



Article Trophic Assessment of an Artificial Kelp *Eisenia bicyclis* Bed Off the Eastern Coast of Korea Based on Stable Isotope Analyses

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Abstract: Effective trophic assessment of restoration success after the creation of an artificial habitat is essential for ecological management. In this study, to evaluate the ecological trophic function of restored kelp beds of artificial macroalgal reefs (AMRs) attached with the kelp species Eisenia bicyclis, we compared carbon and nitrogen stable isotope ratios of organic matter sources and macrobenthic consumers and isotopic indices of functional feeding groups between artificial and reference (natural bed and barren ground, respectively) habitats. There were no significant differences in isotopic values of consumer feeding groups (except for carnivores) and their potential food sources between the artificial and natural sites, suggesting that resource diversity and resource use by consumers was similar across all sites. The isotopic data also exhibited similar or relatively higher trophic niches of feeding groups at the artificial site compared to those at the natural site, indicating that the artificial kelp bed can play important roles in similar ecological functions and services as a natural counterpart. In addition, the present study revealed that the isotopic ranges and niche indices of feeding groups were significantly wider at the artificial and natural kelp beds compared to those at the barren ground, suggesting the trophic importance of macroalgal-derived organic matter to consumer nutrition in coastal ecosystems. Overall, our results support the conclusion that the creation of an Eisenia bicyclis kelp bed by the AMRs may lead to the restoration success of the macroalgae habitat through the recovery of the ecological function of a natural food web structure.

Keywords: artificial kelp bed; trophic assessment; δ^{13} C; δ^{15} N; isotopic niches; restoration

1. Introduction

Several environmental changes (e.g., ocean warming) caused by human activities pose serious threats to coastal ecosystems, leading to the decline in species biodiversity and abundance, habitats, and ecosystem functioning, thereby hindering the provision of ecosystem services [1–3]. In particular, the large-scale loss of macroalgal forests is widely considered to be one of the most important negative impacts on coastal ecosystems globally, which can support high biodiversity and complex food web structures by providing organic matter for consumer production and habitats for marine organisms [4–6]. The restoration of degraded macroalgal habitats through the implementation of many practical approaches can be used to increase species richness and biodiversity and improve natural recovery [7,8]. Consequently, artificial macroalgal beds have received significant attention as an effective man-made method for the protection and management of marine organisms and for mitigating macroalgal deforestation and reversing the collapse of coastal habitats [9–11].

The restoration or enhancement of marine afforestation by the creation of an artificial macroalgal habitat is normally carried out in South Korea, Japan, and the United States



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Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). through the deployment of artificial reefs with attached macroalgae, commonly composed of kelps [12]. These artificial macroalgal reefs (AMRs) can play an important role in enhancing the recovery of abundance, density, and biodiversity in benthic invertebrates and nekton through macroalgal growth and the colonization of barren grounds or damaged macroalgal beds [13,14]. Consequently, many studies have focused on the recovery assessment of abundance and biomass of invertebrates and fishes by monitoring community structures of restored and reference (or damaged) habitats [15–17]. However, considering the high values of ecological functions of macroalgal forests, it is important to understand the roles of AMRs after their deployment in trophic support and energy transfer through complex food webs, along with enhancing animal community structures as natural habitats [18,19]. The trophic importance of macroalgal forests to coastal food webs is recognized worldwide [20–22], An effective ecological management strategy must consider the trophic assessment of consumer species on AMRs by comparing nearby barren ground or natural counterparts. However, few studies have assessed the trophic roles of AMRs on organic matter flow through food webs in response to restoration [23,24].

The analysis of carbon and nitrogen stable isotope ratios has been used widely in identifying dietary resources of consumer species and organic matter flow through food webs [25–28]. The carbon and nitrogen stable isotope ratios of a consumer's tissues tend to reflect those of their dietary items by metabolic trophic fractionations, which are predictable as slight enrichments (less than 1% for carbon and 2–4% for nitrogen) of heavier isotopes between them [25,28–30]. Consequently, this method provides the time-integrated information of nutritional sources assimilated by the consumers and thus trace trophic pathways from basal resources to higher trophic levels. Furthermore, some studies have successfully demonstrated the trophic recovery of consumer species after the restoration of coastal ecosystems by comparing stable isotope ratios between man-made and natural (or damaged) habitats [18,19,23,31].

