MULTIDIMENSIONAL AND TRANSDISCIPLINARY STRATEGIES FOR SUSTAINABLE COEXISTENCE WITH *Varanus salvator* (Reptilia: Varanidae) IN MALAYSIA

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by

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LIST OF SYMBOLS

$\widehat{AC}$	Arc Length
$\overline{AC}$	Claw Length From Base To Tip
$l^1 + l^2$	Inner Claw Length
α	Tip Angle
β	Claw Curvature
κ	Cohen's Kappa
H'	Shannon–Wiener diversity Index
h^1	Claw Height At The Base
h^2	Claw Height At Half The Claw
h^3	Tip Width

LIST OF ABBREVIATIONS

ADA boost	Adaptive Boosting
ANOVA	Analysis of Variance
API	Application Programming Interface
BORG	Barn Owl and Rodent Research Group
BTC	Base-Tail-Circumference
CH	Chagar Hutang Turtle Sanctuary
CV	Computer Vision
DCNN	Deep Convolutional Neural Network
DF	Degrees Of Freedom
DL	Deep Learning
EEL	Eye-To-Ear Length
Grad-CAM	Gradient-Weighted Class Activation Mapping
HWC	Human-Wildlife Conflict
IQR	Interquartile Range
KAP	Knowledge, Attitudes, and Practices
KJ	Kiara Jubli Sdn Bhd
KMO	Kaiser-Meyer-Olkin Test
LASSO	Least Absolute Shrinkage and Selection Operator Regression
ML	Machine Learning
PCA	Principal Components Analysis
PERHILITAN	Jabatan Perlindungan Hidupan Liar Dan Taman Negara
QGIS	Geographic Information System
RFE	Recursive Feature Elimination
RMSE	Root Mean Square Error

SA	Sempadan Asasi Sdn Bhd
SE	Standard Error
SEATRU	Sea Turtle Research Unit
SL	Skull Length
SPSS	Statistical Package for Social Sciences
STL	Snout-Tail-Length
SVL	Snout-Vent-Length
SVM	Support Vector Machine
SVR	Support Vector Regression
SW	Skull Width
TL	Tail Length
TW	Thigh Width
UMT	Universiti Malaysia Terengganu
USM	Universiti Sains Malaysia
XG boost	Extreme Gradient Boosting

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STRATEGI PELBAGAI DIMENSI DAN TRANSDISIPLIN UNTUK KEWUJUDAN BERSAMA YANG LESTARI DENGAN *Varanus salvator* (Reptilia: Varanidae) DI MALAYSIA

ABSTRAK

Penukaran habitat di Semenanjung Malaysia meningkatkan kegantungan spesies seperti *Varanus salvator* terhadap habitat bandar dan pertanian. Kelestarian kewujudan bersama adalah penting untuk mengekalkan *V. salvator*, salah satu daripada pemangsa dan pemulung besar yang masih tinggal di habitat ini. Terdapat kekurangan maklumat yang signifikan mengenai dinamik ini yang memerlukan kajian lanjutan. Dari perspektif manusia, rakyat Malaysia menunjukkan pengetahuan sederhana dan sikap positif terhadap *V. salvator*. Skor pengetahuan dan sikap berkorelasi positif. Konflik (kecederaan dan pemangsaan haiwan domestik) dilaporkan oleh minoriti. Persepsi budaya adalah negatif, tetapi kejaraannya yang jarang berlaku menghadkan pandangan yang bermakna. Dapatan ini menunjukkan koeksistensi boleh dikekalkan dari perspektif manusia. Dari perspektif hidupan liar, *V. salvator* paling banyak dijumpai di kawasan bandar, diikuti oleh habitat pertanian dan hutan. Individu bandar menunjukkan ciri-ciri alometrik yang lebih besar yang dikaitkan dengan dimorfisme seksual, manakala kadal pertanian menunjukkan variasi lebar paha, mencadangkan peningkatan kelajuan berlari. Di seluruh habitat, saiz dan keadaan badan adalah konsisten dan berkorelasi positif, menunjukkan kesihatan keseluruhan yang baik di semua habitat. Disebabkan kaedah penentuan jantina tidak-invasif yang tidak konsisten, kajian ini mengenal pasti pemboleh ubah morfologi untuk penentuan jantina, termasuk keliling pangkal ekor yang sering diabaikan. Hasil ini berguna untuk pemantauan populasi masa depan. Kajian ini juga menganalisis morfologi kuku V.

salvator di sepanjang gradien antropogenik untuk menyiasat lebih lanjut ciri-ciri berkaitan lokomosi. Di habitat pertanian, kuku menunjukkan peralihan ke arah lokomosi terestrial dan peningkatan potensi berlari, serupa dengan variasi lebar paha. Kuku di kawasan bandar dan hutan menunjukkan struktur yang serupa. Penglihatan komputer terbukti lebih efisien dan tepat daripada kaedah tradisional untuk mengklasifikasikan perbezaan cakar berdasarkan habitat, menunjukkan kegunaannya dalam kajian ekologi masa depan. Dari segi tingkah laku, habitat antropogenik tidak meningkatkan agresifan intra-spesifik dalam *V. salvator*. Keagresifan adalah lebih tinggi di habitat hutan, mungkin disebabkan oleh persaingan yang meningkat untuk telur kura-kura yang kaya kalori tetapi kurang banyak. Sebaliknya, persaingan yang kurang di habitat pertanian dan bandar kemungkinan mengurangkan tahap keagresifan, walaupun dengan kehadiran anjing liar. Selain itu, tingkah laku ritual seperti mengangguk kepala membantu mengurangkan konflik dan menghadkan kecederaan, selaras dengan ramalan "game theory". Interaksi anjing di habitat pertanian meningkatkan tingkah laku mengelak, yang kemungkinan menjelaskan variasi lokomotif, menyoroti keperluan untuk mengkaji populasi anjing liar bagi cabaran koeksistensi. Tesis ini menyimpulkan bahawa koeksistensi dengan *V. salvator* adalah boleh dikekalkan merentasi gradien antropogenik, tetapi pemantauan dan pengurusan habitat yang berterusan adalah penting. Tesis ini mencadangkan penyelidikan lanjut mengenai penggunaan habitat di kawasan bandar dan interaksi antara spesies di kawasan pertanian untuk mengoptimumkan pengurusan konflik dan mengekalkan koeksistensi.

