Exploring Interdisciplinary Aspects for Conservation Management: The Case of Land Hermit Crab Wildlife Trade in Taiwan

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Abstract

Most conservation policies and management primarily focus on vertebrate animals. However, considering the high demand for invertebrate species in the exotic pet markets, it is crucial to give them great consideration. This research explores *Coenobita purpureus*, a land hermit crab newly recorded in Taiwan in 2017. We noticed that it has gained popularity in the online pet market recently, despite limited studies confirming its population. To mitigate the potential risks associated with this species, our study investigated online wildlife trade markets, conducted field surveys for its distribution, and scrutinized relevant regulations in Taiwan. The median price of the species significantly increased after its description. This suggests a growing demand in the exotic pet market, potentially leading to unsustainable trade. Besides, the online platform and coloration of individuals also influenced the price. Furthermore, we discovered that *C. purpureus* is more widely distributed in Taiwan than initially described in the literature, confirming its native status, though the population may be small. We also identified limitations in current Taiwanese regulations and policies regarding the risk of unsustainable trade in potentially threatened invertebrate species. Moreover, we found evidence of individuals being smuggled from China through e-commerce channels. Regulatory measures addressing the smuggling of small amounts of wildlife are also insufficient, potentially posing invasion risks from alien species. Finally, we drew upon the conclusions from these aspects to provide integrated and practical management implications for policymakers. Additionally, we aim to offer

this valuable case study to spotlight the state of the global invertebrate trade.

KEYWORDS

Land hermit crabs, *Coenobita purpureus*, wildlife trade, distribution, regulation, conservation management, Taiwan

1. INTRODUCTION

Land hermit crabs belong to the family Coenobitidae, which comprises about 20 species distributed in tropical coastal areas (Burggren & McMahon, 1988). Their larval stages occur in the ocean, and they migrate from the ocean to land only at the megalopa stage, becoming what are so-called “marine creatures on land.” Land hermit crabs, as a type of land crab, play crucial roles in nutrient cycling, serving as a food source for predators, and seed dispersal for coastal forest ecosystems (Alexander et al., 1997; Burggren & McMahon, 1988; Huang & Hsu, 2022; Lindquist et al., 2009). Coastal forests are part of the green infrastructure that helps protect humans against natural hazards, such as storm surges and tsunamis (Hoque et al., 2018; Tanaka et al., 2007). Addressing these issues is crucial for conserving these unique creatures and their ecosystem services. Due to habitat loss and overconsumption, their populations are declining. Regarding overconsumption, only coconut crabs (*Birgus latro*) are considered a food source for humans; other species are kept as exotic pets worldwide (Hsu, 2021). Thus, in the IUCN Red List, only coconut crabs are listed as "Vulnerable" (Cumberlidge, 2020), while other Coenobita species are not evaluated. Understanding their populations, regulations, and market conditions is imperative for conservation management.

Illegal or unsustainable wildlife trades significantly impact wildlife populations (Cardoso et al., 2021; Hinsley et al., 2023). However, the evaluation and regulation for invertebrate species are relatively less compared to vertebrates (Caldas et al., 2018; Cardoso et al., 2011; Caro, 2022; Eisenhauer et al., 2019). Land hermit crabs (*Coenobita* sp.) are popular pets worldwide (Bundhitwongrut, 2020; Marnell, 2016; Sasaki, 2014). Some reports have highlighted the unsustainable trade of land hermit crabs, e.g., PETA investigation (https://reurl.cc/nDg8g2), Thailand (Bundhitwongrut, 2018), and Taiwan (Hsu & Choi, 2016). Furthermore, a recent wildlife smuggling event involving the attempted illegal trafficking of 682 individuals was uncovered in Okinawa, Japan (Hsu, Wang, et al., 2023; Okinawa Times: https://reurl.cc/y7V9oq). Considering that consumers' demand for rare and exotic pets is a major driving force behind the wildlife trade (Bush et al., 2014), adopting a multiple-dimensional approach in wildlife conservation research for invertebrates is crucial.

Unlike certain insect pets, the captive breeding of land hermit crabs for commercial marketing remains challenging, primarily due to the high mortality rate during the larvae stage (Brodie & Harvey, 2001; Liu et al., 2021). Consequently, most land hermit crabs available in the market are sourced through wild capture. This unregulated collection of significant numbers of wild crabs for the pet trade has raised serious concerns. Such practices could lead to the unsustainability of land hermit crab populations (Bundhitwongrut, 2018).

This study was initiated based on the observation of peculiar phenomena within the community of land hermit crab enthusiasts on Facebook. In Taiwan, selling land hermit crabs as pets has a long history. In the past, people could easily buy land hermit crabs in markets near coastal areas or even at night markets. However, we believe that due to rising conservation awareness, sellers now tend to sell crabs more discreetly, often using the internet. Most of the species sold are common in Taiwan, such as *C. brevimanus*, *C. cavipes*, *C. rugosus*, and *C. violascens*. Recently, we have noticed a significant increase in popularity of the land hermit crab species *C. purpureus*, which is rare in Taiwan, among enthusiasts on Facebook and

in the Taiwanese pet market. After the publication of this new record, we observed lively discussions among people regarding the finding. There was a growing number of individuals trying to locate this species around Taiwan, and more people showcasing their pets of this species.

The combination of the high market price and the potential for a low population in the wild in Taiwan (Chia-Hsuan Hsu, personal observation) gives rise to a significant concern known as the Anthropogenic Allee Effect (Courchamp et al., 2006). This effect suggests a positive feedback loop between rarity and price across diverse taxa and geographic regions (Holden & McDonald-Madden, 2017; Siriwat et al., 2019). This interplay ultimately leads to the value rising of a species with its rarity, consequently generating motives for increased exploitation. The impact could worsen by the rise of the Internet, which significantly facilitates the exotic pet trade through extensive advertising and transportation of traded species (Fink et al., 2021; Stringham et al., 2021). The market conditions of *C. purpureus* and identify any advertising effects that may have emerged since the publication of new records (Hsu & Soong, 2017) (i.e., post-2017). We also aimed to evaluate any observed price increases for this species. Additionally, we explored whether other factors, such as the trading platform or the characteristics of individual crabs, influenced the price of *C. purpureus*.