In recent decades, the decline or loss of macroalgal beds has become increasingly apparent on the rocky coastlines of the Korean peninsula. In response, the deployment of AMRs on Korean coasts to mitigate the massive losses of macroalgal habitats is being increasingly used. Restoration projects from the Korea Fisheries Resource Agency in South Korea have focused on the seedling transplantation of the kelp species *Eisenia bicyclis*, Ecklonia cava, Ecklonia stolonifera, and Sargassum to AMRs with sea urchin control on barren grounds [12,32]. In the present study, we analyzed the carbon and nitrogen stable isotope ratios of macroinvertebrate consumers and organic matter sources in a restored kelp community (a canopy-forming species, E. bicyclis) using transplants on artificial reefs off the eastern coast of the Korean peninsula and compared the isotope signatures with those in a nearby natural counterpart and a barren ground community. Our hypothesis is that carbon and nitrogen stable isotope ratios of macrobenthic consumers in the newly created *E. bicyclis* habitat would be similar to those in the natural counterpart when the kelp species was successfully restored with the colonization of the macrobenthic community. Our objective was to assess the restoration success of a restored kelp forest created by the installation of AMRs using a trophic assessment of organic matter pathways and the macrobenthic food web structure of artificial and reference habitats.

2. Material and Methods

2.1. Study Sites

Our study sites of artificial (a) and natural (b) kelp beds and barren ground (c) were located at the shallow zone in Changpohang, Yeongdeok-gun, Gyeongsangbuk-do Province, off the eastern coast of Korea (Figure 1). The deployment of AMRs attached with the canopy-forming kelp *E. bicyclis* was conducted at depths ranging from 8 to 10 m on a subtidal rocky bottom in 2010. A set of AMRs was made by arch-type concrete reefs, with a basal breadth of 3.2 m, a length of 2.4 m, and a height of 2.0 m. Holdfasts of *E. bicyclis* were attached on the blocks of the concrete reefs and installed to the appropriate depth. The natural kelp bed and barren ground site, which were about 100 m and 1 km from the deployment



Figure 1. Location of sampling sites (Changpori) off the eastern coast of Korea. Detailed locations and views of artificial (A) and natural (B) kelp, Eisenia bicyclis, beds, and barren ground (control). Schematic of the artificial macroalgal reef (C, AMR).

area of AMRs at a depth of 5-6 m and 9-10 m, respectively, were selected for comparison. The artificial and natural kelp beds and barren ground were separated from each other by

129°26'20.5"E

a sandy substratum.

2.2. Sample Collection and Treatment

The sample collection of macroalgae, organic matter, and macrobenthic invertebrates was carried out during June 2022 at the artificial and natural *E. bicyclis* beds and the barren ground site. Macroalgae and macrobenthic consumers were sampled by scuba divers, who scrapped substrata attached on the AMRs with a steel knife within a 25×25 cm quadrat. All macroalgae and animals were then sieved onto a 1-mm mesh net and washed with seawater to sort the samples, which were preserved in an ice-box and transported to the laboratory. Macroalgae were scraped with a razor blade to remove epibionts and were then rinsed with filtered seawater. Macrobenthic invertebrates were sorted using a forceps under a stereo microscope, identified to the species level, and kept alive overnight in filtered seawater to evacuate the gut contents. Only the muscle tissue of most macrofauna was dissected by a razor blade, and the whole body of amphipods and polychaetes were prepared for stable isotope analysis. All samples of macroalgae and animals were dried in a drying oven at 60 °C for 72 h, ground to a fine powder with a ball mill (Retsch MM200 Mixer Mill), and then stored in a vacuum desiccator to avoid contamination until isotope analyses.

