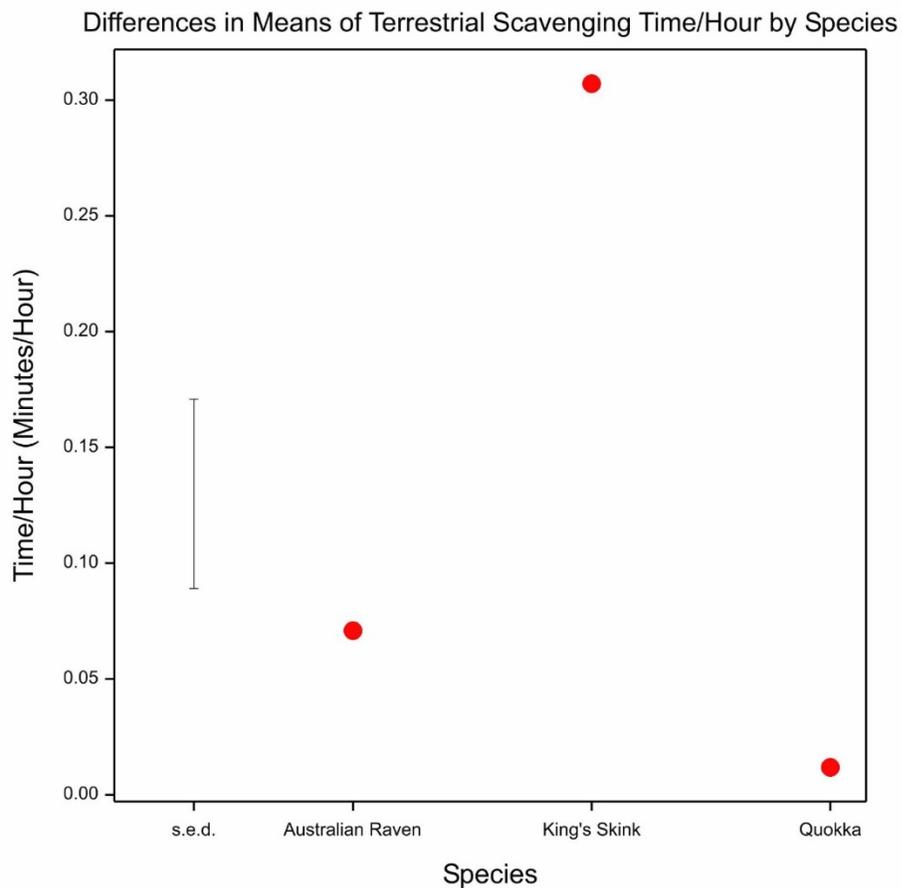


Figure 3.38. Differences in Means of Terrestrial Scavenging Time/Hour by Species. (ANOVA $F_{(2, 759)} = 7.31$, $p < 0.001$, s.e.d. = standard error of differences).

The mean scavenging event duration of each species was compared. There were no differences between the mean feeding duration of any species (Figure 3.39).

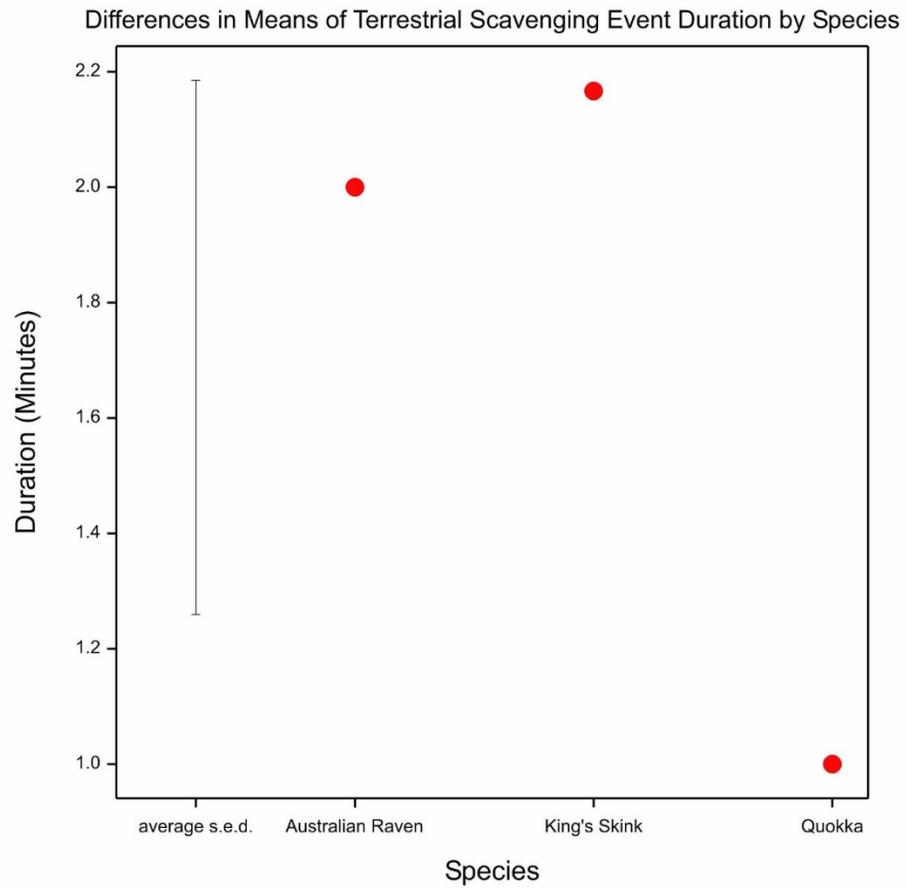


Figure 3.39. Differences in Means of Terrestrial Scavenging Event Duration by Species. (ANOVA $F_{(2, 45)} = 0.66$, $p = 0.519$, s.e.d. = standard error of differences).

3.2.6 Scavenging and Stage of Decomposition

Overall scavenging intensity was plotted by stage of decomposition (Figure 3.40). Scavenging intensity appeared greater during the active stage than when the legs were fresh, but the results indicate that there was no difference.