MULTIDIMENSIONAL AND TRANSDISCIPLINARY STRATEGIES FOR SUSTAINABLE COEXISTANCE WITH *Varanus salvator* (Reptilia: Varanidae) IN MALAYSIA

ABSTRACT

Habitat conversion in Peninsular Malaysia increases the dependence of species like *Varanus salvator* on urban and agricultural habitats. Sustainable coexistence is essential for maintaining *V. salvator*, one of the few remaining large predators and scavengers in these habitats. Significant gaps about these dynamics warrant further research. From the human perspective, Malaysians exhibit moderate knowledge, and positive attitudes toward *V. salvator*. Knowledge and attitude scores were positively correlated. Conflict (injury and domestic animal depredation) was reported by a minority. Cultural perceptions were negative, but their infrequency limits meaningful insights. These findings indicate coexistence to be sustainable from the human perspective. From the wildlife perspective, *V. salvator* was most abundant in urban areas, followed by agricultural and forest habitats. Urban individuals displayed larger allometric traits linked to sexual dimorphism, while agricultural lizards displayed variations in thigh width, suggesting increased sprinting. Across habitats, body size and condition were consistent and positively correlated, suggesting good overall health in all habitats. Due to the unreliability of non-invasive sexing methods, this study identified morphological variables for sex determination, including the overlooked base-tail circumference. These results are useful for future population monitoring. This study analysed *V. salvator* claw morphology across the anthropogenic gradient to investigate locomotion-related traits further. In agricultural habitats, the claws indicate a shift towards more terrestrial locomotion and a potential increase in sprinting, similar

to variations in thigh width. Urban and forest claws exhibited similar structures. Computer vision proved more efficient and accurate than traditional methods for classifying habitat-based claw differences, suggesting its usefulness in future ecological studies. In terms of behaviour, anthropogenic habitats did not increase intra-specific aggression in *V. salvator*. Aggression was higher in forest habitats, potentially from increased competition for calorie-rich but less abundant turtle eggs. In contrast, reduced competition in agricultural and urban settings likely mitigated aggression levels, even with the presence of feral dogs. Additionally, ritualistic behaviours such as head-bobbing helped de-escalate conflicts and limited injuries, aligning with game theory predictions. Dog interactions in agriculture habitats increased avoidance behaviours, likely explaining locomotive variations, highlighting the need to study feral dog populations for coexistence challenges. This thesis concludes that coexistence with *V. salvator* is sustainable across the anthropogenic gradient, but continuous habitat-specific monitoring and management are essential. This thesis recommends further exploration into habitat use in urban areas and inter-specific interactions in agricultural areas to optimise conflict management and sustain coexistence.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

In Peninsular Malaysia, vast expanses of rainforest have been converted into anthropogenic habitats, which range from urban areas to oil palm dominated agriculture landscapes. Anthropogenic habitat disturbance will likely increase in the future following economic and population growth. Such habitat transformations can cause shifts in many natural history traits in wildlife populations, including morphological proportions, sex ratios, diet, and aggressive behaviour (Ngoprasert *et al.*, 2007; Uyeda *et al.*, 2015; Twining *et al.*, 2017). Furthermore, the expansion of anthropogenic habitats can cause more frequent interactions between human communities and wildlife populations which can lead to varying degrees of conflict (Schell *et al.*, 2021). Given the effects of anthropogenic habitat disturbance on both humans and wildlife, a thorough investigation on sustainable human-wildlife coexistence must consider both perspectives. This thesis adapted Carter and Linnell (2016)'s definition of sustainable coexistence: low human-wildlife conflict and minimal negative effects on behaviour and morphology of disturbance-tolerant species in anthropogenic habitats.

Varanus salvator is a widespread species of large lizard that occurs throughout Malaysia (Quah *et al.*, 2021). It was selected as a model for assessing sustainable human-wildlife coexistence because it is tolerant of human disturbance (Twining *et al.*, 2017) and occurs in a diverse range of habitats; from low disturbance habitats such as forests and protected areas (De Lisle, 2007), to highly disturbed areas such as agricultural land (Khadiejah *et al.*, 2019) and human habitation (Kulabtong and Mahaprom, 2014). *Varanus salvator* exhibits a generalist carnivorous diet (Kulabtong

and Mahaprom, 2014) and acquires its prey through active hunting (Cota and Sommerland, 2013) or scavenging (Rusli *et al.,* 2020).

The importance of local communities in maintaining biodiversity has been recently recognised (Moore *et al.*, 2016). With regards to *V. salvator*, surveys conducted outside of Malaysia found that public opinion varied in different regions (Uyeda *et al.,* 2016; Bhattacharya and Koch, 2018; Arida *et al.*, 2020). *Varanus salvator* is abundant surrounding human habitation (Twining *et al.*, 2017), which could lead to high levels of wildlife conflict as this species consumes domesticated species, as shown in Thailand by Kulabtong and Mahaprom, (2014). Studying the knowledge and perceptions of communities coexisting with *V. salvator* will provide a comprehensive understanding with regards to the extent of human-wildlife conflict. This data will potentially provide policy makers with the tools to promote continued sustainable coexistence between *V. salvator* and local communities. Currently, this is the first study to analyse the human perceptions toward this species in Malaysia.