Approximately 20 L of seawater for collecting the suspended particulate organic matter (SPOM) was gathered at each site, pre-filtered with a 200- μ m net to remove any zooplankton and large particles, transported to the laboratory, and then filtered onto pre-combusted (450 °C for 4 h) Whatman GF/F glass fiber filters. Small-sized rocks and leaves of *E. bicyclis* at the artificial and natural beds were collected by scuba divers, and epilithic microalgae were collected in the laboratory by gentle brushing and rinsing with filtered seawater. Samples were pre-filtered through a 100- μ m sieve to remove large particles and epifauna and then filtered again on pre-combusted Whatman GF/F glass fiber filters. All of the treated filter samples were dried in a drying oven at 50 °C for 48 h and then stored in a vacuum desiccator until stable isotope analysis.

2.3. Stable Isotope Analysis

For stable isotope analysis, the powdered and filtered samples were packed into tin capsules and a tin disk, respectively. All wrapped samples were introduced into the elemental analyzer (Vario MICRO Cube elemental analyzer; Elementar Analysensysteme, Hanau, Germany) to oxidize at a high temperature (1030 °C), and the resultant CO₂ and N₂ gases were then analyzed using a linked continuous flow isotope ratio-mass spectrometer (CF-IRMS; IsoPrime100; Cheadle Hulme, UK). Stable isotope data were expressed as the relative difference between isotopic ratios of the sample and conventional standard reference gases of Vienna Pee Dee Belemnite for carbon and atmospheric N₂ for nitrogen. The Delta (δ) notation was used to express the relative differences according to the following equation: δX (‰) = [(R_{sample}/R_{standard}) - 1] × 1000, where X is ¹³C or ¹⁵N and R values are the ¹³C/¹²C or ¹⁵N/¹⁴N ratios. The international standards of sucrose (ANU C₁₂H₂₂O₁₁; NIST, Gaithersburg, MD, USA) and ammonium sulfate ([NH₄]₂SO₄; NIST) were used as the reference materials for checking data calibrations. The analytical reproducibility for 20 replicates of acetanilide was less than 0.14% and 0.23% for δ^{13} C and δ^{15} N, respectively.

2.4. Data Analyses

All statistical analyses were carried out after analyzing the normality and homogeneity of variance tests using the Shapiro–Wilk procedure and Levene's test, respectively. Analyses of all isotope data were performed using commercially available software packages of IBM SPSS Statistics version 21.0 (IBM Corp., Armonk, NY, USA) and PRIMER version 6 combined with PERMANOVA + PRIMER add-on [33]. Significant differences in the δ^{13} C and δ^{15} N values of organic matter sources (SPOM, epilithic microalgae, and macroalgae) and functional feeding groups (herbivores, suspension feeders, deposit feeders, omnivores, and carnivores) among artificial, natural, and barren sites were tested using a permutational multivariate analysis of variance (PERMANOVA). A one-way ANOVA was used to test for significant differences in the δ^{13} C and δ^{15} N values of each sample among the sites, and then Tukey's honest significant difference (HSD) post hoc test was applied to the variables. To assess the effects of AMRs on resource use by macrobenthic consumers and trophic structure, the isotopic niche areas (%²) occupied by each feeding group were compared among artificial, natural, and barren sites using the package Stable Isotope Bayesian Ellipses in R (SIBER; [34]). The isotopic niche indices were estimated using a convex hull-shaped total area (TA) as the volume of the δ^{13} C and δ^{15} N space encompassing all isotopic data points and the community overlap based on standard ellipse areas corrected (SEAc) for small sample sizes [34,35]. The overlap proportion of isotopic niches for each feeding group among the three sampling sites was calculated by the ratio of the overlap areas between the two SEAc and its own SEAc using the "*MaxLikOverlap*" function [36].