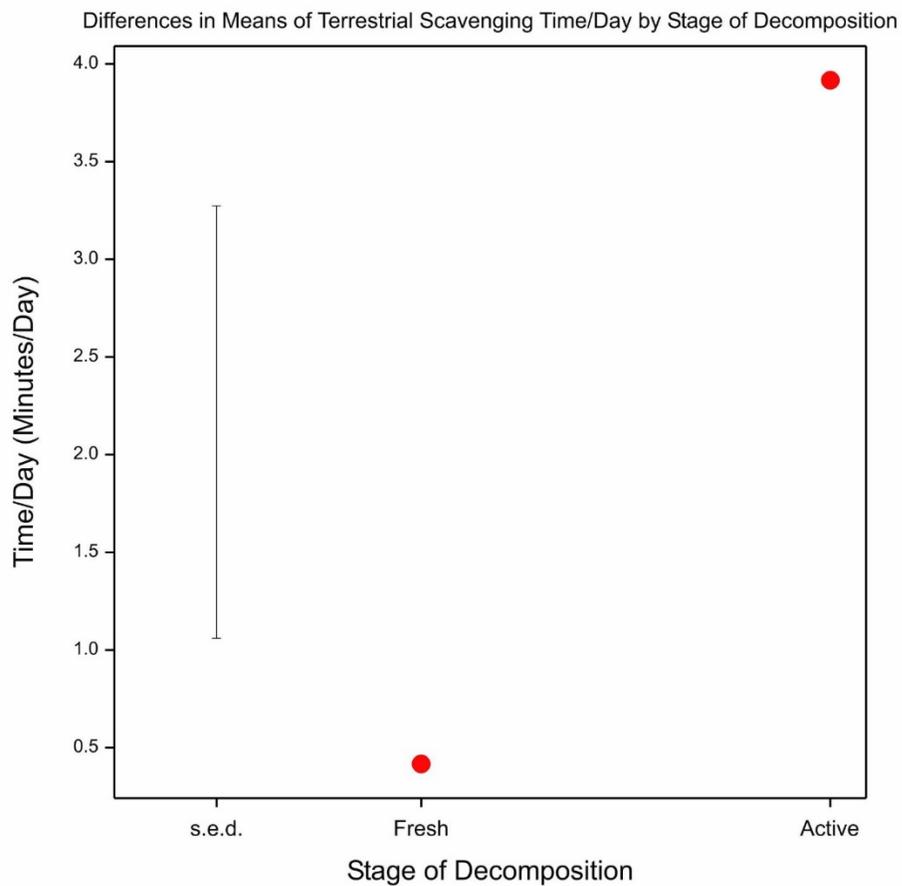


Figure 3.40. Differences in Means of Terrestrial Scavenging Time/Day by Stage of Decomposition. (ANOVA $F_{(1,34)}=2.50$, $p = 0.123$, s.e.d. = standard error of differences).

Overall scavenging event duration was plotted by stage of decomposition (Figure 3.41). Scavenging event duration appeared to be greater during the active stage than when the legs were fresh, but the results indicate that there was no difference.

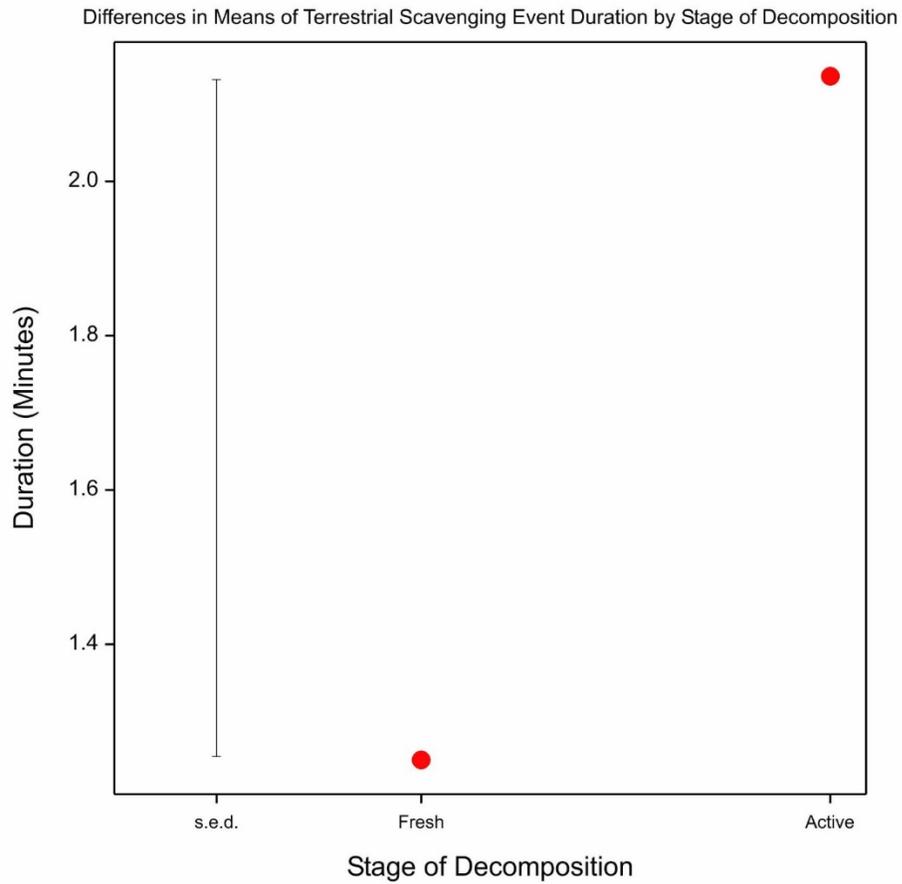


Figure 3.41. Differences in Means of Terrestrial Scavenging Event Duration by Stage of Decomposition. (ANOVA $F_{(1, 46)} = 1.02$, $p = 0.318$, s.e.d. = standard error of differences).

3.3 Hypersaline Results

The mass and size of one hypersaline leg were measured and recorded prior to deployment at Lake Baghdad on 06 Jan 2020 at 15:05. The mass of the leg was 2.895 kg, and the measurements were 48 cm proximal-distal length by 22 cm caudal-cephalic width. The leg was placed partially submerged in the water at the edge of the lake. Daily salinity readings were consistently above 100% and fell outside the range of the instrument.

3.3.1 Environmental Data

The leg remained at a higher temperature than the water throughout the experiment (Figure 3.42). The water temperature ranged from 16.242°C to 25.954°C; water temperature was lowest between 05:00 and 06:00 each morning and highest between 12:00 and 13:00 each day. The leg temperature ranged from 18.773°C to 42.307°C; leg temperature was lowest between 05:30 and 06:30 each morning and highest between 13:00 and 14:00 each afternoon.

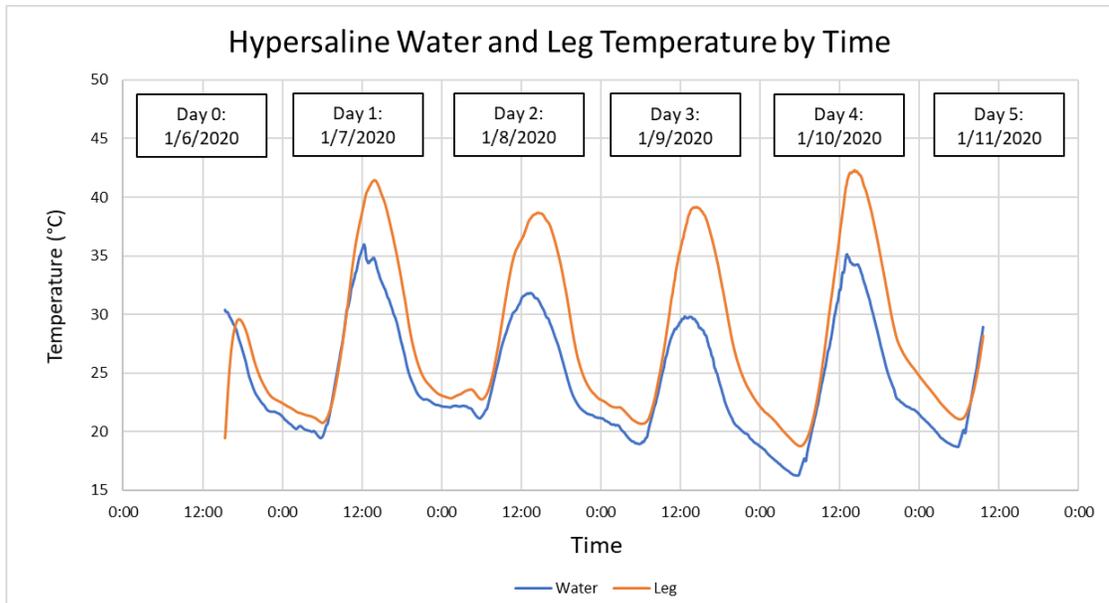


Figure 3.42. Water and pig leg temperature at Lake Baghdad during the experiment.

