Incorporating Species-Conditional Co-Occurrence When Selecting Indicator Species to Monitor Restoration after Mangrove Removal from the Siangshan Wetland, Taiwan

Ta-Jen Chu \(^1,2,3\), Chun-Han Shih \(^3,4,*\), Yu-Ming Lu \(^3,5\), Yi-Jia Shih \(^1,2\), Jia-Qiao Wang \(^1,2\) and Liang-Ming Huang \(^1,2\)

Abstract: This paper presents an approach for incorporating species-conditional co-occurrence into models used for the selection of marine indicator species. Mangrove invasion within the Siangshan Wetland in Hsinchu, Taiwan, has changed the original structures and functions of habitats for benthic organisms. The Hsinchu City Government ran a large-scale mangrove removal project from October 2015 to March 2016 to restore the wetland. From October 2015 to September 2016, we investigated the biological effects of mangrove removal on benthic crabs and their adjacent habitats. Density, number of species, Shannon–Weaver index (\(H''\)) and Palou’s evenness index (\(J'\)) were calculated and compared between mangrove and non-mangrove regions. The results showed that values for these attributes in the non-mangrove regions were higher than those of the mangrove regions. After mangrove removal, species returned to their original habitats and the related density increased significantly. Using conditional co-occurrence algorithms, we identified five indicator species (\(Mictyris brevidactylus\), \(Macrophthalmus banzai\), \(Uca arcuata\), \(Uca lacteal\) and \(Uca boralis\)) with high co-occurrence probabilities, whose population responses provided direct evidence of the benefits of mangrove removal for wetland restoration. The results indicate that mangrove removal is an appropriate habitat rehabilitation strategy for benthic organisms, and that the chosen indicator species may provide valuable ecological information for coastal managers seeking to control the spread of mangroves.

Keywords: benthic organisms; conditional co-occurrence; indicator species; mangrove removal; Siangshan Wetland

1. Introduction

Biological indicators are widely used to assess the effects of environmental impact or biological restoration [1–6]. Generally, indicator species (IS) are used to monitor environmental changes, assess the efficacy of management and provide warning signals for impending ecological shifts [7]. Most IS studies only use a single species as an indicator, and the rest use species groups as indicators [7]. IS, also termed umbrella [8–10], keystone [8,10–12], flagship [8,10,11] or foundation species [12], are living organisms that are easily monitored and whose status reflects or predicts the conditions of their environment [6,13–16]. In other words, the concept of IS is based on the hypothesis that the effects of environmental shifts are reflected in a change in the diversity, abundance or growth rate of species living in a given environment [15–18]. IS are usually used for monitoring wildlife conservation, habitat management and ecological restoration [8,9,19]. They may be used to indicate effects of either short- or long-term changes, thereby allowing researchers
to predict environmental variation. Siddig et al. (2016) [7] suggest that IS may be used for pollution or contamination assessments, environmental or ecosystem health assessments, management-oriented activities, risk or disturbance assessments and early warnings of environmental change.

Many studies, including species, communities, and ecosystems, were identified and widely used in different fields. Such as IS, *Corbula gibba* and *Flexopecten hyalinus*, were used to characterize disturbed and undisturbed areas in terms of chlorophyll *a* concentration in Greece, respectively [20]. The xerophyte inland dunegrass community from Portugal was used to evaluate the relationship between the structure of the dune community, local environmental conditions, and the suitability of climatic conditions for its characteristic species [21]. While IS have rarely proven to be an effective tool for monitoring ecosystems and informing management decisions [22], the use of quantitative methods to determine IS is developing rapidly. Thus, Fleming et al., (2020) [22] extend the conceptual models of IS to include a direct relationship between an indicator species, ecosystem change drivers and latent processes and variables. It allows for latent-state models to be tested empirically, facilitating the robust evaluation and practical use of indicator species for ecosystem science and management [22]. Fifteen species out of 89 plant species were found by principal components analysis to be an IS, which should be benefited for the vegetation change status and sustainable rangeland management under semiarid rangeland conditions [23].

A context-dependent joint species distribution model (JSDM) was built to estimate the residual associations, 161 plant species were selected based on community data from 8660 vegetation plots [24].