3. Results

3.1. Carbon and Nitrogen Isotope Ratios of Organic Matter Sources

The δ^{13} C and δ^{15} N values of organic matter sources (macroalgae, epilithic microalgae, and SPOM) showed very similar distributions at the artificial and natural sites, ranging from -20.9 ± 0.8 % (SPOM at the natural site) to -15.9 ± 0.7 % (*E. bicyclis* at the artificial site), and from 5.5 ± 0.4 % (SPOM at the natural site) to 7.4 ± 0.4 % (*G. elliptica* at the artificial site), respectively (Table 1). There were no significant differences in δ^{13} C and δ^{15} N of epilithic microalgae and SPOM between the artificial and natural sites (PERMANOVA, p > 0.642 for both cases). Similarly, the three macroalgae of *E. bicyclis*, *G. elegans*, and *G. elliptica* did not differ significantly between the two sites (PERMANOVA, p > 0.510 for all cases). However, δ^{13} C and δ^{15} N of SPOM differed significantly among the artificial, natural, and barren sites (PERMANOVA, pseudo- $F_{2, 14} = 7.83$, p = 0.003). No significant difference in δ^{13} C of SPOM was observed among the three sites (Tukey's HSD test, p = 0.492), whereas δ^{15} N was relatively lower at the barren site compared to that at other sites (Tukey's HSD test, p < 0.01).

Table 1. δ^{13} C and δ^{15} N values of organic matter sources (*Eisenia bicyclis; Gelidium elegans; Grateloupia elliptica;* Epilithic microalgae; SPOM, suspended particulate organic matter) at the artificial and natural kelp (*E. bicyclis*) beds and barren ground site. PERMANOVA test of δ^{13} C and δ^{15} N values for each organic matter source between the two sites or among the three sites (significance at *p* < 0.05). Data represent means ± 1 SD.

Organic Matter Source		Artificial	Macro	algal B	ed		Natural N	lacroal	gal Bec	1		Barren	Groun	d Site			
		$\delta^{13}C$ $\delta^{15}N$					$\delta^{13}C$		$\delta^{15}N$			$\delta^{13}C$	$\delta^{15}N$		I ERWANOVA		
	n	Mean	SD	Mea	n SD	n	Mean	SD	D Mean SD		n	Mean	SD	Mean SD		Pseudo-F	p-Value
Eisenia bicyclis	5	-15.9	0.7	5.9	0.5	5	-16.2	0.5	5.6	0.3						0.16	0.770
Gelidium elegans	4	-18.3	0.4	6.3	0.4	4	-18.6	0.3	6.2	0.3						0.49	0.654
Grateloupia elliptica	4	-17.4	0.7	7.4	0.4	4	-17.7	0.3	7.2	0.3						0.73	0.510
Epilithic microalgae	4	-16.3	0.4	6.7	0.5	4	-16.6	0.5	6.4	0.4						0.47	0.642
SPOM	5	-20.7	0.5	5.7	0.5	5	-20.9	0.8	5.5	0.4	5	-21.2	0.6	4.4	0.4	7.83	0.003

3.2. Carbon and Nitrogen Isotope Ratios of Macrobenthic Consumers

A total of 30, 23, and 17 macrobenthic consumers were collected for stable isotope analyses at the artificial, natural, and barren sites, respectively. The overall mean δ^{13} C and δ^{15} N distributions of consumer species were similar at the three sites, ranging from $-22.0 \pm 0.8\%$ (*Boltenia echinata* at the barren site) to $-10.2 \pm 0.4\%$ (*Ophiarachnella gorgonia* at the artificial site) and from $5.0 \pm 0.3\%$ (*Crepidula onyx* at the barren site) to $11.4 \pm 0.4\%$ (*Neptunea cumingii* at the artificial site), respectively (Table 2; Figure 2). A PERMANOVA test showed that except for the carnivore group (pseudo- $F_{1, 21} = 5.87$, p = 0.020), δ^{13} C and δ^{15} N of herbivores (pseudo- $F_{1, 21} = 1.44$, p = 0.266), suspension feeders (pseudo- $F_{1, 50} = 1.64$, p = 0.224), deposit feeders (pseudo- $F_{1, 19} = 1.94$, p = 0.153), and omnivores (pseudo- $F_{1, 24} = 0.35$, p = 0.636) did not differ significantly between the artificial and natural sites. However, the macrobenthic consumers exhibited significant differences in isotopic ratios for all feeding groups (suspension feeders, pseudo- $F_{2, 27} = 5.12$, p = 0.002; omnivores, pseudo- $F_{2, 33} = 2.84$, p = 0.046; carnivores, pseudo- $F_{2, 27} = 5.12$, p = 0.010), except for the herbivore group (pseudo- $F_{2, 66} = 1.12$, p = 0.376), among the artificial, natural, and barren sites.