A second set of water temperature data was obtained to record the water temperature of a 10 cm deep area of the shore approximately 2 m out from the leg. The water temperature ranged from 19.261°C and 30.406°C (Figure 3.43). Water temperature peaked between 15:00 and 16:00 each day; on Days 1 and 4, a first, higher peak also occurred between 11:00 and 12:00, followed by a smaller peak in the afternoon. The lowest water temperatures occurred between 05:00 and 07:00 each day.

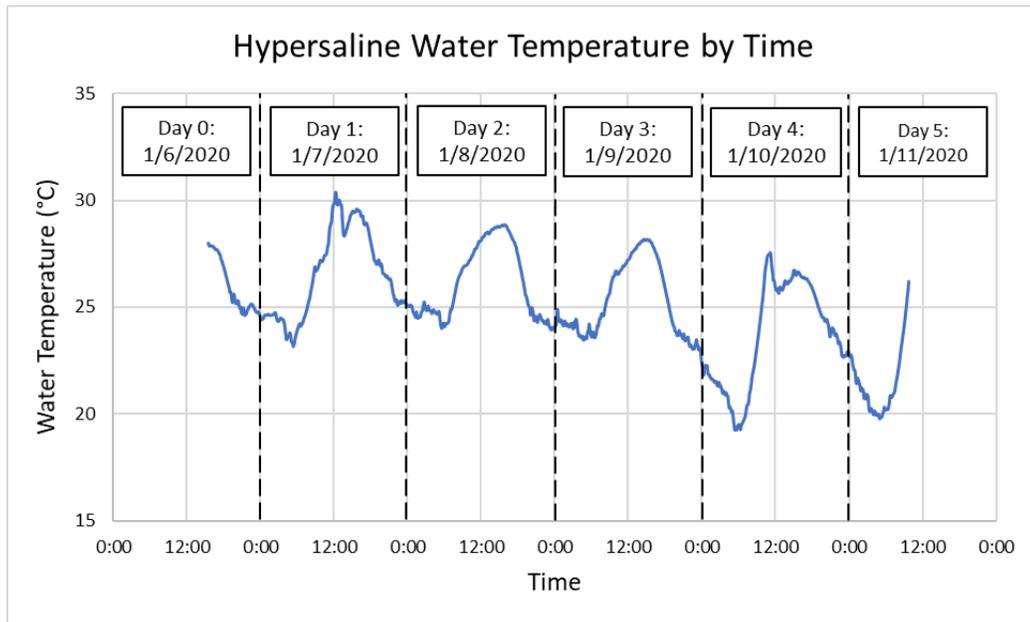


Figure 3.43. Shoreline water temperature of Lake Baghdad during the experiment.

The temperature ranged from 17.220°C to 35.338°C. Humidity ranged from 33.0% RH to 90.0% RH. Ambient temperature and humidity followed inverse trends: temperature was at a maximum during the day, while humidity was at a maximum at night (Figure 3.44).

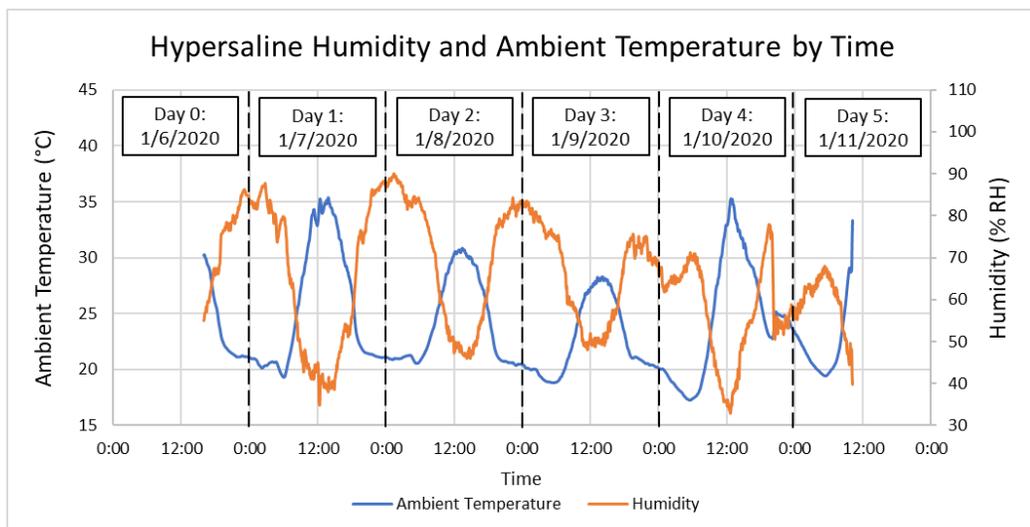


Figure 3.44. Ambient temperature (blue) and humidity (orange) at Lake Baghdad during the experiment.

The ambient light intensity was 0 lux at night and reached up to 231,468 lux during the day (Figure 3.45). Light intensity was highest between 17:00 and 18:00 each day.

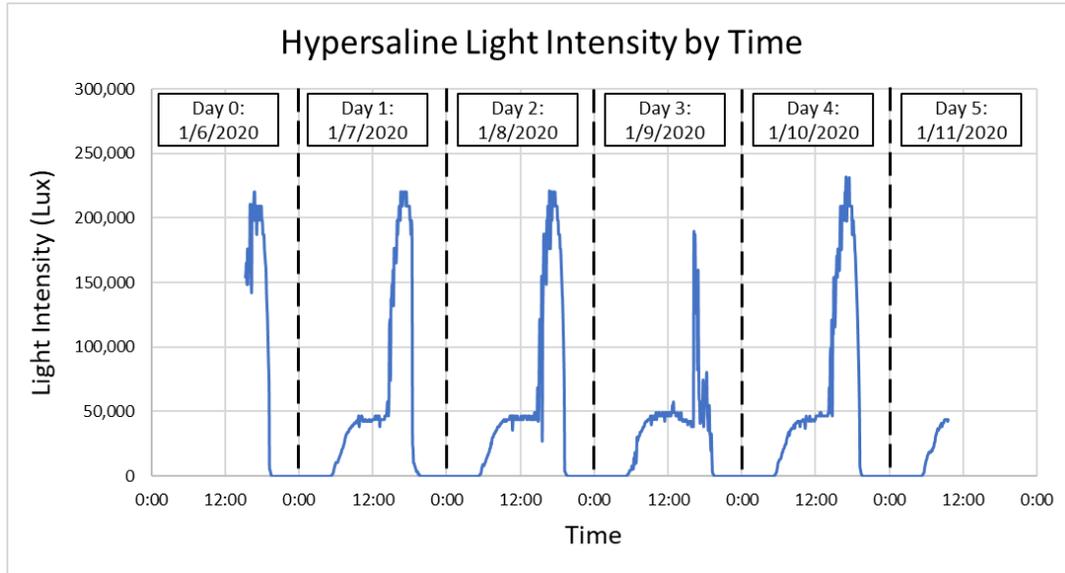


Figure 3.45. Ambient light intensity at Lake Baghdad during the experiment.

3.3.2 Stages of Decomposition

The leg was in the fresh stage on Experimental Days 0 and 1 (Figure 3.46 a-b). The leg became bloated beginning on Day 2, and a froth of blood formed where the temperature probe was inserted into the center of the leg (Figure 3.46 c-e). This marked the beginning of the bloat stage, which persisted for the remainder of the experiment. The froth transitioned from white bubbles on Day 2 to a brown-red pool with some bubbles on the periphery on Days 3, 4, and 5. Salt buildup became visible along the edge of the leg on Day 2. No insect activity was observed on or around the leg.