Anthropogenic disturbance impacts *V. salvator*'s body morphology and condition differently by location. Twining *et al.*, (2017) found larger size and better condition in disturbed habitats but higher body damage, attributing it to resource availability and competition. Khadiejah *et al.*, (2019) observed larger individuals in natural habitats, but similar body condition in mangroves/rice fields and forest/oil palm plantation, suggesting hunting in disturbed areas could limit size. Guerrero-Sanchez *et al.*, (2021; 2023) reported no difference in body size and condition between forests and oil palm plantations in Sabah, suggesting a resource-competition trade-off. Notably, urban areas were not analysed in the papers mentioned above. This study is the first to analyse the effects of the wider anthropogenic disturbance gradient (forest,

agriculture, urban) on the body morphology, condition, ectoparasite load, and scarring of *V. salvator* populations in Malaysia.

There is currently a lack of reliable non-invasive sexing methods for this species, despite the abundant research on general body morphology (Shine *et al.*, 1996; Shine *et al.*, 1998; Koch *et al.*, 2007). Given male-skewed sex ratios due to habitat disturbance (Twining *et al.*, 2017) and its use in the skin trade (Khadiejah *et al.*, 2019), accurate field sexing is vital. This study is the first attempt to formulate a machine learning morphology-based, non-invasive sex identification method for this species, which will streamline future work and improve the accuracy of field sex identification.

Anthropogenic habitats effect the nature of an organism's locomotive interaction with its habitat, either due to low structural diversity in these habitats (Zemp *et al.*, 2019; Falvey *et al.*, 2020), or changes in wildlife communities that necessitate shifts in locomotive behaviours (Azhar *et al.*, 2012). In lizards including Varanids, claw morphology correlates strongly with habitat use and locomotive behavioural strategies (D'Amore *et al.*, 2018; Schwarz *et al.*, 2021). This study is the first to analyse the claw morphology of *V. salvator* and observe any intraspecific variation in these structures, adding to the understanding of *V. salvator*'s environmental interactions and the potential role played by anthropogenic disturbance in this context.

Anthropogenic habitats like agriculture and urban areas typically provide abundant, calorie-rich food sources, including direct food subsidies from human waste and increased prey abundance (Rusli *et al.*, 2020; Guerrero-Sanchez *et al.*, 2023). These resources can have negative effects on predatory animal populations (Guerrero-Sanchez *et al.*, 2023). The effects of trophic subsidies on other Varanid lizards have

been studied previously and shown to lead to increased aggression (Jessop *et al.*, 2012; Ardiantiono *et al.*, 2018). *Varanus salvator* was observed to form size-based dominance hierarchies where trophic subsidies were in sufficiently high concentrations (Uyeda *et al.*, 2015). This behaviour could have significant negative impact over time for this species, especially if *V. salvator* falls into an ecological trap (Schlaepfer *et al.*, 2002). Therefore, analysing the frequency and intensity of aggressive interactions across the anthropogenic disturbance gradient, and disturbance-related factors like scavenger/predator communities and diet diversity, is crucial in providing a comprehensive assessment of human-wildlife coexistence with *V. salvator*.

1.2 Problem Statement and Rationale

In Peninsular Malaysia, the transformation of rainforests into urban and agricultural areas has increased wildlife reliance on anthropogenic habitats and led to more frequent interactions between humans and disturbance-tolerant species such as *Varanus salvator*. Despite the adaptability of *V. salvator*, significant gaps in understanding the dynamics of this coexistence exist, necessitating the need for further research to develop sustainable coexistence strategies. Key gaps include the unclear extent of conflict between Malaysians and this species, and the nature of local perspectives on human-*V. salvator* conflicts, which are crucial for effective wildlife management. Additionally, there is limited knowledge on how anthropogenic disturbances affect the general morphology (body size, condition, and damage) of *V. salvator*, particularly in urban populations, and the absence of non-invasive sex identification methods is a serious inconvenience for ecological studies investigating sex ratios in the field.

The relationship between anthropogenic habitat disturbances and claw morphology, which is vital for understanding adaptive locomotion and habitat utilization, is also poorly understood. Furthermore, the influence of calorie-rich diets from anthropogenic sources on *V. salvator*'s aggression levels needs detailed investigation to assess its implications for sustainable coexistence. These study aims to address these gaps, which are essential for crafting effective strategies to maintain balanced human-wildlife interactions.

1.3 Objectives and Hypotheses:

1. To explore the knowledge, attitudes, interactions, and cultural perceptions of local communities that coexist with *V. salvator*.

    a. H_0: There is no significant difference in knowledge, attitudes, interactions, and cultural perceptions towards *V. salvator* among different demographic variables analysed.

2. To identify and compare important morphological variables across urban, agriculture, and forest habitats.

    a. H_0: There is no significant difference in morphology across urban, agriculture, and forest habitats.

3. To identify important morphological variables for non-invasive sex identification and compare the variations in those variables between sexes.

    a. H_0: There are no significant morphological differences between male and female *V. salvator* that can be used for non-invasive sex identification.

4. To identify and compare important claw structures across urban, agriculture, and forest habitats. Additionally, to compare the efficiency of analysis with manual measurements and computer vision.

    a. H_0: There is no significant variation in claw structures of *V. salvator* across urban, agricultural, and forest habitats.

    b. H_0: There is no significant difference in the efficiency of analyzing claw structures between manual measurements and computer vision techniques.