Table 2. δ^{13} C and δ^{15} N values of macroinvertebrate consumers (herbivore, suspension feeder, deposit feeder, omnivore, and carnivore) collected at the artificial and natural kelp (*Eisenia bicyclis*) beds and barren ground site. The taxon abbreviations are as follows: Biv, Bivalvia; Bry, Bryozoa; Cho, Chordata; Cni, Cnidaria; Cru, Crustacea; Ech, Echinodermata; Pol, Polychaeta; Ppl, Polyplacophora; Sip, Sipunculida. Data represent means ± 1 SD.

			Artificial Macroalgal Bed						Natural N	lacroal	gal Bed	1		Barre	n Grou	Ground $\delta^{15}N$ 0.6 7.4 0.5 0.5 7.9 0.4 0.4 6.4 0.1 0.5 8.2 0.5 0.4 6.4 0.4 0.4 6.4 0.4 0.4 6.4 0.4 0.4 6.4 0.4 0.4 6.4 0.4 0.4 6.4 0.4 0.4 6.4 0.4 0.4 6.4 0.4 0.5 6.4 0.4 0.5 6.8 0.3 0.4 7.2 0.4 0.3 6.8 0.6 0.3 6.8 0.4		
No.	Species Name	Taxon	n	$\delta^{13}C$ $\delta^{15}N$		n	$n = \delta^{13}C$				n	$\delta^{13}C$ δ^{15}		$\delta^{15}N$				
	Herbivore																	
1	Acmaea pallida	Gas	4	-16.6	0.6	9.1	0.3	3	-17.4	0.3	9.4	0.3	3	-15.6	0.6	7.4	0.5	
2	Aplysia kurodai	Gas	3	-15.4	0.3	6.3	0.5											
3	Cantharidus iessoensis	Gas	3	-15.7	0.6	7.8	0.6	3	-17.8	0.1	8.1	0.1						
4	Chlorostoma turbinata	Gas	3	-15.3	0.7	8.3	0.5	3	-17.3	0.6	8.7	0.4	3	-15.8	0.5	7.9	0.4	
5	Kelletia lischkei	Gas	3	-15.6	0.4	10.6	0.4											
6	Nipponacmea radula	Gas							-12.3	0.3	8.0	0.6						
7	Strongulocentrotus nudus	Ech	3	-16.6	0.7	6.4	0.5	3	-12.8	0.4	6.3	0.4	3	-17.5	0.4	6.4	0.1	
8	Tristichotrochus crosslevae	Gas						3	-18.0	0.4	8.7	0.3						
9	Tristichotrochus unicus	Gas	4	-18.3	0.5	9.1	0.4	3	-18.3	0.5	9.0	0.3	3	-18.8	0.5	8.2	0.5	
10	Turbo cornutus	Gas	3	-20.0	0.7	5.9	0.4	4	-19.8	0.3	6.8	0.4	4	-17.4	0.6	7.1	0.3	
	Suspension feeder	0.00						-		0.0			-					
11	Anthonleura sp	Cni	3	-17.8	0.6	82	0.5											
12	Boltenia echinata	Cho	U	17.10	0.0	0.2	0.0						4	-22.0	04	64	04	
13	Bostrucanulus gravisninosus	Gas	3	-174	04	53	04						•		0.1	0.1	0.1	
14	Cardita leana	Biv	U	17.11	0.1	0.0	0.1		-181	04	84	0.2						
15	Chelvosoma dofleini	Cho	4	-20.8	0.5	71	07		10.1	0.1	0.1	0.2						
16	Crassostrea ninnonica	Biv	•	2010	0.0		0.7						3	-19.8	04	6.3	0.3	
17	Crenidula onur	Gas	4	-18.0	0.6	61	03	4	-175	05	6.0	03	4	-20.2	0.7	5.0	0.3	