Mangrove areas were regarded as having high diversity and good ecological value [25,26] because they provide food and shelter and form a rich ecosystem [27]. However, some reasons for this diversity include the construction of aquaculture farms, coastal developments and the purchase of firewood and other products by local residents. Mangroves in some areas were cut and removed [28]. The global decline in mangrove areas is considered a considerable issue for maintaining coastal biodiversity [29]. Therefore, conservation and restoration works were undertaken by mangrove management projects to avoid the destruction and degradation of mangrove habitats [30]. Nevertheless, mangrove conservation and restoration for the aforementioned purposes clearly differ from the goals of mangrove removal. Due to the invasion of mangroves in mudflats, the Siangshan Wetland has indicated that mangrove removal can be considered a case of positive conservation, insofar as it represents an appropriate habitat rehabilitation strategy for benthic organisms [31].

Regional and local groups are often involved in regional planning but, when making decisions, they make insufficient use of scientific knowledge regarding the given ecological system being changed [32]. The ecological basis of regional landscape changes could be improved if knowledge-based systems were tailored to the cyclic process of planning and negotiation, as well as to the expertise of planners, designers and local interest groups [32]. Ecologists or engineers select indicator species for the efficient assessment of the effects of management actions and as warning signals for ecological shifts based on their sensitivity to a particular environmental attribute. Selections may also take into account past published research, high abundance, a charismatic, endangered or invasive species character or any combination of these factors [7]. The ecoprofile method designed by Opdan et al. (2008) [32] combines the foundation of an ecosystem with the spatial conditions of a species metapopulation; the goal of this method is to integrate a suite of species as the core patterns of an ecosystem to allow the aspiration level to be modified during the planning process. This process infers a set of prerequisites for the effective use of biodiversity target setting methods, which can help multi-stakeholder decision making. Kuo et al. (2010) [6] defined indicator species as those whose presence denotes a large number of naturally co-occurring species, and they used algorithms of maximum co-occurrence probability to identify these candidates. Here, co-occurrence probability was defined based on the species that were found together in the same sites. However, it is not possible to distinguish such a relationship among species when using calculated joint probabilities.
In this study, we address this issue by using a novel quantitative method that incorporates species-conditional co-occurrence, which is based on the conditional probability of identifying an indicator species. First, we calculate the presence probability of each species as a condition against other species to appear at the same time, and then further add up the sum of the probability of other species with this species as the condition. This allows for the calculation of probabilities and expected values when only partial survey data are available. We therefore establish the co-occurrence probability of each species with other species. Second, we compare the cumulative co-occurrence probability of each species as judgments, and choose the one with the highest co-occurrence probability as the indicator species. Third, this study hopes to use the selected indicator species as a monitoring tool during the mangrove removal project in the Siangshan Wetland Conservation Area, Hsinchu, Taiwan.

2. Materials and Methods

2.1. Study Area

The study was conducted at the Siangshan Wetland, which is situated north of the Sanxing stream and to the south of the Haishan Fishing Port in Hsinchu, Taiwan (Figure 1). The wetland has a shoreline approximately 8 km in length, and an area of approximately 1600 ha. Due to its abundant ecosystem resources, the Siangshan Wetland was officially selected as a Hsinchu City Coastal Wildlife Sanctuary in 2001. The shoreline is a breeding ground for shrimp, crabs, shellfish and benthic organisms, and it attracts many bird species of conservation interest (National Important Wetland Conservation Project 2014). Two dense mangrove regions and a smaller seedling area within the reserve were selected for this study. The northern mangrove region is in the estuary of the Sanxing stream, and the other is in the northern part of the Haishan Fishing Port.

The mangroves were planted in 1969. A survey of mangroves found that there were as many as 5300 stands in 1992. Mangrove areas were estimated in 0.1-ha areas by the Taiwan Endemic Species Research Institute in 1995. According to the report, the Siangshan Wetland Mangrove Removal and Benefit Assessment Program of the Hsinchu Municipal Government in 2000, the mangrove area covered approximately 107 ha. Due to the continuous spreading of the mangrove in the coastal areas, the effects shown included habitat singularity, decline of species abundance, decline of biodiversity, infilling of estuaries, flooding, and small black mosquito breeding. And then, several small-scale mangrove-removal projects, ranging from 1 to 14 ha, were implemented from 2007 to 2014. Related projects are all entrusted to NGOs. A large-scale removal project was planned in October 2015. Therefore, two dense mangrove regions and a smaller seedling area within the reserve were selected for this study. The northern mangrove region is in the estuary of the Sanxing stream, and the other is in the northern part of the Haishan Fishing Port.