Although *C. purpureus* is becoming popular in Taiwan's pet market, little is known about their current population distribution in Taiwan. Such uncertainty will cause great challenges for their subsequent conservation and management. *Coenobita purpureus* was previously considered an endemic species in Japan (Sanda et al., 2019). However, Hsu & Soong (2017) published the first scientific record of *C. purpureus*, which described a male individual with a light-blue coloration, from Dongji Island in Taiwan. In 2019, an ovigerous female and two male individuals were discovered on Dongsha Island, Taiwan (Hsu et al., 2019). These findings are important because they suggest that *C. purpureus* does inhabit the surrounding islands of Taiwan and they can breed there. However, there are no other further records regarding the distribution of this hermit crab

173 species in mainland Taiwan. Therefore, our second research objective is to
174 confirm the distribution of this species in Taiwan, as a basis for future
175 conservation and management.
176 Regulations concerning invertebrates have received limited attention
177 worldwide (Cardoso et al., 2011; Caro, 2022). Legal regulation is a crucial
178 aspect of conservation (Oldfield, 2003). Legislation aimed at controlling
179 the exploitation and trade of land hermit crabs from natural habitats is
180 currently limited to only a few countries (Table 1). Therefore, the third
181 objective of this study was to conduct an inventory of the relevant laws and
182 regulations about all land hermit crabs and other invertebrates in Taiwan.
183 This is particularly important due to their increasing popularity as pets
184 worldwide (Bundhitwongrut, 2018; Sasaki, 2014), despite the current
185 inability to commercially breed them. In the absence of pertinent
186 regulations for conserving land hermit crabs or other invertebrates, a
187 significant gap in conservation management could emerge. Besides, due to
188 the popularity of *C. purpureus* in the pet market and its high price, there
189 may be smuggling of this species from other countries into Taiwan. Thus,
190 we also documented cases of animal smuggling and presented relevant
191 regulations in Taiwan.
192 Table 1. The regulation related to land hermit crabs in different
193 countries.

Country	**Target species**	**Related regulation**	**Reference**
Australia	*Coenobita variabilis*	Companies wish to sell the Australian land hermit crab must obtain approval from the Wildlife Trade Operation under Part 13A, Section 303FN of the Environment Protection and Biodiversity Conservation Act 1999	Australian Government: https://www.dcceew.gov.au/
Bermuda	*Coenobita clypeatus*	*Coenobita clypeatus* is legally protected as a Level 2 species under the Protected Species Act 2003, prohibiting local collection and the	(Copeland, 2020)

		sale of the species sourced from overseas.	
Japan	*Coenobita* sp.	All species of land hermit crabs are designated as Natural Monuments under the Law for the Protection of Cultural Properties. The sellers are required to obtain permits to catch and sell these species in Japan.	(Nakasone, 2001)
Taiwan	*Birgus latro*	Only coconut crabs (which belong to the same Family, Coenobitidae, as land hermit crabs) are prohibited from being caught under the Wildlife Conservation Act	(Hsu, 2018)

Wildlife trade research should be cross-disciplinary, combining various variables to provide management recommendations for policymakers (Blair et al., 2017). Our research objectives encompass the following disciplines: (1) Market: Investigating market conditions, such as price disparities before and after the publication of the new record (advertising effect), across different platforms, and among individuals with varying coloration scales; (2) Ecology: Gaining an understanding of the distribution of *C. purpureus* and ascertaining their settlement in Taiwan; (3) Regulation: Making an inventory of the relevant laws and regulations applicable to our case. Ultimately, the paramount goal is to offer management implications that can help policymakers in advancing effective conservation strategies.

2. METHOD

The methodology for the study consisted of three main aspects: using the online platforms to understand trading conditions (market aspect), conducting field surveys to investigate the population distribution (ecology

aspect) and compiling an inventory of the relevant laws and regulations applicable to our case. The details of each methodology are as follows.

2.1 Market aspect: Prices and numbers of *C. purpureus* in online platform

To explore the trade conditions of *C. purpureus*, we followed the guidelines for internet monitoring and quantification of wildlife trade provided by (Stringham et al., 2021). We manually examined the prices and counted the number of individuals of the species listed on popular e-commerce platforms such as Yahoo, Shopee, and Ruten in Taiwan, as well as on the social media platform such as Facebook. We used keywords such as “□□□□□□□”, “□□□□□”, and “*C. purpureus*”. The manual data collection took place from June 1st to July 30th, 2023. However, we observed that some sellers were offering the species for sale on Facebook without specifying the price. To gather pricing information in such cases, we utilized anonymous accounts to inquire about the prices. Furthermore, due to the rarity and uniqueness of *C. purpureus* in the past, some of the sale posts with photos and prices were captured and stored as screenshots by one of the authors (Choi). Finally, we recorded the number of individuals, prices, and colors from both sold and unsold crab individuals. We acknowledge that collecting data in this manner may introduce certain biases because some sellers might delete their sales posts after the land hermit crabs are sold, which may lead to underestimations of the sales count.

To analyze all the factors influencing the price of *C. purpureus*, we employed a Generalized Linear Model (GLM) with a Gaussian family distribution, appropriate for continuous dependent variables. The dependent variable in our model was "Price," while the independent variables included "Body size," "Color," "Pub," and "Year." The model fitting was conducted using standard statistical software, ensuring that the assumptions of the GLM were checked and validated. The results from the GLM provided insights into how each independent variable affects the price, allowing us to interpret the significance and magnitude of these effects.

The GLM was formulated as follows:

Where:

- is the dependent variable representing the price of the crabs.
- is a continuous variable measuring the size of the crabs.
- is a categorical variable with levels indicating the color of the crabs (e.g., dark, light).
- is a categorical variable representing different selling platforms.
- is a continuous variable indicating the year of the sale.
- $\beta 0$, $\beta 1$, $\beta 2$, $\beta 3$, $\beta 4$ are the coefficients estimated by the model.
- ϵ is the error term.

To assess the impact of the publication of the new record of *C. purpureus* on January 1st, 2017, on market pricing, we conducted a statistical test comparing prices before and after that specific point in time. Before performing the statistical test, we checked the normality of the data using the Shapiro-Wilk test. If the data were normally distributed, we proceeded with the t-test. However, if the data did not follow a normal distribution, we used non-parametric tests instead. We also compared the different platforms (Facebook and Shopee) to understand whether the prices differ across various online platforms. Additionally, the sellers provided photos of each individual, allowing us to identify the colors. Two researchers then examined the photos and recorded the colors to ensure consistency. If discrepancies arose between researchers' identifications, they discussed them together to ensure consistency, a process that can be considered a form of triangulation. Subsequently, we compared the price between different coloration scales of individuals (Light color and dark color).

Fisher’s exact test was employed to assess whether the sale of *C. purpureus* individuals before and after 2017 was related to the publication of the new record of the species on January 1st, 2017, and the platforms (i.e., Shopee and Facebook). Additionally, we also utilized Fisher’s exact test to investigate the potential association between publication time (i.e., the publication of the new record of the species) and the coloration scale (dark and light colors) of the crab individuals. Furthermore, we utilized

Fisher's exact test to explore whether distinct platforms exhibited variations in the coloration scale of the individuals for sale.

In this section, all the statistical tests were conducted using R 4.2.1(R Core Team, 2022) for analysis. Additionally, R was also utilized for the visualization of the results, providing a comprehensive and coherent representation of the findings.