18	Flustrellidra akkeshiensis	Bry	3	-20.5	0.5	5.1	0.3	1	17.0	0.0	0.0	0.0	-	20.2	0.7	0.0	0.0	
19	Halocunthia roretzi	Cho	3	-20.0	0.5	78	0.3						4	-211	05	64	04	
20	Hudroides ezoensis	Pol	3	-20.0	0.7	81	0.5	з	-20.0	03	66	03	3	-20.4	0.5	6.8	0.4	
20	I eiosolenus lischkei	Biv	0	20.0	0.7	0.1	0.0	0	_18.4	0.3	6.8	0.3	0	20.1	0.0	0.0	0.0	
21	Modiolus agripetus Iredale	Biv	з	_19.9	04	52	04		10.4	0.5	0.0	0.5						
22	Phascolosoma scolors	Sin	3	-10.9 -16.1	0.4	9.2	0.4	з	-16.8	0.5	89	0.2	з	_179	04	72	0.4	
23	Stuela clava	Cho	3	-20.6	0.2	75	0.4	3	-20.6	0.5	6.8	0.2	4	_21.2	0.4	67	0.4	
24	Deposit feeder	Cho	5	-20.0	0.0	7.5	0.5	5	-20.0	0.0	0.0	0.4	-	-21.2	0.5	0.7	0.0	
25	Amnithog lacertosa	Cm	4	_16.8	0.5	58	0.5											
25	Holotelson tuberculatus	Cru	3	-10.0 -21.3	0.5	8.1	0.3											
20	Pagurus provinus	Cru	3	-21.3 -14.2	0.4	72	0.5											
27	Pagurus proximus	Cru	5	-14.2	0.4	1.2	0.5	2	12.4	0.2	71	0.4						
20	Paramuithoa co	Cru						4	-12.4	0.3	5.0	0.4						
29	Pilumnus minutus	Cru	3	_11.0	0.4	82	0.5	4	-17.0	0.5	5.0	0.5						
50	Ompiyore	Ciu	5	-11.9	0.4	0.2	0.5											
21	Acanthochitona achatac	Prol	4	21.2	0.4	67	0.5											
32	Actorias amurans	Ech	-#	-21.5	0.4	0.7	0.5	3	_137	0.4	76	0.4	3	_15.0	03	73	0.5	
32	Astering postinifera	Ech	2	12.5	0.4	82	07	2	-13.7	0.4	2.0	0.4	2	-13.0	0.3	6.8	0.5	
34	Halocudna brazicatoca	Pol	5	-12.0	0.4	0.5	0.7	3	-12.5 -17.7	0.3	0.7	0.5	5	-15.1	0.5	0.0	0.0	
25	Hannicia laniuscula	T OI E ala						3	-17.7	0.5	9.1	0.4	2	12.0	0.2	60	0.4	
35	Owbigrachwelle gorgowie	Ech	2	10.2	0.4	86	0.4						5	-12.9	0.5	0.0	0.4	
30	Diatumarais hisanalisulata	Pol	2	-10.2	0.4	0.0	0.4	2	17.0	0.4	0.4	0.4						
37	Furynereis bicununcunun	1.01	3	-10.1	0.4	9.5	0.2	3	-17.0	0.4	9.4	0.4						
28	Landica antonnata	Pol	2	17.0	0.2	10.0	0.2											
30	Leouice unternation	Pol	5	-17.0	0.5	10.0	0.2	3	_16.0	0.2	03	03						
40	Mitralla hicineta		3	_16.1	03	99	0.2	3	-10.9	0.4	9.5 10.0	0.5	3	_16.4	03	03	0.4	
41	Nantunga cumingii	Cas	3	-14.0	0.5	9.9 11 /	0.2	5	-10.0	0.4	10.0	0.1	5	-10.4	0.5	9.5	0.4	
41	Reichia browni	Gas	3	-14.0	0.4	10.1	0.4	Л	_172	0.4	10.5	0.2	2	_172	03	0.4	0.6	
44	Keisnin Dionni	Gas	+	-10.0	0.0	10.1	0.5	4	-17.5	0.4	10.5	0.5	3	-17.5	0.5	9.0	0.0	