Hsinchu City’s industry is dominated by electronic component manufacturing, among which Hsinchu Science Park is an important pillar of Hsinchu’s economic development. The most serious threat to the Siangshan Wetland is pollution, its source comes from the inflow of sewage from rivers such as Keya Creek and Yanshui Creek. These pollutions mainly come from the Hsinchu Science Park. For many years, residents living by the wetlands have had a high level of environmental protection awareness. So far, the problem of mangrove forests was also reported by residents, and the government has dealt with the removal of mangroves in response to public opinion.
2.2. Mangrove Removal

A survey of mangrove stands in 1992 yielded an upper estimate of 5300 mangroves. While the Taiwan Endemic Species Research Institute in 1995 estimated the extent of the mangrove area as 0.1 ha, the “Siangshan Wetland Mangrove Removal and Benefit Assessment Program” of the Hsinchu Municipal Government reported that the mangrove area had reached approximately 107 ha by the year 2000. Repercussions of this continuous mangrove invasion include habitat singularity, a decline in species abundance and biodiversity, flooding and enhanced mosquito recruitment. According to the “2011 National Important Wetland Ecological Environment Investigation and Rehabilitation Project—Hsinchu City Wild Animal Sanctuary Habitat Rehabilitation Program”, as the mangroves continue to expand, the government will adopt mechanical methods to cut them down and transport them to an incinerator by truck. At this point, these implementations did not seem to solve the continuous expansion of mangroves.

In October 2015, a large-scale removal project was planned by the Hsinchu Municipal Government to resolve the problem of mangrove expansion. The mangrove forest was divided into three regions—two densely and one sparsely forested. A mechanical removal method was used in the densely forested regions while, in the sparsely forested region, mangroves were removed manually. Finally, in March 2016, the cumulative removed mangrove area was 348 ha, which included 48 ha from the densely forested regions and approximately 300 ha from the sparsely forested region.
2.3. Biological Survey and Experimental Design

In this study, crabs were sampled monthly from October 2015 to September 2016. The A, B, and C survey transects ran from north to south, and 5 sampling sites were positioned along each transect, resulting in 15 sampling sites, as shown in Figure 1. Transect A was designed to understand the occurrence of species in the mangrove area. However, transects B and C were designed to understand the occurrence of species in non-mangrove areas. Sites A1, A2, A3, and A5 were in the densely forested mangrove regions. A4 was located in the sparse mangrove seedling area. The three transects of space could help us understand how species distribute and change in space, especially in relation to changes before and after the removal of mangroves. Monthly sampling and spatial comparison could also help in clarifying the seasonal effects of species.

The semidiurnal and diurnal tides have a tidal range of 2.7 m along the Siangshan Wetland. Samples were collected on the tidal flats by excavating within a 1 m$^2$ frame to a depth of 30 cm. Ten random frames were placed at each site. The samples were sieved through 1 mm mesh and preserved in an 8% formaldehyde–seawater solution. In the laboratory, crabs were sorted and species were identified, counted and preserved in a 70% alcohol solution. Samples were then used for species identification, quantity computation and for a before/after comparison of the effect of mangrove removal.

2.4. Statistical Analysis

Animal density was estimated as the number of individual organisms (N) per unit area, and species richness was determined as the total number of species (S). Diversity ($H'$, log) was estimated using the Shannon–Weaver index [33], and evenness ($J'$) was estimated following [34]. The community structures of the crabs were analyzed using the PRIMER 6.0 multivariate statistics program [35]. Species abundance was fourth root-transformed before communities were compared using the Bray–Curtis similarity index [36]. Individual samples were compared between sites and dates using a group-averaged cluster analysis and non-metric multidimensional scaled (n-MDS) ordination. Grouped communities at each site were compared using ANOSIM, with sample dates used as replicates within a site [35].