2.2 Ecology aspect: Distribution survey of *C. purpureus* in Taiwan

To determine the extent of *C. purpureus* distribution in Taiwan, we conducted an unsystematic survey to investigate settled populations of *C. purpureus* between 2018 and 2023. Due to the unsystematic nature of the surveys, the selection of survey locations and times was non-randomized. Consequently, the survey efforts, timing, and locations may lack standardization, making it challenging to directly compare abundance and density across different sites. When encountering the target species, we temporarily placed them in a box due to the small number of individuals. After counting and double-checking the species, we released them and recorded the numbers. Species identification was done by referencing previous literature (Yukio, 1988), and the distinct characteristics of *C. purpureus* made them easy to recognize. Any uncertainty was addressed by taking photos and confirming with other team members. We identified *C. purpureus* on beaches through visual examination.

Considering the potential risk of poaching, we chose not to disclose the exact locations in this paper, as recommended by Lindenmayer & Scheele (2017). Instead, we present descriptive statistics and maps at the city, county, or island level to illustrate the number of individuals observed at each location.

2.3 Law and Regulation Aspect: Regulations and Cases about *C. purpureus* in Taiwan

To understand the regulations related to this case, we provided some relevant regulations and previous cases associated with our target species for this study. As our target species is not a protected species in Taiwan,

the regulations might not be specific to *C. purpureus*, but could potentially apply to other species of land hermit crabs or even other animals. First, we identified potential regulations that pertain to the wild catching or the smuggling. The corresponding laws and regulations were searched using the Laws & Regulation Database of Taiwan (https://law.moj.gov.tw/ENG/Index.aspx). Subsequently, we searched the Judicial Yuan Law and Regulations Retrieving System (https://judgment.judicial.gov.tw/FJUD/default.aspx) to find similar cases to provide implications for our case.

3. RESULT

3.1 Market aspect: prices and counts of *C. purpureus* in the online platform

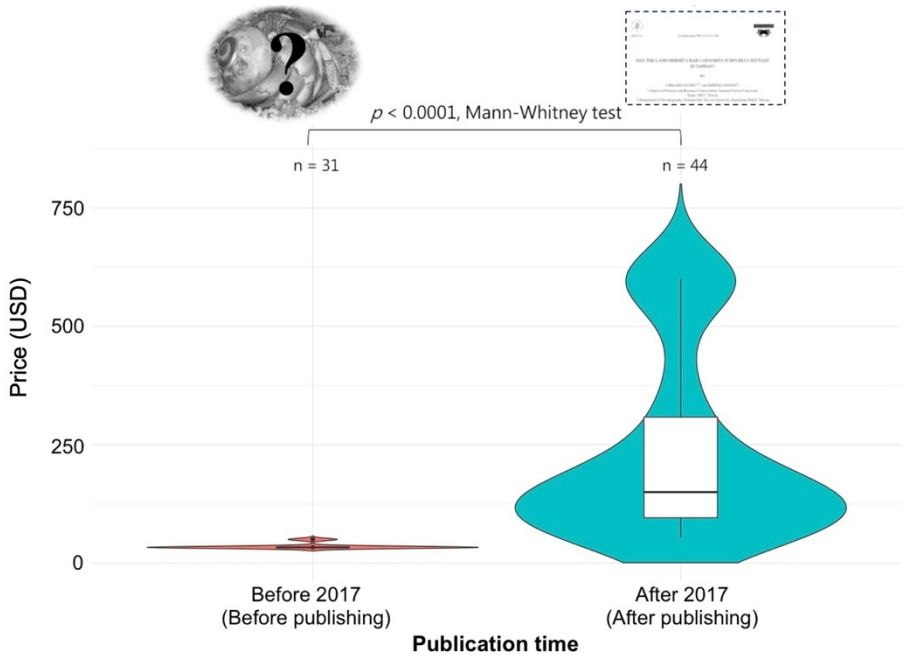
Based on GLM conducted, several key factors were found to significantly influence the pricing of products. The intercept suggests a baseline price of -35995.864 units, with a t-value of -6.188 ($p < 0.001$), indicating a strong negative relationship. Body size positively correlates with price (t = 4.824, $p < 0.001$), implying that larger crabs tend to command higher prices. Selling platform also plays a role, as products listed on Shopee are associated with lower prices (t = -2.125, $p = 0.037$), albeit with a modest effect. Moreover, products in lighter colors tend to be priced lower (t = -2.234, p = 0.029), reflecting consumer preferences. Finally, Year adds approximately 17.760 units to the price (t = 6.160, $p < 0.001$), indicating a positive trend over time. The summary of the GLM is presented in Table 2.

TABLE 2 Generalized Linear Model summary including coefficients, standard errors, t-values, and p-values for variables predicting the dependent variable. Significance codes indicate the level of statistical significance (* p < 0.05, ** p < 0.01, *** p < 0.001). Additional model diagnostics Akaike Information Criterion (AIC) = 900.84.

Variable	Coefficient	SE	t-value	p-value
Intercept	-35995.864	5817.037	-6.188	< 0.001***
Body size	206.757	42.856	4.824	<

				0.001***
Selling platform (Shopee)	-66.856	31.455	-2.125	0.037*
Color (light)	-78.605	35.184	-2.234	0.029*
Year	17.76	2.883	6.16	< 0.001***