3.3. Isotopic Niche Indices of Macrobenthic Consumers

The isotopic niche indices of TA and SEAc for the herbivore group exhibited very similar areas between the artificial (20.69 and 8.27, respectively) and natural (22.24 and 8.97, respectively) sites (Table 3). However, the TA and SEAc values for all the other groups were relatively wider in the artificial site (from 3.67 and 1.72 for carnivores to 21.55 and 15.61 for omnivores, respectively) compared to those in the natural site (from 1.50 and 1.10 for carnivores to 9.29 and 4.78 for suspension feeders, respectively). In contrast, the TA and SEAc values of all feeding groups in the barren site (from 1.13 and 1.10 for carnivores to 7.85 and 3.03 for suspension feeders, respectively) exhibited narrower ranges than those in the artificial and natural sites. The isotopic niches for the two groups of herbivores (70%) and suspension feeders (64%) considerably overlapped between the artificial and natural sites, while those for deposit feeders (14%), omnivores (37%), and carnivores (13%) exhibited relatively low overlapping proportions between the artificial and barren sites or between the natural and barren sites showed relatively low values, ranging from 0%



(omnivores between the natural and barren sites) to 54% (herbivores between the artificial and barren sites).

Figure 2. Dual isotope plots of δ^{13} C and δ^{15} N values of consumers (green circles, herbivores; red circles, suspension feeders; yellow circles, deposit feeders; blue circles, omnivores; pink circles, carnivores) at the artificial (**A**) and natural (**B**) kelp (*Eisenia bicyclis*) beds and barren ground (**C**) site. Values of the organic matter sources are illustrated with black squares: *E. bicyclis, Eisenia bicyclis; G. elegans, Gelidium elegans; G. elliptica, Grateloupia elliptica;* Em, ephilithic microalgae; SPOM, suspended particulate organic matter. Values are means (%) \pm 1 SD.

Table 3. δ^{13} C and δ^{15} N values of functional feeding groups (herbivore, suspension feeder, deposit feeder, omnivore, and carnivore) at the artificial and natural kelp (*Eisenia bicyclis*) beds and barren ground site. PERMANOVA test of δ^{13} C and δ^{15} N values for each feeding guild between the two sites or among the three sites (significance at p < 0.05). Data represent means ± 1 SD. Isotopic niche areas of each feeding group are estimated as the total area (TA) and standard ellipse area (SEAc) and isotopic niche overlaps (percentage, %) between the two sites (A/N, artificial and natural beds; A/B, artificial bed and barren ground site; N/B, natural bed and barren ground site) using the Stable Isotope Bayesian Ellipse in the R (SIBER) procedure.

Fooding Crown	Artificial Macroalgal Bed						Natural M	lacroa	lgal Be	d		Barren G	Groun	d Site	PERMANONA		NOM	
reeding Group	δ ¹³ C			δ ¹⁵ N			$\delta^{13}C$		$\delta^{15}N$			δ ¹³ C			V	PEKWANOVA		
	n	Mean	SD	SD Mean SD		n	n Mean		SD Mean SD		n	Mean S) Mean SD		Pseudo-F		p-Value
Herbivore	26	-16.7	1.6	8.0 1.6		25	-16.8	2.6	8.1	1.1	16	-17.1	1.3	7.4	0.7	1	.12	0.376
Suspension feeder	32	-19.2	1.7	6.9 1.4		19	-18.5	1.4	1.4 7.2 1.1		25	-20.5	1.3	6.4 0.7		6.45		0.002
Deposit feeder	13	-16.1	3.5	7.2	1.1	7	-15.0	2.5	5.9	1.2						1	.94	0.153
Ômnivore	13	-15.9	4.7	8.1	1.1	12	-15.3	2.3	8.7	0.8	9	-13.7 1.0		7.0	0.5	2.84		0.046
Carnivore	13	-16.0	1.3	10.3	0.7	9	-17.4	0.6	9.9	0.5	6	-16.9	0.6	9.4	0.5	5.12		0.010
Isotonis nicho aroas	Artificial macroalgal bed					Natural macroalgal bed						Percentage overlap (%)						
isotopic filche areas	TA			SEAc			TA SE.			SEAc TA			SEAc			A/N	A/B	N/B
Herbivore		20.69		8.27		22.24			8.97			6.14		3.09		70	54	39
Suspension feeder		19.23 7		7.71			9.29		4.78			7.85		3.03		64	36	13
Deposit feeder		19.11	1 13.60)	4.82			4.04							14		
Ômnivore		21.55	15.61			8.17			4.93			2.16		1.56		37	2	0
Carnivore		3.67	1.72			1.50 1.00				1.13		1.10	1.10		18	30		