2.5. Model Building

Usually, the conservation of higher biodiversity is a fundamental goal of ecological restoration. When biodiversity is high, it means there are many different types of organisms and species present, meaning greater biodiversity in ecosystems, species and individuals, leading to greater stability. Therefore, indicator species are defined as those whose presence denotes the maximum number of naturally conditionally co-occurring species [6, 36]. The IS should appear in habitats with high biodiversity in either a particular habitat, community or ecosystem. In addition, an umbrella species is defined as a species whose conservation is expected to confer protection to a large number of naturally co-occurring species; this concept has attracted greater attention in recent years because it provides a tool for the conservation of biodiversity [37]. When one protects the living environment of an asylum species, one also protects other species within this habitat. An umbrella species is usually widely distributed in a habitat and can show the needs of some or all species that inhabit the same locale. In other words, the habitat needs of this species are similar to those for other species living in the same community [38]. Thus, when it is ensured that these groups can survive, the survival of other species in the same habitat is also stable. With limited funds, knowledge and time constraints, the most efficient conservation plan must be adopted to maintain biodiversity. However, it is difficult to comprehensively study all species in a given ecosystem, so scientists can only focus on some specific species, and asylum species play an important role in these studies.

Therefore, we formalize the quantities that can be calculated from the species survey data to establish a quantitative method that may be used to determine an indicator species. For selecting indicator species, we use the concept of maximum conditional co-occurrence
First, let $S_i$ or $S_j$ be the random variable denoting the presence or absence of species $i$ or $j$. Let $S_i = 1$ or $S_j = 1$ when species $i$ or $j$ is present, and $S_i = 0$ or $S_j = 0$ when species $i$ or $j$ is absent. We suppose that $n$ species are present and sampled simultaneously at the $k$th site, so that the co-occurrence probability of each species is calculated as the proportion $1/n$. Given that species $i$ or $j$ is present and sampled simultaneously at the $k$th site, the probability of observing species $i$, knowing that species $j$ is already present, defines species $j$ as a conditional co-occurrence of species $i$. The conditional co-occurrence probability of each species $i$ integrated over different species $j$ is calculated by Formula (1).

$$P_{co}(S_i) = \sum_{j=1}^{n} P(S_j \mid S_i)$$

The co-occurrence probability of each species $i$ integrated over different sites $k$ is calculated by Formula (2).

$$P_{co-site}(S_i) = \prod_{k=1}^{p} P_{co}(S_i)_k$$

where $k = 1, 2, \ldots, p$-th site for the $i$th species. In addition, a small value is given when some species are absent in the $k$th site, and inserted into the formula.

The co-occurrence probability of each species $i$ integrated over different months $t$ is calculated by formula (3).

$$P_{co-site-month}(S_i) = \prod_{t=1}^{m} P_{co-site}(S_i)_t$$

where $t = 1, 2, \ldots, m$-th site for the $i$th species.

For determining suitable indicator species, the maximum probability value among all species was selected.

$$\max P_{c.s.m.}(S_i)$$

3. Results and Discussion

3.1. Biological Survey and Community Structure

Fluctuations in density and number of crab species across the survey period are shown in Figure 2. Before mangrove removal, density ranged from 1 to 11 individuals (ind.)/m$^2$, and the number of crabs ranged from 0 to 2 at sampling sites A1, A2, A3, and A5. The crab species included $M. banzai$, $U. arcuata$ and $U. borealis$. After mangrove removal, density rose to 4–60 ind./m$^2$ and the number of crab species increased to 2–5. The additional crab species were $Helice formosensis$, $U. formosensis$ and $U. lactea$. These results show that density and number of species increased after mangrove removal. The lowest density occurred in January 2016 and the highest in September 2016. The lowest number of species was recorded in February 2016 and the highest in August 2016.

At the sampling sites of the non-mangrove region, density ranged from 7 to 108 ind./m$^2$, and the number of species ranged from 2 to 14 before mangrove removal. On the tidal flats in the non-mangrove region, the dominant species consisted of $M. brevidactylus$, $M. banzai$ and $U. arcuata$. After mangrove removal, the density increased to 26–232 ind./m$^2$, and the number of species recorded increased to 2–12. The lowest density was recorded in January 2016 and highest in September 2016. The highest diversity was recorded in October 2015 and the lowest in January 2016. These results indicate that the density and number of species change seasonally in the Siangshan Wetland, decreasing in winter and spring and increasing in summer.
Figure 2. Fluctuations in density and number of crab species over the survey period.