5. To investigate the frequency and intensity of intraspecific aggression within *V. salvator* across urban, agriculture, and forest habitats. Additionally, to explore the potential impact of diet diversity, interspecific competition, and predation on aggression levels.

    a. H_0: The frequency and intensity of intraspecific aggression in *V. salvator* do not differ significantly across urban, agricultural, and forest habitats.

    b. H_0: Diet diversity, interspecific competition, and predation do not have a significant impact on the aggression levels of *V. salvator*.

CHAPTER 2

LITERATURE REVIEW

2.1 The Importance of Sustainable Human-Wildlife Coexistence

The Anthropocene has resulted in the widespread encroachment of anthropogenic activities into wildlife habitats. Malaysia is a country with expanding urbanisation and agricultural land use and is no exception to anthropogenic habitat expansion. Currently, 58% of Malaysia's land area is classified as forest (The World Bank, 2024). However, recently, large areas of rainforest have been cleared and replaced with crop plants, primarily oil palm (2.74 million hectares as of 2020, MPOB, 2020). Urban areas also constitute a substantial land area in Malaysia, though less than agricultural land (The World Bank, 2024). As a result of this disturbance, biodiversity in these disturbed areas is lower, but the abundance of disturbance-tolerant species is higher (Fitzherbert *et al.*, 2008; Teuscher *et al.*, 2015; Pashkevich *et al.*, 2021).

The large amount of anthropogenic land area has consequences for both humans and wildlife. From the human perspective, increased interactions with disturbance-tolerant species often lead to human-wildlife conflict (Anand and Radhakrishna, 2017). From the wildlife perspective, disturbance-tolerant species are likely to face challenges associated with anthropogenic habitats such as shifts in behaviours and morphology (Ngoprasert *et al.*, 2007; Franssen, 2011). Therefore, a comprehensive study on sustainable human-wildlife coexistence must encompass both perspectives. Considering only one perspective could lead to key aspects that require improvement to be overlooked, especially given that the nature of coexistence depends on factors such as human densities and the wildlife species in question (Mekonen, 2020).

This study adapts the definition of sustainable coexistence from Carter and Linnell, (2016), such that human-wildlife coexistence is considered sustainable if levels of human-wildlife conflict is low, and disturbance-tolerant species in anthropogenic habitats do not suffer negative effects on behaviour or morphology compared to conspecifics in more natural habitats. The mutual minimization of negative impacts on both humans and wildlife is essential for achieving sustainable coexistence. The focus on morphology and behaviour in this definition is a result of constraints on the length of this thesis. While other aspects of wildlife health, such as the influence of anthropogenic disturbance on home range behaviour, genetic diversity, and ectoparasite load are significant in the literature (Twining *et al.*, 2017; Lino *et al.*, 2019; Guerrero-sanchez *et al.*, 2021; 2023), they fall outside the scope of this thesis. This study selected *Varanus salvator* as the focal wildlife species of this thesis, because of its abundance in anthropogenic habitats in Malaysia, ecological role in carrion removal, and large predator (Twining *et al.*, 2017; Kulabtong and Mahaprom, 2014). A detailed explanation of the significance of this species and the rationale for its selection in the context of sustainable coexistence is provided in a subsequent section of this literature review.

2.2 A Comprehensive Introduction to *Varanus salvator*

2.2.1 Order: Squamata, Family: Varanidae, Genus: *Varanus*.

The order Squamata comprises a diverse group of reptiles, including lizards, snakes, dibamids, and amphisbaenians (Rest *et al.*, 2003; Townsend *et al.*, 2004). As of March 2022, there were 11,349 species within Squamata (Uetz *et al.*, 2022), a substantial number compared to other clades. For reference, the largest order of mammals, Rodentia, includes 2,635 species (Mammal Diversity Database, 2022). Within Squamata, the family Varanidae stands out, containing the single genus *Varanus* (Fitch *et al.*, 2006), further divided into 11 subgenera (Auliya and Koch, 2020). The focal species of this thesis, *Varanus salvator*, belongs to the subgenus *Soterosaurus* (Koch *et al.*, 2013). Currently, there are 89 recognized species of Varanid lizards within Varanidae (Uetz *et al.*, 2022).

The family Varanidae have an extensive geographic distribution, spanning much of the old world (Koch *et al.*, 2013). These lizards exhibit diverse ecological tolerances, from arboreal behaviour (Chiszar *et al.*, 1999; Ziegler *et al.*, 2007) to semi-aquatic lifestyles (Mazumder *et al.*, 2020). Most Varanid species are carnivorous predators or scavengers, while some species like *V. bitatawa* and *V. olivaceus* are frugivorous (Bennett, 2014; Law *et al.*, 2016). Some Varanids possess venom, such as *V. komodoensis* and *V. varius* (Fry *et al.*, 2009). Despite variations in size, Varanids maintain a common body shape (Koch *et al.*, 2010). The largest discovered Varanid is currently the extinct species *V. priscus*, known as Megalania, with a total length exceeding 5.5 m and a weight of over 575 kg (Fry *et al.*, 2009).

2.2.2 Varanids of Malaysia

Malaysia has four Varanid species: *V. dumerilii*, *V. rudicollis*, *V. nebulosus*, and *V. salvator* (Bayless, 2004; Bennett and Lim, 1995). Dumeril's Monitor, *V. dumerilii*, is the smallest, with males around 130 cm and females 100 cm in total length (Auliya and Koch, 2020). It is rarely seen in Malaysia and is associated with wet forest habitats and has unique bright head coloration in hatchlings (Cota and Krebs, 2015). It is popular in the pet trade, but the sustainability of harvesting this species from the wild has not been assessed. It is currently listed as "Data Deficient" on the IUCN Red List (Iskandar *et al.*, 2021).