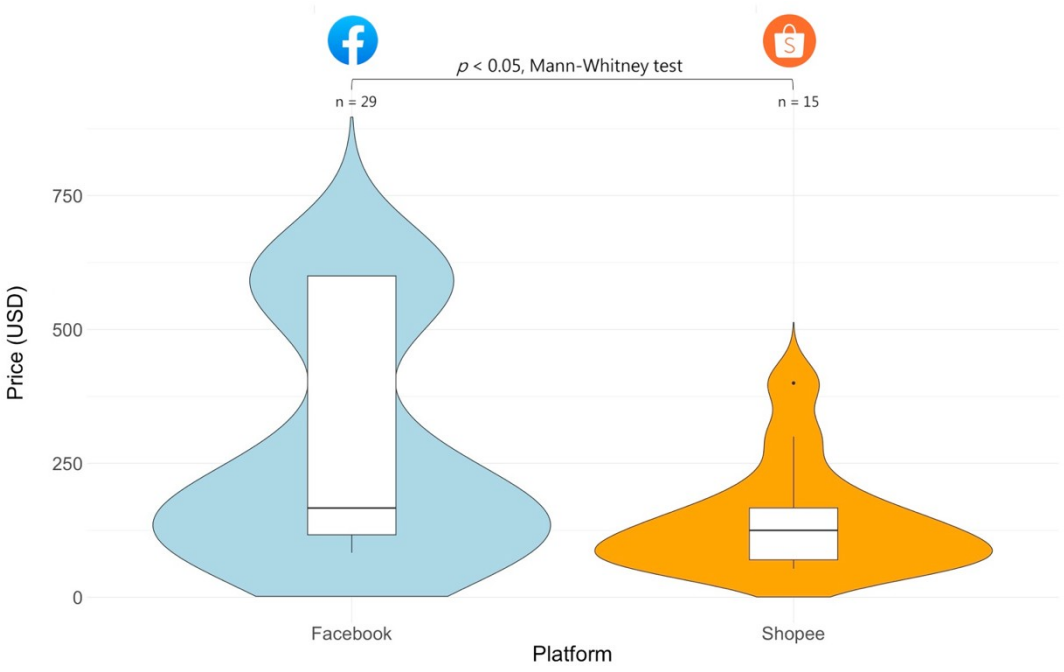
As the price data for *C. purpureus* exhibited a non-normal distribution ($p < 0.001$, Shapiro-Wilk test), we employed the Mann-Whitney test to compare price variations. The time series price plot revealing the data distribution is included in the supplementary materials (S1). Since no selling cases were found on platforms like Rutan and Yahoo, we only analyzed data from Shopee and Facebook. Regarding the price fluctuations before and after the publication of the new record in 2017, it is noteworthy that the price exhibited a significant increase compared to the price prior to the publication of the new record, with the median price being five times higher than that before 2017 ($p < 0.001$, Mann-Whitney test) (Figure 1; Table 3). In terms of the platform effect, because no crab individuals were sold on Shopee before the new record was published in 2017, we only compared the prices on different platforms after 2017. The prices of *C. purpureus* showed significant differences ($p = 0.012$, Mann-Whitney test), with the median price being 33% higher on Facebook than on Shopee (Figure 2; Table 3). Furthermore, when comparing the prices of *C. purpureus* with different colorations, the prices of dark-colored individuals were significantly higher than those of their light-colored counterparts, with the median price of dark-colored individuals being 1.5 and 3.7 times higher than that of light-colored ones before 2017 and after 2017, respectively ($p < 0.001$, Mann-Whitney test) (Figure. 3; Table 3).



364

365 FIGURE 1. The difference in *C. purpureus* prices before and after the
366 publication of the new record in 2017 ($p < 0.0001$, Mann-Whitney test).
367 The colored areas represent density plots of frequency.

368



369

370 FIGURE 2. Comparison of *C. purpureus* prices between different online
371 platforms (Facebook and Shopee) after the publication of the new record in
372 2017 ($p = 0.012$, Mann-Whitney test). The colored areas represent density
373 plots of frequency.

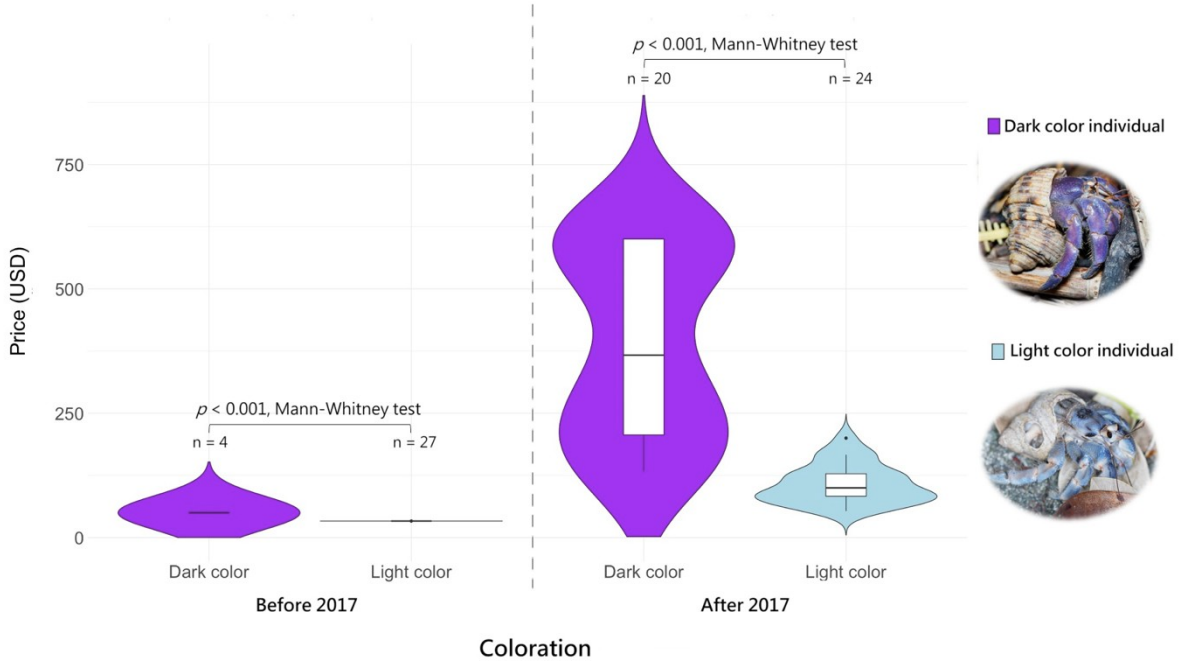


FIGURE 3. Comparing the prices of individuals with different colorations. The prices of dark-colored individuals were significantly higher than light-colored individuals, both before and after the publication of the new record publishing in 2017 ($p < 0.001$, Mann-Whitney test). The colored areas represent density plots of frequency.

TABLE 3. The information on *C. purpureus* prices among variables (*<0.05, **<0.01, ***<0.001). The publication of the new record of *C. purpureus* in Taiwan is on January 1st, 2017.

		Price (USD)			Sample size (n)	*p*-value (M-W test)
		25th percentile	**Median**	**75th percentile**		
Time category	Before 2017	33.33	33.33	33.33	31	< 0.001***
	After 2017	308.33	150	95.83	44	
Platform (after 2017)	Facebook	600	166.67	116.67	29	0.012*
	Shopee	166.67	125	70	15	
Coloration (before 2017)	Dark	50	50	50	4	< 0.001***
	Light	33.33	33.33	33.33	27	
Coloration (after 2017)	Dark	600	366.67	206.67	20	< 0.001***
	Light	128.33	100	83.33	24	

A statistically significant dependence was observed between the publication time and the platforms, indicating that the proportion of *C. purpureus* individuals for sale on Shopee increased after 2017 ($p < 0.001$, Fisher's exact test, Table 4). Furthermore, a significant dependence was noted between the publication time and the color scale of the specimens, indicating that the proportion of dark-colored individuals being sold increased after 2017 ($p < 0.001$, Fisher's exact test, Table 4). However, no statistically significant dependence was observed between the selling platforms and the color scale ($p = 1$, Fisher's exact test, Table 4), indicating that the proportion of dark-colored individuals and light-colored individuals being sold was similar on each platform.

TABLE 4 The information of the Fisher's exact test in this study (*<0.05, **<0.01, ***<0.001). The publication of the new record of *C. purpureus* in Taiwan is on January 1st, 2017.