Shannon–Weaver index (H') and Palou's evenness index (J') are shown in Figure 3. The value of H' ranged from 0 to 0.64, and J' ranged from 0 to 0.92 before mangrove removal. However, after mangrove removal, H' ranged from 0 to 1.53 and J' ranged from 0.74 to 1.00. Lower H' and J' values were found in November 2015, December 2015, January 2016 and March 2016, and the highest H' was found in July 2016. These results of transect A illustrate that both indices increased after mangrove removal, indicating an increase in biodiversity. In the non-mangrove region, H' ranged from 0.56 to 2.25 and J' ranged from 0.60 to 0.99 before mangrove removal. After mangrove removal, H' ranged from 0.67 to 1.97 and J' ranged from 0.54 to 0.98. Thus, the Shannon–Weaver index decreased in winter and increased gradually in spring and summer.

The results of the non-metric MDS ordination paralleled those produced by the classification (stress = 0.14). MDS ordination divided the sampling area into three categories: the first category (I) included most sites located in the non-mangrove region; the second category (II) included sites A1, A2, and A3, which were located in mangrove removal regions, and clustered data from the period after mangrove removal; and the third category (III), comprising sites A1, A2, A3, and A5, also contained sites located in the mangrove removal region, but clustered data from the period before mangrove removal in Figure 4. Generally, the MDS ordination revealed a clear gradual temporal continuum of change in species composition from October 2015 to June 2016 in mangrove removal regions in a counterclockwise direction (Figure 4).
Figure 3. Shannon–Weaver index (H') and Palou's evenness index (J') over the survey period.

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Cluster analyses were used to demonstrate the grouping patterns of organism communities. The groups were primarily determined by the sample site, together with the sampling month (Figure 5). Samples were clearly separated into two major categories (I and II) at a similarity level of 0.30. The first category (I) included data from sites A1, A2, A3, and A5 in the mangrove removal region. The second category (II) comprised data from the non-mangrove region.

3.2. Identifying Indicator Species

The maximum conditional co-occurrence probability, Equation (1)–(4), was used to identify the most suitable indicator species. These species were selected to have the highest conditional co-occurrence probability (Table 1). Similarly, we also sorted and tabulated the indicator species rank according to the probability values of each month (Table 2), which clearly shows that the sorting varies monthly and seasonally. A clear monthly ranking would help us understand the seasonal changes in co-occurrence between species. Moreover, we still have to accumulate monthly rankings for the annual rankings (Table 2). Through a comprehensive analysis of the two tables, we found that M. banzai, U. arcuata and M. brevidactylus were the major indicator species in winter and spring. In summer and autumn, the major target species showed little change and consisted of U. lacteal, U. arcuata, U. borealis and H. formosensis. Finally, the most suitable indicator species were selected, including M. brevidactylus, M. banzai, U. arcuata, U. lacteal, U. borealis and H. formosensis.
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Table 1. The conditional co-occurrence probabilities of crab species in different months.

| Species                | 2015 | 2016 | $P_{\text{cum}}(S_i)$ |
|------------------------|------|------|-----------------------|
|                        | Oct  | Nov  | Dec      | Jan  | Feb  | Mar  | Apr  | May  | June | July | Aug  | Sep  |
| Helicna doerjesi       | 0.002| 0.004| 0.000    | 0.000| 0.001| 0.000| 0.001| 0.000| 0.001| 0.002| 0.001| 0.001|
| Helice formosensis     | 0.000| 0.001| 0.000    | 0.000| 0.000| 0.002| 0.001| 0.007| 0.007| 0.074| 0.075| 0.074|
| Mictyris brevidactylus | 0.079| 0.077| 0.072    | 0.069| 0.074| 0.071| 0.074| 0.075| 0.076| 0.071| 0.076| 0.075|
| Macrophthalmus banzai  | 0.139| 0.077| 0.072    | 0.039| 0.074| 0.040| 0.074| 0.041| 0.076| 0.071| 0.076| 0.075|
| Macrophthalmus suevicus| 0.001| 0.007| 0.001    | 0.001| 0.001| 0.000| 0.001| 0.000| 0.001| 0.001| 0.001| 0.001|
| Ocypode ceratophthalma | 0.002| 0.007| 0.001    | 0.000| 0.000| 0.000| 0.002| 0.001| 0.000| 0.000| 0.000| 0.001|
| Ocypode stimpsoni      | 0.000| 0.002| 0.001    | 0.001| 0.001| 0.002| 0.001| 0.001| 0.001| 0.001| 0.002| 8.5  
| Ocypode sinensis       | 0.007| 0.001| 0.000    | 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 2.0  
| Uca arcuata            | 0.135| 0.023| 0.012    | 0.007| 0.039| 0.004| 0.039| 0.039| 0.246| 0.074| 0.250| 0.074|
| Uca formosensis        | 0.000| 0.000| 0.000    | 0.001| 0.000| 0.001| 0.004| 0.001| 0.012| 0.013| 0.013| 1.1  
| Uca lactea             | 0.013| 0.013| 0.002    | 0.004| 0.012| 0.004| 0.012| 0.069| 0.246| 0.074| 0.250| 0.074|