The Rough-necked Monitor, *V. rudicollis*, is the second smallest, with males measuring roughly 146 cm and females around 124 cm in total length (Auliya and Koch, 2020). Like *V. dumerilii*, it prefers forest habitats and swamps (Quah *et al.*, 2013), and faces threats from harvesting and habitat loss, with a "Data Deficient" status on the IUCN Red List (Phimmachak *et al.*, 2021). *Varanus nebulosus* is slightly larger with males reaching about 150 cm and females around 120 cm in total length (Auliya and Koch, 2020), and is a generalist species that tolerates human disturbance. It inhabits forests, agriculture, and urban areas, often alongside *V. salvator* (Laton and Mohammed, 2022). Human proximity exposes it to risks such as roadkill and consumption by certain ethnicities (Suzuki *et al.*, 2015). This species was previously listed as a subspecies of *V. bengalensis*, and its taxonomic status is still in debate (Goodyear *et al.*, 2022). Currently, *V. nebulosus* has not been evaluated by the IUCN Red List of Threatened Species and is still listed under *V. bengalensis* (Cota *et al.*, 2021).

2.2.3 The Asian Water Monitor, *Varanus salvator* Species Complex

The Asian Water Monitor complex, *Varanus salvator* ssp., is the second largest Varanid lizard after the Komodo Dragon, *V. komodoensis* (Gaulke and Horn, 2004). For comparison, a large male *V. komodoensis* can achieve a total length of 304 cm whereas reported total lengths of *V. salvator* are typically less than 230 cm but can also very rarely exceed 300 cm (Auliya and Koch, 2020). The geographic distribution of the *V. salvator* complex is vast. This species complex has the largest geographic distribution of any Varanid lizard The *V. salvator* complex ranges from India (Mazumder *et al*., 2020), Sri Lanka (Koch *et al*., 2007), Bangladesh (Rahman *et al*., 2017), China (Wei *et al*., 2002), Myanmar (Oo and Bates, 2016), Lao PDR (Suzuki *et al*., 2015), Vietnam (Amin *et al*., 2008), Cambodia (Thaung *et al*., 2018), Thailand (Cota *et al*., 2009), Malaysia including Northern Borneo (Guerrero-Sanchez *et* al., 2021; Khadiejah *et al*., 2019), Singapore (Bungum and Johns, 2022), Indonesia (Arida *et al*., 2020), and the Philippines (Koch *et al*., 2010).

The *V. salvator* complex consists of five subspecies; *V. s. salvator* (Sri Lanka), *V. s. bivittatus* (several Lesser Sunda Islands and Java), *V.s. andamanesis* (Andaman Islands), *V. s. macromaculatus* (South and Southeast Asia), *V. s. ziegleri* (Obi Island) (Koch and Böhme, 2010; Koch *et al*., 2007). As *V. s. macromaculatus* is the only subspecies present in Malaysia, it will be referred to as *V. salvator* for the rest of this thesis. This species is typically diurnal active hours from 0700-1700 hrs (Wikramanayake and Dryden, 1993. Similar to the majority of other Varanid species, *V. salvator* are carnivorous hunters and scavengers (Kulabtong and Mahaprom, 2014). This species potentially has two reproductive cycles a year that are closely followed by the rainy seasons, where a female can lay more than one clutch of 5 to 22 eggs per clutch (Cota, 2011b; Shine *et al*., 1996).

In terms of habitat use, *V. salvator* exhibits a strong preference toward a semi-aquatic lifestyle and is often found near waterways (Cota *et al*., 2009) including beaches and islands (Rusli *et al*., 2020). As a result of high ecological plasticity trademark of Varanid species, *V. salvator* is also proficient in climbing (Stanner, 2020) and burrowing (Wikramanayake and Dryden, 1993; Traeholt, 1995; Traeholt, 1997; Cota, 2011a). In addition to the significant ecological plasticity, this species also displays a high level of disturbance tolerance and has the capacity to inhabit and occur in high abundances in a variety of habitats, including forests, coastal areas, agriculture land, and urban areas (Twining *et* al., 2017; Rusli *et* al., 2020; Guerrero-Sanchez *et* al., 2021; Wongtienchai *et al*., 2021).

The widespread abundance and close proximity to humans has led to some consequences for this species, mainly in terms of roadkill, and human use. *V. salvator* is particularly susceptible to roadkill. From PERHILITAN data on wildlife roadkill, a study showed that between 2012 and 2017, *V. salvator* accounted for just over 30% (742 instances) of the total 2,444 animal collisions in this time period, holding the largest percentage of any species in this study (Kasmuri *et al*., 2020). Next in terms of human use, globally, huge numbers of *V. salvator* are hunted for the leather, meat, and traditional medicine trades (Uyeda *et* al., 2014; Arida *et* al., 2020;) This is also true in Malaysia, that reported an exported amount of 588,796 skins from 2011 to 2019 (Khadiejah *et al*., 2020).

Despite the seemingly intense harvesting from this species' wild population, a recent report indicated that population abundance and distributions were not significantly affected, but populations were denser, and individuals were smaller where harvesting occurred (Khadiejah *et al*., 2019). In addition to this, the current

IUCN Red List listing for *V. salvator* as of 2021 is “Least Concern”, which suggests this species’ continued persistence given the threats discussed above (Quah *et al*., 2021). Given that a substantial part of *V. salvator*'s population resides in disturbed habitats in Malaysia, where agricultural and urban areas make up 41.8% of total land area (The World Bank, 2024), further research is essential to comprehensively understand the potential impacts of habitat disturbance on this species.