		Publication time (2017)		
		Before 2017	**After 2017**	***p*-value (Fisher's exact test)**
Selling platform	Facebook	31	29	
	Shopee	0	15	< 0.001***
Coloration	Dark color	4	20	
	Light color	27	24	0.005**
		Selling platforms		
		Facebook	**Shopee**	
Coloration	Dark color	19	5	
	Light color	41	10	1

3.2 Ecological aspect: Current Distribution of *C. purpureus* in Taiwan

We identified the distribution of *C. purpureus* in numerous locations across Taiwan (Figure. 4, Table 5). Following the discovery sequence, subsequent locations included Lanyu, New Taipei City, Keelung, Yilan County, Green Island, and Kaohsiung City. We have also integrated the prior discovery sites identified by our team, namely Dongji Island (Hsu & Soong, 2017) and Dongsha Island (Hsu et al., 2019) (Figure 4; Table 4). Due to variations in survey efforts at each location, determining the exact population size is not feasible; however, we have provided this information as a reference in Table 4.

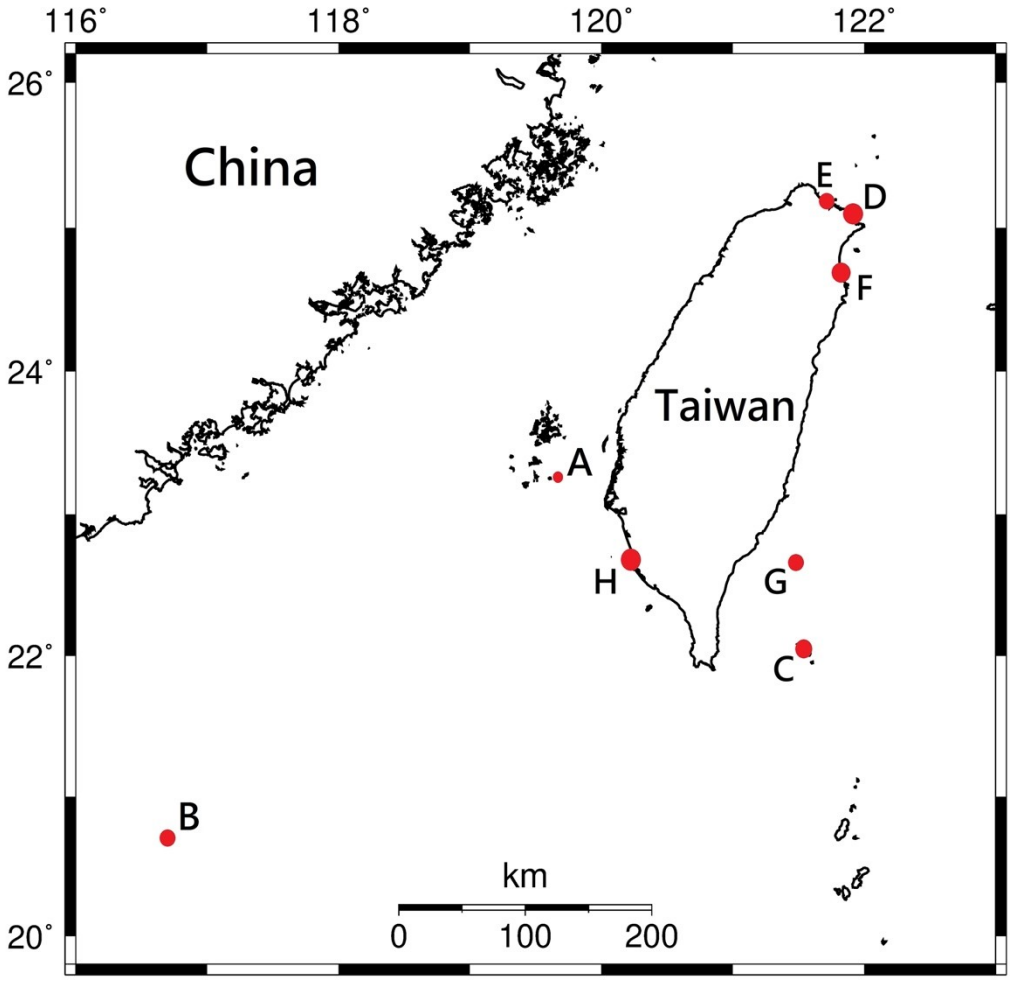


FIGURE 4. The Current distribution of *C. purpureus* in Taiwan. A: Dongji Island; B: Dongsha Island; C: Lanyu; D: New Taipei City; E: Keelung; F: Yilan County; G: Green Island; H: Kaohsiung City.

433 TABLE 5. The table of *C. purpureus* distribution information in Taiwan and
434 the survey efforts.

Code	Location	Finding years	Total number of individuals	Data source	Memo (approximate survey efforts)
A	Dongji Island	2015	1	Hsu & Soong (2017)	Three nights (6 hours) of survey
B	Dongsha Island	2018	3	Hsu et al. (2019)	Five days (15 hours) of survey for one year, a total 4 years (60 hours)
C	Lanyu	2019	4	This study	Surveyed 4 times (20 hours)
D	New Taipei City	2019-2023	28	This study	Surveyed 53 times (65 hours)
E	Keelung	2021	2	From Hung-Chi Tu	Every month survey 2 times (4 hours) for one year (48 hours)
F	Yilan County	2022, 2023	4	This study	Survey 5 times (5 hours)
G	Green	2022	1	From Yi-	Occasionally

	Island			Xuan Xiao	
H	Kaohsiung City	2023	1	This study	Surveyed 9 days (18 hours)

3.3 Laws and regulations aspect: Regulations and cases related to *C. purpureus* in Taiwan

3.3.1 Wild-catch using prohibited methods

Since *C. purpureus* is not a protected species under the Wildlife Conservation Act in Taiwan, there are no restrictions on wild catching in normal situations. The only relevant Articles under the Wildlife Conservation Act are Article 19, which states that wildlife of general species shall not be captured using explosives, other blasting devices, poisons, electricity, narcotics, or paralysis methods, setting nets, firearms other than authorized hunting rifle, traps, snares, or other prohibited items or methods announced by the authorities, and Article 49, which specifies that violators shall be subjected a penalty ranging from NT$60,000 (2,000 USD) to NT$300,000 (10,000 USD).

3.3.2 Wild-catch in the National Park

If people catch land hermit crabs in the National Parks, they will be in violation of the National Park Law. According to Article 13, Subsection 2 of the National Parks Law, it is prohibited to hunt animals or catch fish in National Parks, and Article 25 states that violators of Section 2 of Article 13 shall be punished up to NT$ 3,000 (approximately 100 USD). If the circumstances of the offense are serious and result in severe damage, the offender shall be sentenced to imprisonment of up to one year or receive a fine of up to NT$ 3,000. Criminal offenses can only be established if they are recognized as having severe circumstances by the National Parks Agency and confirmed by the court. Most of these cases fined by this regulation involved illegal coral harvesting.