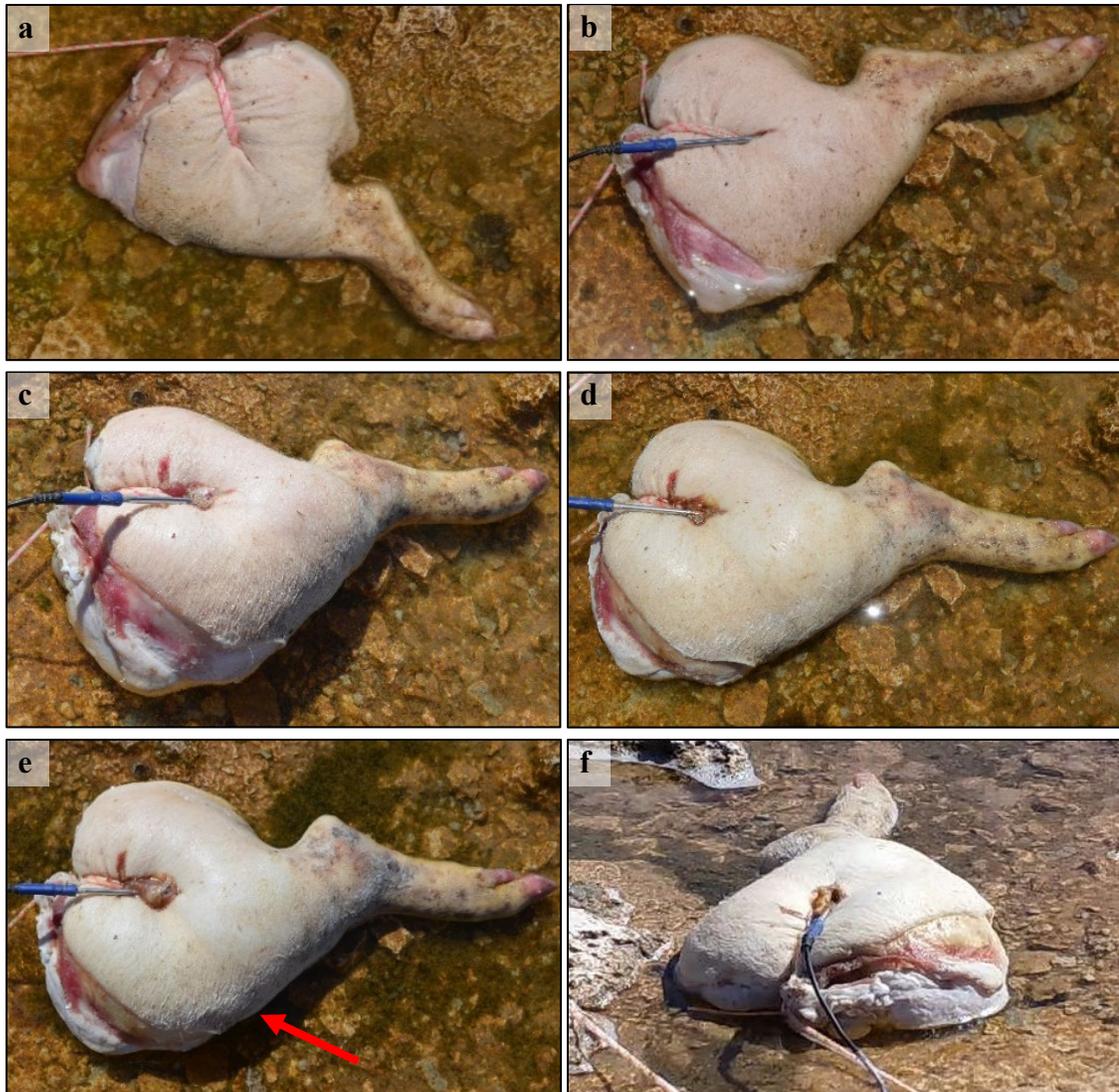


Figure 3.46 a-f. The stages of decomposition of the hypersaline leg. **(a)** Day 0: fresh. **(b)** Day 1: fresh. **(c)** Day 2: bloat. **(d)** Day 3: bloat. **(e)** Day 4: bloat. Note the salt buildup (indicated by an arrow) and discoloration from algae on the leg. **(f)** Day 5: bloat (photograph credit: Courtney Newberry).

3.3.3 Scavengers

No scavenging was observed on the hypersaline leg despite abundant avian activity in the surrounding water. Four species of birds were observed within camera view of the leg: Red-necked Stint (*Calidris ruficollis*), Banded Stilt (*Cladorhynchus*

leucocephalus), Red-capped Dotterel (also called Red-capped Plover; *Charadrius ruficapillus*), and Australian Shelduck (*Tadorna tadornoides*).

Red-necked Stints were frequently observed wading through the water on the sheets of rock around the leg, pecking at the water (Figure 3.47 a-b). The birds were observed both individually and in small groups; when present in groups, the birds typically kept at a distance from each other. Some birds occasionally flew between sheets of rock.

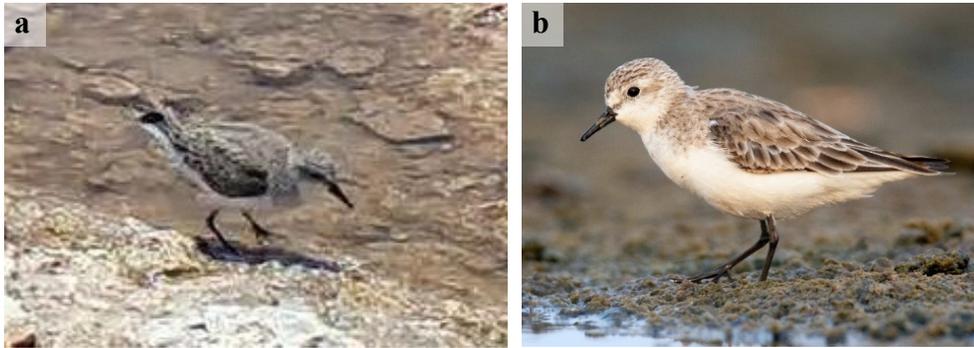


Figure 3.47 a-b. A Red-necked Stint (a) at Lake Baghdad (photograph credit: Courtney Newberry) and (b) reference picture (Jearwattanakanok, 2017).

A Banded Stilt was observed standing and pecking at the water several meters away from the leg (Figure 3.48 a-b).

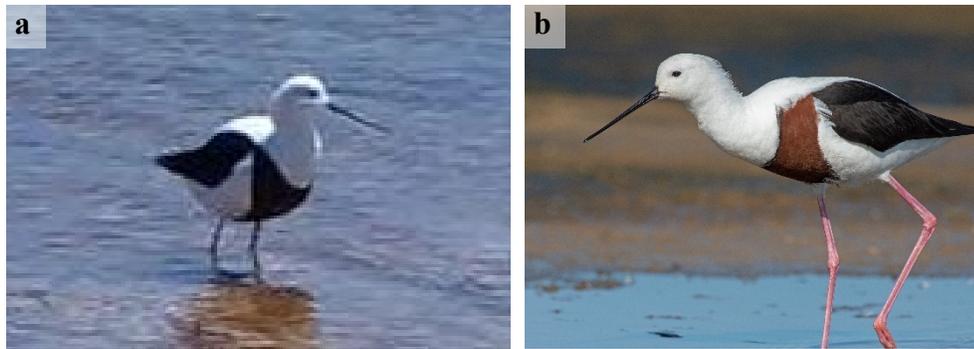


Figure 3.48 a-b. A Banded Stilt (a) at Lake Baghdad (photograph credit: Courtney Newberry) and (b) reference picture (Anderson, 2019).