2.3 The Human Perspective

From the human perspective, human-wildlife interactions exist on a spectrum of positive, neutral, and negative interactions (Bhatia *et al.*, 2020). Whether an interaction is positive or negative, is not principally dependent on the outcome of the interaction, but the human perception and tolerance toward said species (Marker *et al.*, 2003). In general, interactions that result in a positive outcome on human wellbeing such as pollination and biological control are perceived as positive interactions (Abdollahzadeh *et al.*, 2015; Penn *et al.*, 2019). Other interactions such as bird feeding, which has no direct benefit to humans is perceived neutrally in much of the world (Baverstock *et al.*, 2019). Most negative interactions, however, are the result of negative outcomes, though not all negative outcomes yield negative interactions (Marker *et al.*, 2003). Examples of negative interactions range from crop raiding in monkeys and elephants (Siljander *et al.*, 2020; Tiller *et al.*, 2021), consumption of domesticated species by leopards and pythons (Bista *et al.*, 2022; Mishra *et al.*, 2022), to injury and death by large mammals (Acharya *et al.*, 2016).

The term 'human-wildlife conflict' (HWC) in the literature is loosely used to include all occurrences of human-wildlife interactions that resulted in a negative outcome (regardless of severity), to humans or the wildlife species (Woodroffe *et al.*, 2005). HWC is an increasing global phenomenon with negative consequences for humans and wildlife (Anand and Radhakrishna, 2017). However, the increase in reports of HWC in the literature is in large the product of biasness toward studying negative human wildlife interactions (Peterson *et al.*, 2010), resulting in an overrepresentation of HWC in the literature (71% of 250 human-wildlife papers surveyed; Bhatia *et al.*, 2020). Despite this, these conflicts are still relevant to the

understanding the capacity for sustainable human-wildlife coexistence from the human perspective and should not be discounted.

The primary cause of these conflicts is the encroachment of agriculture and urbanization into wildlife habitats (Nyhus, 2016), which has had damaging effects on local ecosystems in the form of habitat fragmentation, food web disruptions, altered spatial and temporal resource distributions, and the presence of abundant anthropogenic food items (Oro *et al.*, 2013; Seveque *et al.*, 2020; Pires *et al.*, 2023; Tan *et al.*, 2023). The consequences of these conflicts on wildlife populations can be extreme. In severe cases, local communities utilize lethal control as retaliation toward troublesome species, significantly reducing their populations. Examples of lethal retaliation for crop raiding and village attacks are observed in the numerous reports of poisoning, such as those reported in the Asian Elephant (*Elephas maximus*), and African Bush Elephant (*Loxodonta Africana*) (Zimmermann *et al.*, 2009; Doyle *et al.*, 2010; Muboko *et al.*, 2014). The killing of endangered and protected species has raised conservation concern (Seoraj-Pillai and Pillay, 2016), but a variety of methods have been utilized globally to mitigate conflict, with varying degrees of success (Ravenelle and Nyhus, 2017; Feuerbacher *et al.*, 2021; Sibanda *et al.*, 2022).

Malaysia, a tropical country with expanding agriculture and urban industries is not free of HWC. The Department of Wildlife and National Parks Peninsular Malaysia (PERHILITAN) reported 80,040 complaints of HWC from the years 2006 to 2015, 733 injuries and 48 deaths from 2004 to 2015, a total loss of RM 550,233 and RM 27,995,969 from livestock depredation and crop damage respectively from 2007 to 2015 (Saaban *et al.*, 2016). The same report identified the Long-tailed Macaque (*Macaca fascicularis*) as the species most involved in HWC (66% of total reported

cases), followed by the Asian Elephant (*E. maximus*) (9%), the Wild Boar (*Sus scrofa*) (7%), and the Common Palm Civet (*Paradoxurus hermaphroditus*) (6%). Other species were individually responsible for less than 5% of reported cases and were thus not mentioned here. However, it is worth noting that collectively, predatory species were responsible for only a total of 3% of reported HWC; Tiger (*Panthera tigris tigris*), Python (unspecified species), and Cobra (unspecified species). It is strange that *Varanus salvator* was not reported in any HWC cases during the time of this report.

Roadkill is also a significant form of HWC in Malaysia. A study conducted between 2012 and 2017 reported a total of 2,444 instances of roadkill (Kasmuri *et al.*, 2020). The study above identified that species most frequently involved in roadkill incidents were disturbance tolerant species, notably; *V. salvator* (742 instances, 30.4%), Long-tailed Macaque (*M. fascicularis*) (439 instances, 18%), Common Palm Civet (*P. hermaphroditus*) (418 instances, 17.1%), and the Wild Boar (*S. scrofa*) (265 instances, 10.8%). *Varanus salvator* is observed as roadkill and many other areas within (Allain and Goodman, 2020), and outside Malaysia (Mahaprom *et al.*, 2015). In an agriculture area of Pahang, *V. salvator* was reported as roadkill on three occasions (4.83% of 62 reported incidents) (Laton and Mohammed, 2022). On Langkawi Island, *V. salvator* was recorded in roadkill incidents on 32 occasions (24.4% of 131 reported incidents) (Ayob *et al.*, 2020). From these reports, the literature suggests that HWC involving *V. salvator* in Malaysia is most prevalent in the form of roadkill. Predation of livestock and domestic animals likely occur at potentially negligible frequencies, explaining why instances of these interactions are not reported in the Malaysian context This is curious given *V. salvator*'s high abundance near human habitation (Twining *et al.*, 2017), and tendency to consume domesticated species (Kulabtong and Mahaprom, 2014).