Additionally, according to the Directions for Fines for Cases of Violation of the National Park Law, for those who hunt animals or catch fish, the fine for the first offense is NT$3000 (100 USD), and for subsequent offenses, the fine remains at NT$3000. Some real cases of people being fined under the National Park Law for catching land hermit crabs. For instance, in 2020, a man was fined NT$3000 for catching 30 individuals of land hermit crabs (News: https://reurl.cc/mDQeoG).

3.3.3 Selling the wildlife

According to Article 36, Paragraph 1 of the Wildlife Conservation Act, those who engage in the commercial activities of for-profit raising, breeding, trading, processing, import, or export of wildlife shall be approved by municipal or county (city) authorities and shall obtain a business license according to the law. Violators shall be subjected to a fine of not less than NT$60,000 and not more than NT$300,000 (approximately 2,000 to 10,000 USD), as stipulated in Article 49, Paragraph 1, Subparagraph 1 of the Wildlife Conservation Act.

In one case, a person was reported for selling general wildlife and cobras online without permission. The man violated Article 36, Paragraph 1 of the Wildlife Conservation Act and, according to Article 49, Paragraph 1, Subparagraph 6 of the same act, was fined NT$60,000 (approximately 2,000 USD).

3.3.4 Smuggling from other countries

Due to the limited population of *C. purpureus* in Taiwan, it is possible that individuals of this species are being smuggled from China. How do we know it's from China and not Japan? We asked several online sellers in China if they had experience shipping *C. purpureus* to Taiwan. Some of them responded affirmatively, stating a success rate of 50%. That's why we have to include the relevant laws related to smuggling in our study.

Article 2, paragraph 1 of the Smuggling Penalty Act states: "Offenders of illegally import or export controlled articles are subject to a fixed-term imprisonment of 7 years maximum, and may be fined no more than three million New Taiwan Dollars (approximately 100,000 USD)." Constituent elements:

a. The customs taxable value must exceed one hundred thousand New Taiwan Dollars or the weight must exceed one thousand kilograms.
b. The goods are smuggled from Mainland China in a single shipment.
c. The items, rice, rice flour, peanuts, tea leaves, or seeds (bulbs) have not been allowed for import by the competent authority.

In these criminal penalties of smuggling cases, the verdicts are as follows: Clams (*Mercenaria mercenarius*) (total weight 9,808.9 kilograms, 836 bags) resulted in a 5-month imprisonment. 154 various breeds of cats led to a sentence of 6 months of imprisonment with probation. As for the smuggling of 8,086 kilograms of clams (*M. mercenaria*), the sentence was 7 months of imprisonment.

Another related to smuggling belongs to administrative sanction is Article 51, Subparagraph 3 of the Wildlife Conservation Act states: Violation of Article 24, Paragraph 1 by import or export of General Wildlife without the approval of the National Principal Authority (NPA), shall be subjected to a fine of not less than NT$10,000 and not more than NT$50,000 (approximately 333 to 1667 USD).

(1) Constituent elements: In accordance with Article 3, Subparagraph 1, and Article 24, Paragraph 1 of the Wildlife Conservation Act.
a. No import or export of live wildlife or Protected Wildlife products is allowed without prior approval from the NPA.
b. Wildlife: In common circumstances, any animal living in a natural habitat, including mammals, birds, reptiles, amphibians, fish, insects, and other kinds of animals.
(2) Seizing live animals: According to the "Procedure for Handling Seized Animals and Related Goods in Smuggling Cases," all confiscated live animals shall be destroyed.

In conclusion, our study has identified two laws that may be relevant to our research. The first is the Smuggling Penalty Act, which deals with criminal penalties for smuggling activities. The second is the Wildlife Conservation Act, which imposes administrative sanctions for violations related to wildlife conservation. In the next section, we will delve into a

detailed discussion of these two laws and their implications for the management of land hermit crabs in Taiwan.

4. DISCUSSION

4.1 Wildlife trade of *C. purpureus*

We confirmed a significant rise in the price of *C. purpureus* for sale on platforms, notably following the year 2017, which coincides with the publication of the new record in Taiwan during that same year. This suggests that the publication of this new record may have triggered an “advertising effect”, potentially leading to increased public notice and interest. Such an effect can be further supported by other aspects that we found the publication in 2017 did ignite discussions within various hermit crab enthusiast communities in Taiwan (personal observation). We attempted to conduct text or content analysis using communities' discussion posts. However, we encountered challenges as some of the communities changed or closed, resulting in the disappearance of discussion posts. Consequently, we could only rely on "Personal observation" to describe this phenomenon. The advertising effect has not only occurred in *C. purpureus* but has been documented in other taxa, e.g., spiders (Henriques, 2020) and amphibians (Gluszek et al., 2021), that they become targets for poaching in the pet market after their publication as new species. The substantial rising prices strongly suggest a continued upward trend in species demand. Policymakers should direct their attention toward the decline in local populations and occurrences of smuggling.

We found a significant dependence between the selling platform and publication time (Table 4), with the proportion of *C. purpureus* individuals for sale on Shopee increasing after 2017, whereas no such increase was observed on Facebook. This discrepancy could potentially be attributed to the fact that the Shopee company was established in 2015 and gained more popularity by 2017. Consequently, sellers predominantly utilized Shopee as a selling platform only after 2017. In contrast, with Facebook, sellers used it as a selling platform irrespective of whether it was before or after

2017. In the realm of e-commerce wildlife trade, Taiwan’s renowned shopping website, Shopee, has made a declaration that prohibits sellers from vending live animals on their platform. However, sellers have adopted the strategy of labeling their offerings as “models” or “toys” to evade detection by the website’s policies and still sell live species. We recommend that the company and policymakers devise strategies to counteract sellers who exploit these loopholes.

Regarding the price of body coloration, we discovered that the price of dark-colored individuals was significantly higher than that of light-colored individuals. This discrepancy is logically understandable, as dark-colored individuals tend to be more vivid and attractive, thus commanding a higher selling price. However, it’s important to take into account that dark-colored individuals also tend to exhibit larger body sizes [personal observation for *C. purpureus* and evidence for marine hermit crab *Clibanarius virescens* (Yoshikawa et al., 2020)], and consequently, their higher pricing can also be attributed to their larger size. In Table 3, we found a significant dependence between publication time and coloration, highlighting a prevalence of dark-colored individuals post-2017. This finding suggests that following the publication of the new record, there was a preference for darker and larger individuals. Consequently, policymakers should pay more attention to larger-sized individuals, as they tend to exhibit greater fecundity potential, similar to other crustaceans (Hamasaki et al., 2006; Mantelatto et al., 2002). Moreover, land hermit crabs are long-lived and slow-maturing animals. Liu et al. (2021) revealed that *C. rugosus* takes 8 years to reach maturity in captivity. If larger and older individuals are caught, this could potentially have a severe impact on the population, similar to the situation with coconut crabs. While we acknowledge that the time factor might influence the price analysis when considering the coloration of individuals, it does not affect the outcome that darker and larger individuals tend to command higher prices in this study.