A Red-capped Dotterel was observed once, walking on an exposed sheet of rock approximately a meter away from the leg (Figure 3.49 a-b).

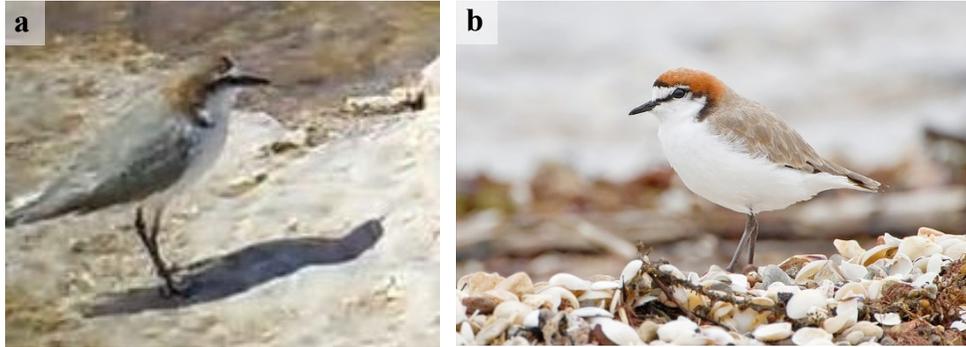


Figure 3.49 a-b. A Red-capped Dotterel (a) at Lake Baghdad (photograph credit: Courtney Newberry) and (b) reference picture (Harrison, 2010).

An Australian Shelduck was observed once, swimming across the camera's field of view several meters away from the leg (Figure 3.50 a-b).

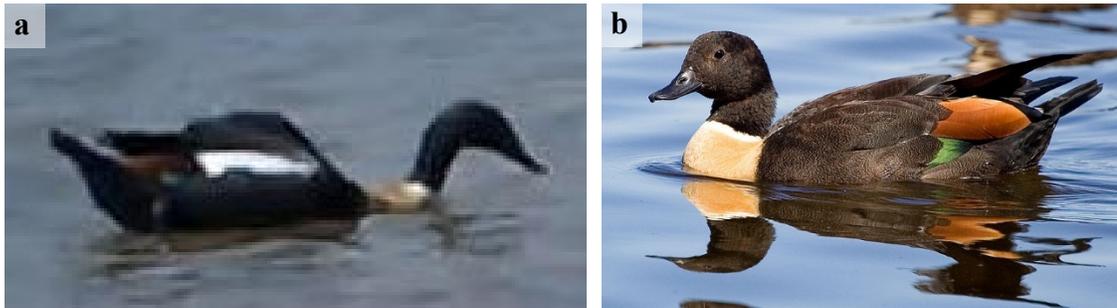


Figure 3.50 a-b. An Australian Shelduck (a) at Lake Baghdad (photograph credit: Courtney Newberry) and (b) reference picture (Pot, 2008).

3.4 Site Comparisons

The two sites with scavenging activity were compared to determine what differences in scavenging guilds and intensity existed between the marine and terrestrial environments. As expected, the scavenging guilds showed no overlap between the two sites (Table 3.3). Seven scavengers were documented scavenging on the marine legs, while only three scavenged on the terrestrial legs.

Table 3.3. Scavenging guilds at the marine (Bickley Point) and terrestrial (Forbes Hill) sites.

Marine Scavengers	Terrestrial Scavengers
Australian herring (<i>Arripis georgianus</i>)	Australian Raven (<i>Corvus coronoides</i>)
Banded Sweep (<i>Scorpiis georgiana</i>)	King's skink (<i>Egernia kingii</i>)
Brownspotted Wrasse (<i>Notolabrus parilus</i>)	Quokka (<i>Setonix brachyurus</i>)
Weeping Toadfish (<i>Torquigener pleurogramma</i>)	
Common octopus (<i>Octopus sp.</i>)	
Tiger shark (<i>Galeocerdo cuvier</i>)	
Unknown crab (Family: <i>Portunidae</i>)	

Average scavenging event duration (measured in minutes) was compared between the two sites (Figure 3.51). There was no difference in average scavenging event duration between the two sites.

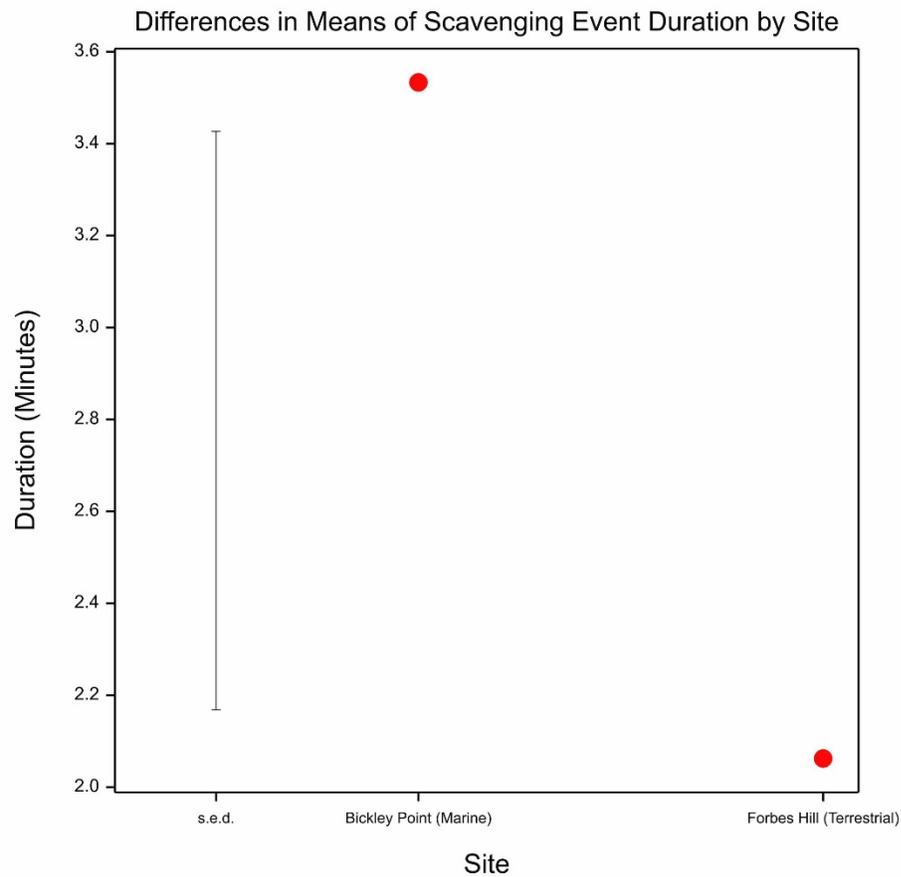


Figure 3.51. Differences in Means of Scavenging Event Duration by Location. (ANOVA $F_{(1, 372)} = 1.37$, $p = 0.243$, s.e.d. = standard error of differences).

Average scavenging intensity (measured in minutes/hour) was compared between the two sites (Figure 3.52). Scavenging intensity at Bickley Point was higher than that at Forbes Hill.