As previously mentioned, whether an interaction is deemed negative or otherwise is determined by two factors; the outcome of the interaction, and more importantly, the human perception toward the species in question (Marker *et al.*, 2003). Measuring the outcome of an interaction is relatively straightforward, and conventional methods of observation suffice. Measuring human perception on the other hand, requires the careful use of questionnaires targeted at the knowledge, attitudes, and practices (KAP) of communities interacting with wildlife. KAP questionnaires have been used in many instances internationally to assess perceptions of local communities toward wildlife species and to assess potential levels of HWC (Shanko *et al.*, 2021; Temesgen *et al.*, 2022; Yeshey *et al.*, 2023).

In Malaysia, KAP questionnaires have also been utilized toward the same end. For example, Karimullah *et al.*, (2022) investigated the effects of factors such as knowledge levels on primates and prior negative experience, on the attitudes and behaviours of Malaysian people toward primates. That study reported that higher knowledge levels on primates can potentially reduce HWC with these animals. Next, Tan *et al.*, (2020) compared the attitudes of Malaysians living in areas with different levels of urbanization toward local conflict-prone megafauna and found that mitigation efforts should be tailored slightly differently between areas, by promoting responsibility in urban areas, and focus on reducing the cost of conflicts in rural areas.

As a final example, Aziz *et al.*, (2017) assessed the knowledge and attitudes of local communities on Tioman Island toward the Flying Fox (*Pteropus hypomelanus*), a species that damages fruits in the area. The study reported that general knowledge on this species was low, and attitudes toward this species were generally negative amongst sampled individuals. Furthermore, Aziz *et al.*, (2017) identified that older

men, particularly those who depend on fruit trees for income are more likely to kill these species. Many other KAP studies have been conducted in Malaysia to understand the nature of the different human-wildlife interactions specific to the species studied (Hassan *et al.*, 2017; Lim and Wilson, 2019; Ten *et al.*, 2021). In almost all cases, assessing a person's knowledge level, and subsequently their attitude towards the animal studied is crucial in understanding their motivations and behaviours in a HWC situation. This information is important for the use of wildlife management and conservation.

Varanus salvator is a species of ecological significance, and is protected under CITES appendix II (IUCN, 2023). It is one of the few large predators in Malaysia capable of tolerating high levels of disturbance (Khadiejah *et al.*, 2019). It also plays an important role as a scavenger (Twining *et al.*, 2017). However as previously mentioned, its capacity for disturbance tolerance has allowed it to achieve high abundances in urban habitats (Karunarathna, *et al.*, 2017), and its generalist diet also includes livestock and domesticated species (Kulabtong and Mahaprom, 2014). These aspects of *V. salvator*'s ecology are a cause for HWC concern, especially in urban areas. It is therefore odd that no KAP studies concerning *V. salvator* have been conducted in Malaysia to assess this potential issue.

Questionnaires and interviews have been conducted to understand public perception on Varanid lizards internationally (Khatiwada and Ghimire, 2009; Ghimire *et al.*, 2014; Chatterjee and Bhattacharyya, 2015). This also includes *V. salvator*, in countries such as India (Bhattacharya and Koch, 2018; Mazumder *et al.*, 2020), Bangladesh (Rahman *et al.*, 2017b; Mou *et al.*, 2021), the Philippines, (Tanalgo, 2017), and Indonesia (Uyeda *et al.*, 2016; Arida *et al.*, 2020; Yudha *et al.*, 2022). In India,

questionnaires conducted by Mazumder *et al.*, (2020) revealed *V. salvator* as a pest that consumes livestock and is thus killed but not consumed. Furthermore, the same study reported that younger respondents (children of unspecified ages) feared the lizards could cause harm, despite no reports of human attacks existing in the studied area. Next, Bhattacharya and Koch, (2018) showed that respondents viewed *V. salvator* positively as a biological control of snakes, and as a useful agent of carrion removal despite reports from respondents of livestock and domestic animal consumption.

In Bangladesh, Mou *et al.*, (2021) assessed the public attitudes toward *V. salvator* in an urban environment and found that attitudes were positive, despite a significant number of respondents having low levels of knowledge, and the majority of respondents having experienced some form of attack on livestock or domestic animals in the past. Also in Bangladesh, Rahman *et al.*, (2017b) reported low levels of knowledge on *V. salvator* and negative attitudes among respondents. Furthermore, it was also reported that most cases, killings were the result of myths surrounding this species (such as it possesses venom), and misconceptions about the harm this species poses toward children in particular. In the Philippines, Tanalgo, (2017) reported that *V. salvator* is considered a livestock predator and thus is killed. It is also occasionally hunted as a source of protein.

In Indonesia, Yudha *et al.*, (2022) reported that *V. salvator* is hunted in West Java as a form of recreational activity, though in many cases hunted animals are consumed and their oil is used in traditional medicine. Hunters in these areas also view *V. salvator* as a livestock pest and consider the hunting of this species a form of pest management. Also in West Java, Uyeda *et al.*, (2016) similarly identified *V. salvator*

as a livestock pest that is occasionally killed. However, the lizards are not viewed as dangerous in these habitats. This study also reported that some communities do not hunt *V. salvator* due to a local taboo of possessive spirits surrounding this species. This highlights the importance of local beliefs on the behaviours of local communities toward wildlife. Finally, Arida *et al.*, (2020) identified *V. salvator* as an important source of income and protein in North Sumatra. Communities in this region sell the lizard skins to the leather trade and consume the meat and organs as a cheap protein source.

In almost all studies discussed above, *V. salvator* is described as a pest species for livestock and domesticated animals and is often killed because of it. Studies that measured attitudes found that there was a lot of variation between sampled communities, and that the positivity or negativity of respondents were depended on factors such as knowledge levels and usefulness of the species in the environments of interaction. Knowledge levels were also used to measure the prevalence of misconceptions toward this species among respondents. Many studies also highlight the prevalence of this species as a form of protein for some communities, along with the effects of traditional beliefs on the behaviours of those communities.