In terms of statistical methods in this study, we acknowledge that Fisher's exact test does not account for the temporal sequence of events.

Establishing causality often requires demonstrating that changes in one variable precede changes in another, a consideration not addressed by Fisher's exact test. Furthermore, this test does not ascertain the direction of the relationship between variables; it merely indicates whether an association exists. Without knowledge of the direction of the relationship, inferring causality becomes challenging.

In addition, we found an intriguing phenomenon on these e-commerce platforms involves the sale of species not native to Taiwan, such as *C. clypeatus* and *C. lila*, which raises smuggling concerns related to *C. purpureus* on these platforms. We searched the database of the Taiwanese Bureau of Foreign Trade and found no records of legally imported land hermit crabs. Therefore, species sold online in Taiwan but not naturally distributed here must be the result of smuggling. Our target species, *C. purpureus*, also carries a significant potential for smuggling, either directly or indirectly from Japan (Environmental Information Center News: https://e-info.org.tw/node/77197), given the limited populations found in Taiwan. We noted numerous sellers offering *C. purpureus* on Taobao, the largest online shopping platform in China. The current event involved a couple who were land hermit crab sellers on Taobao in China, and they intended to smuggle 682 individuals of *C. purpureus* from Okinawa, Japan (Hsu, Wang, et al., 2023; Okinawa Times: https://reurl.cc/y7V9oq). We gathered information from sellers on Taobao who admitted to smuggling live land hermit crabs into Taiwan from Hong Kong and mainland China through messages on online platforms. Furthermore, the smuggling event may not just occur directly from Okinawa to China; a local person told us that she had been asked to catch the *C. purpureus* from Okinawa and send them to mainland Japan by Chinese people. Thus, we provided the potential smuggling path of *C. purpureus* can be found in Figure 5.

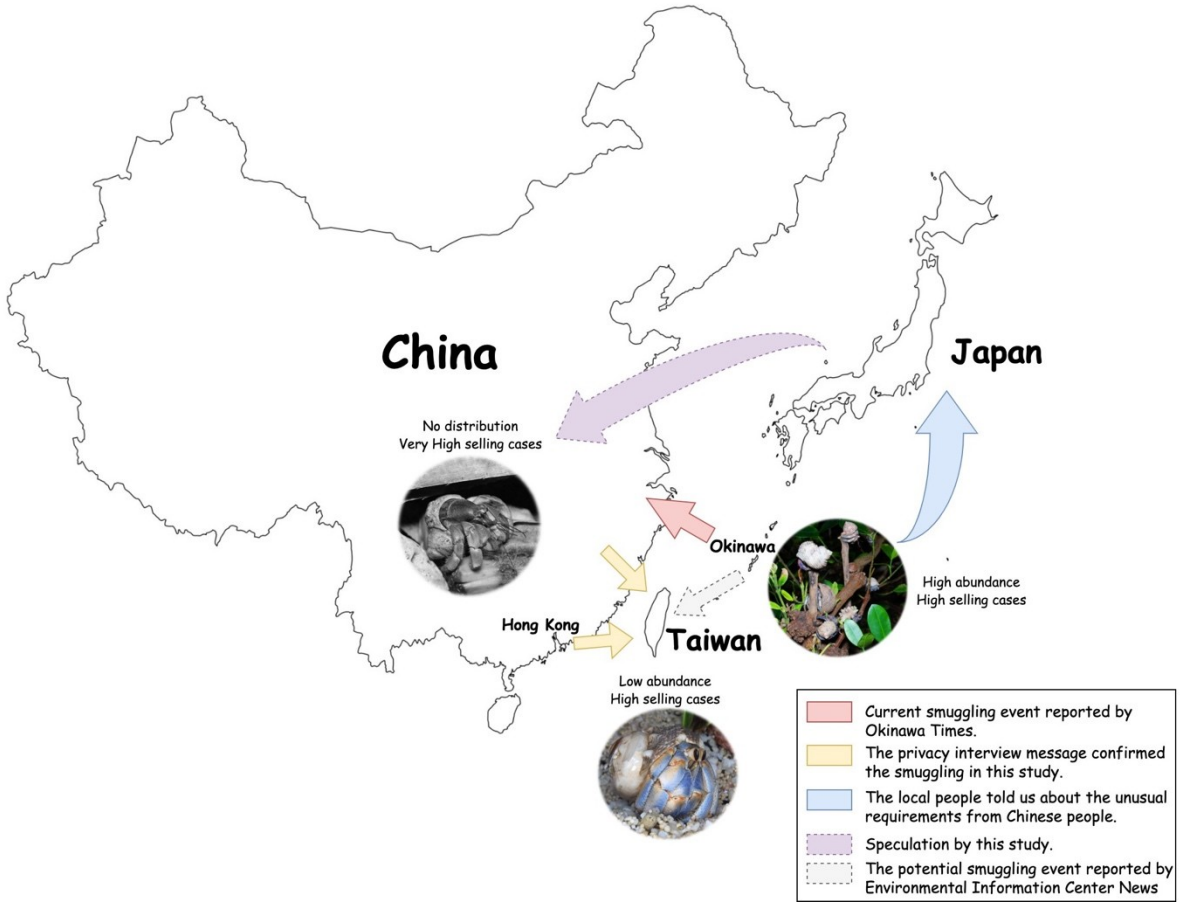


FIGURE 5. The potential smuggling path of *C. purpureus*.

We suggest that managers take the issue of illegal wildlife trade seriously, since land hermit crabs are relatively small and cold-blooded, which increases the difficulty of detecting smuggling (Fukushima et al., 2021). While land hermit crabs are not classified as an invasive species in Taiwan, we recommend that policymakers focus on regulating animal smuggling, particularly for invertebrates. This is crucial to prevent other potentially invasive species from negatively impacting local ecosystems, such as the case of crayfish (Chucholl, 2013; Faulkes, 2010) and the spider (Shivambu et al., 2020).

Furthermore, not only *C. purpureus* but also other species of land hermit crab, *C. perlatus* and *C. pseudorugosus*, have been newly recorded in Taiwan (Chen et al., 2024; Hsu et al., 2022). Especially, the population of *C. perlatus* is much smaller than that of *C. purpureus*, it is also popular on online shopping platforms (Personal observation). Hence, a similar

situation might potentially occur with *C. perlatus*, warranting further attention and concern.

4.2 Distribution of *C. purpureus* in Taiwan

We conducted unsystematic surveys focusing on *C. purpureus*, spanning the years 2018 to 2023, across the main island and neighboring islands of Taiwan. To our surprise, the presence of *C. purpureus* encompasses New Taipei, Yilan, and Kaohsiung, along with adjacent islands like Lanyu, Green Island, and Dongsha Island. As a result, we can definitively affirm the natural distribution of *C. purpureus* in Taiwan.