Figure 5. Dendrogram of hierarchical clustering of monthly crab communities, using group-average linking of Bray–Curtis similarities calculated from fourth root transformed abundance data.
Spatial variations in indicator species composition are shown in Figure 6. Two crab species, *U. arcuata* and *U. borealis*, were observed at the sampling sites within the mangrove region before mangrove removal. After mangrove removal, four species *U. arcuata*, *U. borealis*, *U. lactea*, and *H. formosensis* were observed. *U. arcuata*, *U. lactea*, and *U. borealis* were distributed across sites A1, A2, A3, B1, and B2. *H. formosensis* and *M. banzai* were located outside these sites. A comparison between habitat types showed that *H. formosensis* and *M. banzai* favor sandy over muddy locations. After mangrove removal, *U. lactea* returned to the area. Within the non-mangrove regions, species composition also varied both spatially and seasonally. The species within the mangrove regions increased after mangrove removal.
In general, *U. arcuate*, *U. lactea*, and *U. borealis* were commonly found in mangroves, salt marshes and sandy or muddy areas in Siangshan Wetland. These species play a vital role in the preservation of wetland environments due to their feeding method of sifting through the sand, which aerates the substrate and prevents the development of anaerobic conditions [37]. *U. arcuate* tends to prefer wet habitats and thus is more likely to be found next to waterways and tidal pools in wetlands at low tide. Expanding mangroves often block waterways, while their removal re-opens them and promotes the return of these species to their original location.

Alfaro (2010) [30] explored the effect of mangrove removal on the community ecology of Mangawhai Estuary, northern New Zealand, between March 2004 and September 2006. The results showed that, after the mangroves were eradicated, sediments immediately changed from muddy to sandy, which is conducive to an overall increase in the number of crabs, snails, and bivalves. Alfaro’s study (2010) [30] provides direct evidence of the impact of mangroves on sediment and benthic characteristics, as well as the importance of imports from catchment areas to estuarine ecosystems [6,30].

The temporal density changes in the five indicator species in the two different regions (mangrove: A1, A5, and non-mangrove: B1, B5) are compared in Figure 7. Densities varied monthly and were significantly lower in the mangrove region than in the non-mangrove region. Our results indicate that these benthic organisms were forced to migrate from their original habitat to nearby areas when the mangroves invaded, and returned to their original habitat shortly after mangrove removal.

Figure 6. The spatial variation in indicator species with their quantities.
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Figure 7. Densities of five indicator species at four sites, A1, B1, A5, and B5, in October 2015 and February, June, and August 2016.

In order to analyze the influence of seasonal change, we compare the result from Ecological Restoration in Kaya Water Recycling Center, Hsinchu City -Habitat Improvement Restoration (Sub-project 2-1: Research on U. formosensis and its habitat) [39]. The seasonal fluctuations in number of crab species, U. formosensis, was shown from December 2006 to November 2008 (Figure 8). Two peaks are shown here in two years, which means that crabs appear less in winter and peaks in summer. As shown in Figure 2 above, comparing the density and number of crab species during the two survey periods, it shows consistent fluctuations. Similarly, the increase in species number indicated at A1 and A2 in Figure 6, it is due to the migration after mangroves removal. Coupled with the increase in the number of individuals due to seasonal factors (Figure 7). Therefore, in this paper, the temporal density of five indicator species change in two different regions (mangrove region in transect A and non-mangrove region in transect B) which can help clarify the influence of seasonal factors or removal.
These results suggest that these five species may be considered for use as indicator species, which will allow for the identification of environmental changes, indicating habitat restoration as a result of mangrove removal. All species co-occurring with well-chosen indicator species are supposed to benefit from measures that improve habitat quality [40–42]. Our results clearly support the notion that these indicator species should occur in the mangrove region, as well as in the non-mangrove region and, in turn, represent excellent proxies for higher conditional co-occurrence probabilities in those species assemblages. The biodiversity indices calculated for the sites further indicate a strong relationship between biodiversity and these selected indicator species.