It is highly likely that interactions with *V. salvator* in Malaysia are of a similar nature to those reported in the countries mentioned above. It is possible however, that livestock depredation is very infrequent in Malaysia, or that Malaysians simply do not report cases of livestock depredation to the authorities and choose deal with such instances at their discretion (which can carry legal consequences as *V. salvator* is a protected species IUCN, 2023). It is also possible that Malaysians are tolerant of this species and view their behaviours as a natural part of ecosystem functioning.

Furthermore, it is unclear if the general Malaysian public know of *V. salvator*'s value in the skin trade, given the large volumes of skins harvested from the country (Khadiejah *et al.*, 2020).

2.4 The Wildlife Perspective: Morphology, Condition, and Body Damage

Habitat disturbance can cause morphological changes in wildlife species (Hendry *et al.*, 2017). These changes result from complex biotic and abiotic interactions that vary by species and location, but some general concepts are worth discussion. Morphological changes in disturbed habitats may represent adaptive traits that enhance fitness by reducing predation or human conflict-related mortality. For example, a study on Gray Squirrels, *Sciurus carolinensis*, found the black morph is favoured in urban areas due to its reduced risk of roadkill (Gibbs *et al.*, 2019). Anthropogenic habitats can impose strong penalties on specific phenotypes (Johnson and Munshi-South, 2017). For example, urban populations of Western Fence Lizards (*Sceloporus occidentalis*) in the USA exhibit shorter limbs due to differences in available substrates (Putman *et al.*, 2019). These urban lizards also have fewer dorsal scales, an adaptation to mitigate water loss caused by high temperatures. Changes in food availability are also relevant for discussion. Urban House Finch (*Carpodacus mexicanus*) populations have larger, stronger bills, driven by a diet shift to harder and larger sunflower seeds from bird feeders compared to their natural diet of grasses and small seeds (Badyaev *et al.*, 2008).

Other than directional selection, genetic predispositions or stochastic allele frequency changes may lead to observed variations in morphology (Kvie *et al.*, 2019). Genetic mutations, influenced by chance among other factors, can also create adaptive or maladaptive traits (Putnins and Androulakis, 2021). Additionally, species exhibit differing levels of phenotypic plasticity, which restricts the amount of morphological variation experienced, regardless of environmental factors experienced (Nelson *et al.*, 2015). In terms of morphological change in the form of body size, the effects of anthropogenic disturbance vary between species. Invertebrates and some birds in

disturbed habitats tend to exhibit reduced body size, possibly due to limited natural food sources (Messina *et al.*, 2021), though, not all bird species display this trend (Evans *et al.*, 2009). Some frog species also experience size reduction in highly disturbed areas, possibly due to habitat conditions or predation (Delgado-Acevedo and Restrepo, 2008; Matías-Ferrer and Escalante, 2015).

Lizards, including the iguana *Cyclura cychlura inornata* and *V. komodoensis* in ecotourism areas often exhibit larger body sizes in anthropogenic habitats (Smith and Iverson, 2016; Ardiantiono *et al.*, 2018). Trophic subsidies from tourist feeding and refuse consumption are key contributors to this pattern (Jessop *et al.*, 2012). However, not all medium to large lizard species benefit from larger body sizes in disturbed areas. Large individuals in populations of the iguana *Ctenosaura melanosterna* tend to have smaller body sizes near humans due to hunting pressure on large individuals (Pasachnik *et al.*, 2012).

The impact of anthropogenic disturbance on the body morphology and condition of *V. salvator* varies by location. Twining *et al.*, (2017) compared individuals from forests to logged areas and oil palm plantations in Sabah, finding that those in more disturbed habitats tended to be larger with better body condition (weight-to-body length ratios) but had a higher incidence of body damage (number of scars). Increased resource availability and competition in disturbed areas were proposed explanations. Twining *et al.*, (2017) also noted a skewed sex ratio favouring males in these habitats, though the authors did provide further explanation for this observation, highlighting the need for future work in this area. Next, Khadiejah *et al.*, (2019) examined individuals from four habitats: forests, mangroves, oil palm plantations, and rice fields across Peninsular Malaysia. They found that individuals in natural habitats

tended to be larger, contrasting with Twining *et al.*, (2017). However, body condition similarities were observed between mangrove and rice fields, as well as between forest and oil palm plantation habitats. This study suggested that hunting in disturbed areas could limit body size. In Sabah, Guerrero-Sanchez *et al.*, (2021; 2023) reported no difference in body size and condition between forest habitats and oil palm plantations, proposing a trade-off between improved resources in oil palm plantations and elevated competition in forests. Additionally, these studies revealed that condition was influenced by factors beyond diet quality, including sedentary behaviour and pathogen exposure (Guerrero-Sanchez *et al.*, 2021; 2023). Notably, urban areas were not included in the studies mentioned above, emphasizing the need for further investigation in these populations.

Based on the discussed papers, larger individuals may have advantages in resource acquisition in these habitats. However, a population biased toward larger individuals could have long-term negative consequences. *Varanus salvator* congregates around high food density areas, leading to increased intraspecific interactions that may result in more scarring in disturbed areas (Uyeda *et al.*, 2015; Twining *et al.*, 2017). Individuals in disturbed habitats also face the risk of cannibalism, a known behaviour in *V. salvator* (Shine *et al.*, 1996; Bhattacharya and Koch, 2018). While these negative impacts take time to manifest severe negative consequences, they could create an ecological trap as individuals still find the habitat attractive (Fletcher *et al.*, 2012). Currently, there is insufficient literature on the long-term effects of increased body size in *V. salvator* in human-disturbed habitats on the species' longevity, preventing definitive conclusions.