Although *C. purpureus* can be found in Taiwan, information regarding its population size remains limited. It appears that the population is higher in Northern Taiwan; however, this observation might be biased because the surveyors reside in Northern Taiwan. It is not possible to directly compare the population sizes among survey locations due to variations in survey efforts. Nevertheless, it seems that the population of *C. purpureus* is relatively limited when compared to the sympatric land hermit crab species, *C. rugosus* (personal observation). From 2018 to 2023, there are some systematic survey studies about land hermit crabs in Taiwan, including Kenting (Hsu et al., 2018), Wang-An Island (Hsu, Fang, Jiang, et al., 2023), Dongsha Island (Hsu, Liang, et al., 2019), and Yilan Dakenggu Community (Hsu, Fang, Chiu, et al., 2023). Nevertheless, only three individuals of *C. purpureus* were found on Donsha Island (Hsu, Liang, et al., 2019). This indicates that the population size of *C. purpureus* is quite low in Taiwan.

As *C. purpureus* has gained significant popularity among the Taiwanese hermit crab enthusiast community, conducting further ecological research to comprehensively understand the population dynamics and distribution patterns of *C. purpureus*. This is imperative for accurately assessing the conservation status of this species. Notably, the commercial captive breeding of land hermit crabs remains an unachieved feat at present (Liu et al., 2021). Given this circumstance, any involvement of this species in the wildlife trade could potentially result in overexploitation, further

exacerbating the risk of regional extinction. Besides, Thus, the relevant regulation and management strategy should be imperative.

4.3 Laws and regulations related to our case

In terms of improper methods to catch land hermit crabs, it is known that most of the land hermit crab poaching is done using food bait or direct capture, and not by using methods prohibited by the law, such as anesthetics or paralysis, setting nets, firearms other than hunting guns, traps, snares, or other specially prohibited hunting tools. Therefore, Article 19 of the Wildlife Conservation Act may not be applicable to land hermit crab poaching cases, and there have been no precedents of such cases being penalized under this Act.

The National Park areas are the most abundant habitats for land hermit crabs. According to the National Park Law, criminal penalties are imposed only in severe circumstances. The capture of land hermit crabs is generally not considered a serious offense; most serious poaching cases are related to corals. Currently, there is one reported case of 9 hermit crabs being captured in Kenting National Park (it is uncertain whether they were marine hermit crabs or land hermit crabs). However, the prosecutor did not find the case to involve serious circumstances and decided not to pursue prosecution. For the general circumstances of poaching the land hermit crabs in the National Park, according to the Directions for Fines for Cases of Violation of the National Park Law, regardless of whether it is the first offense or a repeat offense, the fine for each violation is only NT$3,000 (about 100 USD), which lacks any deterrent effect. Due to the high prices of individual *C. purpureus*, one violation may surpass the penalty, while for other species like *C. brevimanus*, just 5 individuals could exceed the penalty. The profitability often outweighs the penalty in illegal or unsustainable wildlife trades (Hsu, 2024; Van Song, 2008; Wellsmith, 2011), which is believed to be a significant reason for the frequent occurrence of such trades. However, we don't know if higher penalties can increase the deterrent effect. At least, a higher fine can be used as funding for wildlife conservation and restoration.

In terms of smuggling, we believe that constituting a criminal penalty under the Smuggling Penalty Act for smuggling land hermit crabs is extremely difficult, almost impossible, due to the requirement of a large quantity.

5. MANAGEMENT IMPLICATION

According to our study, we offer some suggestions for policymakers. First, ecological information is crucial. We need to conduct further research to understand habitat preferences, hotspots, population sizes, and more. The significance of scientific knowledge is evident in Aichi Target 19, which emphasizes enhancing "scientific knowledge about biodiversity and its applicability in decision-making" as a fundamental factor for shaping the Strategic Plan for Biodiversity's development (Marques et al., 2014). With this information, we can determine the conservation status of *C. purpureus* or establish wildlife refuges as needed.

Based on our preliminary findings, we believe that the population of *C. purpureus* is low in Taiwan. Conducting an ecological study requires a certain amount of time; however, the capturing and wildlife trading of this species is still ongoing. Thus, we suggest considering referencing the Japanese policy applied to certain species, which involves one giant centipede (*Scolopendra alcyona*), two cockroaches (*Eucorydia donanensis* and *Eucorydia miyakoensis*), and one damselfly (*Platycnemis phyllopoda*). This policy involves the implementation of a temporary ban on capturing, importing, exporting, transferring, and displaying or advertising the species after its discovery, to ensure its conservation status (From Ministry of Environment, Japan: https://www.env.go.jp/nature/kisho/kinkyushiteishu.html). Besides, there is another Japanese policy known as the "Specified Type 2 Domestic Endangered Species of Wild Fauna and Flora," which allows individuals to use the species for research, environmental education, breeding, and other non-commercial purposes, while imposing restrictions on their

transfer, display, or advertisement. This policy involves 13 salamander species belonging to the Family Hynobiidae, one freshwater fish (*Hemigrammocypris neglectus*), and one insect (*Kirkaldyia deyrolli*) (From Ministry of Environment, Japan: https://www.env.go.jp/page_00707.html). We believe that this regulation is reasonable and recommend its reference, as introducing a species to the market could lead to a higher demand than personal small-scale catching.

Regarding the risk of potential smuggling, we propose that policymakers establish regulations for wildlife smuggling, even in the case of small quantities. This precaution is crucial due to the possible introduction of invasive species into Taiwan. Furthermore, we suggest the revision of wildlife conservation regulations to suit current requirements better, particularly emphasizing the importance of invertebrates and ensuring that these regulations carry a robust deterrent effect. Additionally, a focus on enhancing technological advancements in detection and enforcement is necessary to effectively combat illegal wildlife smuggling.

Preserving intact habitats for land hermit crabs is of utmost importance. These crab species inhabit coastal forests and migrate to the seashore during the breeding season. However, numerous coastal forests are under threat due to tourism development, solar panel installations, road construction, and unnecessary building projects. An encouraging example comes from the Dakenggu community in Yilan County, where residents-initiated surveys and restoration efforts for the coastal forest. They aim to bolster the population of land crabs for environmental education and ecotourism purposes (Hsu, Fang, Chiu, et al., 2023). Collaboration with residents and developing a citizen science project for long-term monitoring and guarding against poaching are essential for effective conservation (Hsu, Chang, et al., 2019).

Education plays a crucial role in raising public conservation awareness. We firmly believe that the ecology of land hermit crabs offers valuable material for environmental education. Their life cycle spans both the ocean and land, providing insights into marine and coastal forest ecosystems.

Ultimately, the key objective is to shift public behavior towards conserving land hermit crab species and other wildlife.

Declaration of competing interest

The authors have no conflict of interest.

Data availability

Data will be made available on request.

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