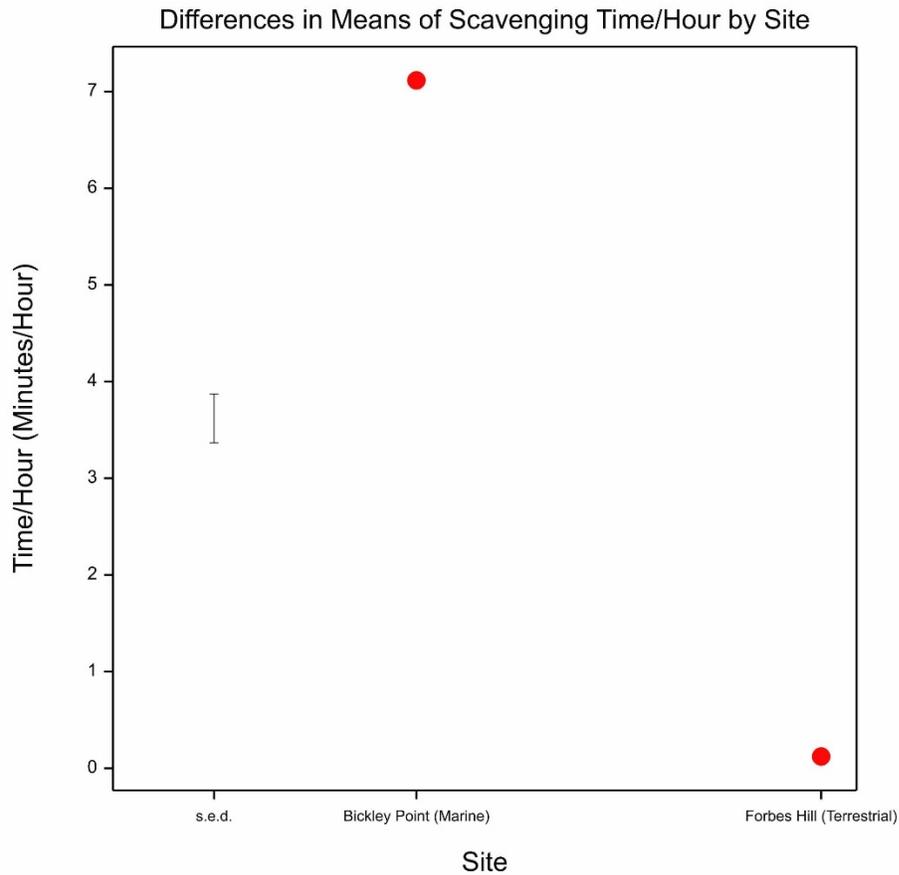


Figure 3.52. Differences in Means of Scavenging Time/Hour by Site. (ANOVA $F_{(1, 970)} = 191.00$, $p < 0.001$, s.e.d. = standard error of differences).

Both the Bickley Point and Forbes Hill pig legs were scavenged, while no scavenging was observed on the leg at Lake Baghdad. The marine and terrestrial scavenging guilds varied drastically between the two environments. The mean scavenging time/hour was greater at Bickley Point, but the mean scavenging event duration did not differ between the two sites. While the progression through the stages of

decomposition could not be monitored for the marine legs, the terrestrial and hypersaline legs decomposed differently; the former became desiccated and advanced to active decay, while the latter became bloated and remained in the bloat stage for the latter half of the experiment.



Chapter 4: Discussion



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4.1 Scope of the Present Study

This study examined the scavenging guilds and early decomposition rates of pig legs in three different environments on Rottnest Island, Western Australia. It is the first to study forensic taphonomy on Rottnest Island. The study demonstrated that scavenging guilds and taphonomic processes are unique to the environment in which a body is located.

The scavenging activity of different species was shown to vary with the stage of decomposition, time of day, and location. The primary marine scavengers were the Australian herring (*Arripis georgianus*), Banded Sweep (*Scorpiis georgiana*), Brownspotted Wrasse (*Notolabrus parilus*), and Weeping Toadfish (*Torquigener pleurogramma*). Direct feeding on the remains by a common octopus (*Octopus sp.*), tiger shark (*Galeocerdo cuvier*), and an unknown crab (Family: *Portunidae*) was also observed. The primary terrestrial scavenger was the King's skink (*Egernia kingii*). Direct feeding by the Australian Raven (*Corvus coronoides*) and quokka (*Setonix brachyurus*) was also observed. No scavenging was observed at the hypersaline site despite avian activity in the surrounding water.

The chief limitation of this study lay in the limited timeframe allowed for the experiment as the legs did not have sufficient time to progress through all stages of decomposition. Nevertheless, it is the first study of its kind on Rottnest Island and highlights the need for further, more extensive study on the island.

The research follows the lead of O'Brien's (pers comm, 2018, 2019) research, which includes the first major Australian decomposition and scavenging study and subsequent investigations into small island taphonomy. A novel, continuous recording

system was used to monitor marine scavenging and revealed scavenger interactions that would not be evident from episodic data. Terrestrial and hypersaline legs were monitored with motion-based trail cameras; while this successfully captured scavenging events, it is possible for gaps in scavenging activity to exist where continuous monitoring would have been desired.

4.2 Rate of Decomposition

A significant difference between this research and previous studies is the experiment location on Rottnest Island, Western Australia. The climate, environment, conservation efforts, and animal communities vary between Rottnest Island and well-researched locations like North America, so the rates of decomposition can be expected to vary as well.

As the legs used in this study were prematurely collected before skeletonization was achieved due to the logistics of the project, only the beginning stages of decomposition can be compared. Even so, this study used pig legs as a substrate and not whole pigs, which are typically used for larger-scale research, so differences may arise from differences in carcass size and skin coverage as well.

Galloway (1997) found that active decay began between the first and fifth day after death and ended between days three and eight in the Sonoran Desert in Arizona. In some circumstances, active decay persisted for as long as two months but ended by one month in most cases (Galloway, 1997). Bass (1997) reported that bodies in Tennessee transitioned from fresh to bloated during the first week postmortem and from bloated to active decay in the second through fourth weeks postmortem.

Decomposition of the terrestrial legs in this experiment differed from that of these studies by the absence of the bloat stage. The rate of decomposition observed was also accelerated when compared to Bass's (1997) results but fit into Galloway's (1997) timeline, although the remains in Galloway's study also went through the bloat stage. This could be due to the similarly hot and arid environments between the two studies. On average, the Sonoran Desert has between 18 and 56 cm of rainfall annually and Rottnest Island has 56 cm, while Knoxville, TN has nearly twice that at 121 cm. The desiccation and lack of bloating observed in this study can be attributed to this disparity.

Insect activity generally increases with increasing temperature until the heat becomes lethal to insects, which has been reported to 30-35°C for *Calliphoridae* maggots (O'Brien, 2008; Voss et al., 2014). The ambient terrestrial temperature in this study reached a maximum of 34.812°C, which is near the threshold for maggot survival. While eggs and maggots were present on both legs throughout the experiment, neither were particularly prolific nor grew into maggot masses. It is possible that the high temperatures that stunted maggot growth and hardened the flesh also slowed the rate of decomposition.

The rate of decomposition observed in the hypersaline leg appeared to agree with Bass's (1997) and Galloway's (1997) studies. However, the experiment concluded before the bloat stage ended, so the exact length of this stage cannot be compared. The similarities in extended lengths of bloating can be attributed to the water the leg was placed in, which kept the flesh hydrated despite experiencing constant, higher light intensity than the terrestrial legs. Additionally, this leg was placed with the exposed flesh against the ground, so gases formed during decomposition were trapped by the skin.