Some studies have proved that it is possible to express environmental categories or changes. For example, Moraitis et al., (2018) [20] advocate the use of C. gibba as a proxy for eutrophication and the incorporation of this species in monitoring studies through SDM methods. For the Mediterranean Sea, they suggest the use of F. hyalinus in SDM as an indicator of environmental stability and a possible forecasting tool for salinity fluctuations [20]. It is possible to screen out some meaningful IS from a variety of plants through multivariate statistical methods and principal component analysis. These results are conducive to grasping the state of vegetation change and sustainable management under semi-arid rangeland conditions [23]. Cazelles et al. (2016) [36] mention that species co-occurrences are central in community ecology since the foundation of the discipline [36]. They think that a theory of species co-occurrence in ecological networks is needed to better inform interpretation of co-occurrence data. The procedure will analyze the relationship between biotic and abiotic factors for different community mechanisms. When a clear community mechanism is analyzed, it is conducive to policy formulation at the current stage and future maintenance and management. Melinda et al. (2021) [24] found that the interaction between species is increasingly recognized as an important driving factor for the distribution of species, but it is not clear whether changes in the interaction caused by pressure will affect the distribution of species [23].

While the status of well-chosen indicator organisms can frequently be treated as reflecting the fundamental conditions and range in conditions required by all species in an ecosystem [6,42], some authors have suggested that such species may not respond uniformly to restoration measures and thus may fail to predict similar responses at an ecosystem level. Pander and Geist (2013) [43] proposed that the evaluation of conservation

Figure 8. Fluctuations in number of crab species, Uca formosensis, from December 2006 to November 2008 [39]. Note: This figure cites from Ecological Restoration in Kaya Water Recycling Center, Hsinchu City Habitat Improvement Restoration (Sub-project 2-1: Research on Uca formosensis and Its Habitat).
measures or restoration might require a holistic approach integrating several endpoints at different scales (e.g., target species, indicator groups and ecosystem scale) [43]. In the present paper, indicator species were specifically selected to assess environmental changes after mangrove removal. For further investigation of the use of indicator species in understanding the structure and function of marine environments, it is necessary to merge various approaches into more holistic perspectives.

4. Conclusions

The concept of indicator species is widely applied in wildlife conservation, habitat management, and ecosystem restoration. The identification of appropriate indicator species possesses an undeniable appeal for conservationists, managers, and government officials who desire a clear means and target to assess impacts on environments or ecosystems. However, minimal attempts have been made to develop quantitative methods to select an indicator species from species assemblage data. Here, we develop a novel approach by incorporating species conditional co-occurrence probability into a selection model. A case study was conducted to explore and monitor wetland restoration at Siangshan Wetland, Hsinchu, Taiwan, focusing on crab species. The five indicator species with the highest conditional co-occurrence probabilities were *M. brevidactylus*, *M. banzai*, *U. arcuata*, *U. lactea* and *U. borealis*. Population dynamics of the selected species can be used to explain how species assemblage composition is affected by the environmental shifts engendered by mangrove removal. The proposed method provides an innovative approach for monitoring habitat quality, determining effects of restoration and managing conservation areas. The continually increasing complexity of maintaining wetland ecosystems is widely acknowledged, and better understanding this complexity will assist in further improving the evaluation models used to select indicator species.

We believe that this research still has limitations, such as the inability to clearly explain the ecological meanings of species-conditional co-occurrence, how to prove that IS is an effective tool for monitoring ecosystems and informing management decisions and how to integrate biodiversity-oriented policies. Especially, it must justify the selection of IS and be able to assess that IS can accurately reflect or predict environmental conditions. At the same time, it shows the quality of the species as a surrogate for its environment, and the relationship between species and ecological variation. Therefore, more research is needed in further.

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