4.3 Scavengers

4.3.1 Marine Scavengers

The Australian herring (*Arripis georgianus*) is known to feed on small fish and crustaceans (“Fisheries Fact Sheet: Australian Herring,” 2015). Likewise, the Brownspotted Wrasse (*Notolabrus parilus*) and Weeping Toadfish (*Torquigener pleurogramma*) are also carnivorous and feed on invertebrates, including mollusks and amphipods, although the prey of choice varies somewhat between the two species (Bray, 2017, 2020). It is reasonable that these three species scavenged on the legs frequently and can be concluded that the fish were feeding on the flesh. Additionally, the Weeping Toadfish remained deflated throughout the duration of the experiment and fed on the legs for extended periods of time, indicating that the fish did not feel threatened while feeding. The Australian herring also scavenged for extended lengths of time, indicating the species did not feel threatened either.

On the other hand, the Banded Sweep (*Scorpiis georgiana*) is known to feed on algae and zooplankton. Several species of fish have been observed feeding on algae adhering the surface of bodies and bones, resulting in surface scoring (Pokines & Higgs, 2015). The Banded Sweep was likely not feeding on the legs for the flesh, but rather for the microorganisms that were deposited on the surface.

The common octopus (*Octopus sp.*) is carnivorous and generally feeds at night (“Common Octopus,” n.d.). The octopus in this study scavenged around noon and took self-defensive measures by ejecting ink, repelling backwards, and attempting to take the leg. These factors indicate that the octopus had an aversion to predation. The octopus likely attempted to move the leg to a safer location but quickly gave up on its prey after

failing to remove it. Rather than remain vulnerable near the shore, the octopus retreated. An octopus was also seen three hours later, although it cannot be determined if the same octopus returned for a second attempt to remove its prey, or if a second octopus discovered the legs.

The tiger shark (*Galeocerdo cuvier*) is nocturnal (Whisson & Hoschke, 2017). Sharks are known predators that sometimes scavenge on live humans and remains (Burgess & Callahan, 1996; Clua et al., 2014; Iscan & McCabe, 1995; Rathbun & Rathbun, 1984). This is consistent with the observation that no other fish were in the area when the shark appeared. Additionally, the shark scavenged at dusk and at high tide, which was able to accommodate the shark's large size. The shark's powerful jaws made cutting the rope and eating the whole leg in one bite possible as well.

There was no difference between the duration of scavenging events of all seven marine scavengers. This was a surprising find because initial impressions during image processing were that the Australian herring, Banded Sweep, Brownspotted Wrasse, and Weeping Toadfish spent the most time near the legs. This can possibly be attributed to the limited amount of meat that the fish can consume at one time. Although these fish remained near the legs for extended periods of time, much of that time was spent idling due to small stomach capacity or inability to feed during strong currents.

4.3.2 Terrestrial Scavengers

The Australian Raven (*Corvus coronoides*) is a prolific scavenger in Western Australia. The ravens are most active during autumn and winter, during the final stage of the breeding cycle (O'Brien et al., 2010). In a previous study, the birds scavenged in

flocks for extended periods of time (O'Brien, 2008). The Australian Raven was not a frequent scavenger in this research, most likely because the study did not coincide with the breeding season. The birds that were imaged surveyed the surrounding area between bites, indicating a fear of predation. Additionally, only one bird was present at any one time, so there was no protection from a group.

The King's skink (*Egernia kingii*) is an omnivore that is endemic to Western Australia (Arena & Wooller, 2003). The skink's diet consists largely of plants and is supplemented with invertebrates on an opportunistic basis (Arena & Wooller, 2003). The skinks also live on offshore islands in this region, where many factors that may adversely impact the reptiles are absent (Arena & Wooller, 2003). With the highest scavenging intensity, The King's skink was the primary terrestrial scavenger. The skinks were also voracious scavengers, employing energy-consuming tactics to remove flesh from the leg. The animals were likely able to spend extended lengths of time feeding because of the absence of many predacious species that would have otherwise been present on the mainland and did not feel like they were in danger. Additionally, large prey with no self-defense was prime choice for opportunistic scavengers that otherwise would have needed to fight for protein and risk injury in an altercation.

The quokka (*Setonix brachyurus*) is nocturnal and herbivorous (Rippey & Hobbs, 2003). The quokka sightings in this study coincide with the quokka's active hours. The few and feeble scavenging events attempted by the quokka in this study indicate that the events were likely anomalies, especially considering the typical diet. The quokka indirectly approached the leg, indicating an aversion to predation and lack of interest in the leg.

4.4 Influences on Scavenging Intensity

Ecological research on scavenging has suggested that the nature of scavenging species, the weather, and the state and characteristics of remains may influence scavenging patterns (Selva, Jędrzejewska, Jędrzejewski, & Wajrak, 2005).

Avian scavengers are best suited for locating remains, and ravens in particular can do so efficiently (Ruxton & Houston, 2004; Stahler, Heinrich, & Smith, 2002). These birds are more likely to scavenge on remains that are fresh or are located where tree coverage is minimal (Selva et al., 2005). This was not observed in this study, as the fresh and active stages of decomposition showed no difference in Australian Raven (*Corvus coronoides*) scavenging intensity, and the raven did not appear at the experimental site until the active stage began. A combination of several factors may have contributed to this result. The tree coverage on Forbes Hill, while patchy, may have effectively concealed the legs from view from the sky. Additionally, a large Australian Raven population resides around the Thompson Bay Settlement on Rottnest Island, which is a hub for tourists and is rarely lacking in trash and abandoned scraps of food. Rottnest Island ravens may have grown accustomed to the readily available food found in the Thompson Bay Settlement so that few individuals search for food in the less populated regions of the island. A few other explanations are also possible and are discussed in the following sections.

Extreme temperatures have been shown to alter scavenging activity; sub-freezing temperatures have been linked to increased scavenging, while high temperatures have been shown to have the opposite effect for some species (O'Brien, 2008; Selva et al., 2005). High temperatures present the need for thermoregulation, which alters animals'

typical behavior by increasing their dependence on inactivity and water conservation. Australian Raven scavenging reportedly begins to drop in the 20°C range (O'Brien, 2008). Temperatures in this study remained well above 20°C for most daylight hours during this experiment, which could account for the minimal raven scavenging activity.

Unlike birds and mammals, most reptiles are ectothermic and rely on external heat sources to maintain their body temperature (Garrick, 2008). The two major means of thermoregulation are heliothermy (the gain of heat from solar radiation) and thigmothermy (the gain of heat from direct contact with warm objects) (Garrick, 2008). Skinks and other diurnal lizards in hot and arid environments tend to be heliothermic and bask in the sun, while nocturnal and forest-dwelling lizards are thigmothermic (Garrick, 2008). The King's skink (*Egernia kingii*) was the primary terrestrial scavenger likely because of the species' thermoregulatory abilities. The skinks were observed during the heat of the day when temperature and light intensity were highest; feeding on the leg allowed the skinks to bask in the sun and feed simultaneously. The skinks' use of high-energy scavenging tactics is also an indication that the animals were secure in the environment and had access to a reliable source of water, where they were able to between scavenging events. Despite this, the skinks' average scavenging event duration was not greater than that of the other scavengers, indicating that the skinks required breaks throughout the day to conserve water and energy.

High temperatures can also alter remains, subsequently influencing scavenging intensity. Mummification of skin can encase the flesh inside a hard shell that only the strongest carnivores can penetrate (O'Brien, 2008). While the legs in this study did not mummify, they did become desiccated. The hardness of the flesh may have deterred the

Australian Raven, which did not scavenge after Day 3, because the energy cost outweighed the reward of scavenging. On the other hand, the King's skink was better suited to tear through the hardened flesh and returned to the legs every day beginning on Day 1.

Scavenging intensity tends to increase as decomposition progresses due to increased opportunity for scavengers to find the remains and the exposure of flesh following the termination of the bloat stage and during advanced decay (O'Brien, 2008). In O'Brien's (2008) study, the Australian Raven was among the first scavengers to arrive at remains, but extensive feeding was not observed until advanced decay processes had softened the skin. This is consistent with the findings in this study; had the experiment continued into later stages of decomposition, it is possible that the Australian Raven scavenging intensity would have increased as the flesh decomposed and softened.

4.5 Forensic Implications

Three swimming and boat accidents have occurred between Rottnest Island and Fremantle, the major mainland port city, have been reported in the last five years, however rare. On the night of March 21, 2016, Matthew James Bale went missing from Rottnest Island during a holiday with his parents and wife ("Matthew James BALE," 2019). The night of his disappearance, Bale's wife confronted him about his drinking and bought him a return ferry ticket. Later that night, Bale's father saw him on a beach with two young women and observed them from afar until Bale noticed and told his father to leave. Bale did not return to the family's accommodations that night, and the family assumed he used the ferry ticket to return home to Fremantle. Upon arriving

home later in the week, Bale's family discovered this was not the case and alerted police. Despite a 100-volunteer search of the island, no sign of Bale was discovered. Two years following his disappearance, a woman came forward and revealed she was one of the women Bale was with on the beach on the night of his disappearance. She revealed that she and her friend were on the beach watching the sunset when Bale appeared with a box of wine and asked to join them. Bale said he wanted to go back to Fremantle, but the last ferry had left for the evening; he announced he would swim to the mainland instead, but the women thought he was joking. Following this new information, the Deputy State Coroner ruled in 2019 that Bale was deceased beyond a reasonable doubt, although the exact cause of death cannot be determined.

A boating incident on October 3, 2018 left three fishermen dead and the fourth still missing (7NEWS Perth, 2019). The bodies of Jacob Pham and Justin O'Neill were found in the days after the group failed to return home from fishing. The search for the other two fishermen was called off a week after the incident. A few weeks later, a fisherman found debris in the water between Carnac Island and Rottnest Island, prompting the search to restart. Human remains belonging to Uock Pham were discovered by divers shortly thereafter. After finding the boat on the ocean floor nearly two months after the incident, the missing passenger, Tuan Pham, was declared deceased as well.

The following year, Peter Tuohey went missing after falling overboard from a friend's boat while he, his wife, and four friends were returning from Rottnest to Hillarys Boat Harbor on September 8, 2019 (Hickey, 2019). Between 10 and 15 minutes elapsed between the last sighting of Tuohey onboard the boat and being declared missing, and

none of the passengers saw Tuohey leave the boat. The following day, his body was found near Burns Beach and Quinns Rock area, which is on the mainland approximately 35-40 km northeast of Rottneest Island. A cause of death was not included in the report.

Knowledge of the marine scavenging guild near Rottneest Island could have served two main purposes in these three cases. First, for the cases in which remains were recovered, artefacts on the skin and/or bones likely resulted from marine scavengers, but this is not a guarantee. Knowing which species inhabit those waters and feed on remains can help identify scavenging artefacts and rule out perimortem altercations when analyzing wounds during an autopsy. Second, for the missing persons cases, knowledge that sharks inhabit the water and feed on remains gives weight to the conclusions that the missing men died at sea.

4.6 Limitations of this Study

The terrestrial experiment was limited in design because of the use of motion-detection pictures and video as the only imagery collected. While this should be good in theory, the cameras sometimes began recording after a scavenging event had already begun and stopped recording before the event ended. This resulted in estimated event start and times, so the true length of the event was unknown. Additionally, some events at one leg were recorded on one camera but not the other. This gives rise to the possibility that one or more scavenging events occurred but were not recorded on either camera. Furthermore, the cameras aimed at Terrestrial 1 were far from the leg; this would have been ideal had large groups of scavengers been present at the leg and

interacted with each other, but for this experiment it made it difficult to determine if an animal was feeding or simply near the leg.

The experiments at all three sites were limited in their short duration, which prohibited the study of all stages of decomposition. The marine experiment in particular was short-lived, with all legs remaining in the water for fewer than ten hours. While part of this was a result of scavenging, experimental error was the culprit on the second day, and more care can be taken to secure the legs in future research. For all three sites, a longer experiment duration that would allow all legs to reach skeletonization would be ideal because remains are not always found in early stages of decomposition, as evidenced in the case reports.

The applicability of this study is also limited, both by the geographic isolation and low death rate on the island. Although several cases of marine deaths were reported, no deaths or missing remains have been reported on land. While knowledge of the terrestrial scavenging guild and apparent lack of hypersaline scavenging is interesting information, it will likely never need to be applied.

4.7 Further Studies

Further taphonomic research on Rottnest Island would address the limitations of this project. As this project focused heavily on scavenging, no controls were used; future research should include controls that prohibit access to scavengers so the impact on scavenging on decomposition rates can be determined.

Future research should also aim to obtain a year-round catalogue of the scavenging guilds on the island by deploying replicates throughout each season.

Including multiple replicates over several years would also shed light on the effect of climactic anomalies, such as unusual rain or temperature conditions, on scavenging guilds and decomposition. Additionally, a long-term study could determine what impact, if any, global warming will have as well.

The study should also be extended to other small islands, both near Rottneet Island and in different regions of the world. This would help establish what taphonomic processes are unique to small islands as opposed to large land masses or deep-sea environments, or which variations in these processes are a result of inter-island differences in environment and animal populations.



Chapter 5: Conclusions



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This study was an important step in cataloging the scavenging guilds on Rottneest Island and understanding the differences in early decomposition rates between different environments. There were marked differences in scavenging between the marine, terrestrial, and hypersaline environments chosen for this study. Differences in the early stages of decomposition were also observed between the terrestrial and hypersaline environments.

Seven marine scavengers were observed at Bickley Point, four of which were the primary scavengers. Of the primary scavengers, three were carnivorous, and one was likely feeding on algae adhering to the leg. While the primary scavengers had higher scavenging intensities, the average duration did not vary between all seven scavengers. Marine decomposition rates could not be determined because all marine replicates ended earlier than anticipated.

Three terrestrial scavengers were observed at Forbes Hill, one of which was the primary scavenger. The thermoregulating ability of the King's skink (*Egernia kingii*) allowed the skinks to scavenge throughout the day despite high ambient temperatures. A quokka (*Setonix brachyurus*) interacted briefly with the legs, but this is likely an anomaly resulting from curiosity rather than intention to scavenge. The Australian Raven (*Corvus coronoides*) is a prolific scavenger in Western Australia but scavenged infrequently in this study, perhaps due to the high temperatures and desiccation of the legs. The legs did not bloat and transitioned directly to active decay following the end of the fresh stage of decomposition. Fly, ant, and beetle activity was also observed, although the extreme heat appeared to stunt maggot growth.

No hypersaline scavenging was observed at Lake Baghdad despite frequent avian activity in the surrounding water. The leg's partial submersion in the water hydrated the flesh and caused the leg to bloat. Bloating persisted from the end of the fresh stage to the breakdown of the experiment.

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