Figure 3. Isotopic niche areas of each feeding group (**A**, herbivores; **B**, suspension feeders; **C**, deposit feeders; **D**, omnivores; **E**, carnivores) estimated as the total area (TA, dotted lines) and standard ellipse area (SEAc, solid lines) at the artificial (red lines) and natural (green lines) kelp (*Eisenia bicyclis*) beds and barren ground (black lines) site using the Stable Isotope Bayesian Ellipse in R (SIBER) procedure.

4. Discussion

The present study assessed the similarity of the trophic structure of benthic invertebrates between artificial reef and natural macroalgal habitats using isotopic niche metrics to assess the trophic recovery for a macrobenthic community in a restored kelp bed. Several studies on kelp forest restoration have focused on the colonization of benthic communities on AMRs during recovery using a quantitative comparison of multivariate community indices across artificial and natural habitats [11,16,37]. However, considering the effect of trophic cascades by kelp forests on energy flow, the trophic assessment of AMRs is a critical ecological indicator of ecosystem functioning. The introduction of artificial habitats may create a new community of plants and animals, which may alter the food web functioning of natural ecosystems in terms of energy flows [38]. Our results showed that the isotopic values and niches of trophic groups were very similar for herbivores and suspension feeders, but very different for deposit feeders, omnivores, and carnivores, between artificial and natural sites. Accordingly, isotopic signatures of macrobenthic consumers at the artificial and natural habitats highlight the trophic functioning and food web structure of AMRs, which is associated with the importance of macroalgal production as carbon sources and can provide insights to achieve the efficient management of restored kelp forests.

The restoration success of man-made ecosystems through the transplantation of primary producers (e.g., macroalgae and seagrass) generally involves the recovery of biological structure and ecological function in artificial habitats relative to natural habitats [11,39,40]. Specifically, in terms of the recovery of food web characteristics, ecological restoration emphasizes that transplanted plants in established artificial ecosystems can play important ecological roles in supporting trophic structure and pathways [23,41]. In our study, the δ^{13} C and δ^{15} N values of major organic matter sources (macroalgae, epilithic microalgae, and SPOM) did not differ between the artificial and natural sites, suggesting the isotopic similarity of basal resources supporting the food webs of restored and natural macroalgal habitats. The δ^{13} C and δ^{15} N values of the three carbon sources at both the artificial and natural sites were within the ranges in the eastern coastal waters of the Korean peninsula previously reported in several studies [23,42–44]. In addition, δ^{13} C among the sources were reflective of the isotopic distinction of benthic (macroalgae and epilithic microalgae) and pelagic (SPOM) sources [18,25]. The transplanted kelps for habitat restoration act as foundational species, providing structural habitats for flora and fauna, controlling the quantity and quality of primary production and organic matter pools, and thereby directly or indirectly affecting the food web structure in a significant manner [45]. Because transplanted kelp, *E. bicyclis*, may alter the trophic function of other basal resources (epilithic microalgae and SPOM), the isotopic similarity of basal resources between the artificial and natural sites can be an important restoration assessment when recovery of an artificial kelp bed is relatively high compared to the ecological level of a natural bed.

In general, the isotopic signatures of consumer species vary considerably with functional feeding strategies rather than taxonomic groups and/or habitats; the same feeding type among consumers is likely to be reflected in isotopic similarities [46,47]. In our study, at both the artificial and natural sites, macrobenthic consumers exhibited similar isotopic ranges within feeding groups; suspension feeders and carnivores generally had the lowest δ^{13} C and highest δ^{15} N values, respectively. However, the overall δ^{13} C value of consumers in the same feeding groups, except for the carnivorous group, showed wide ranges at both sites. The $\delta^{13}C$ ranges of suspension feeders were almost consistent between the artificial and natural sites and exhibited a wide range, from -20.8 to -16.1 and from -20.6 to -16.8, respectively, with overlapping isotopic values of SPOM as a pelagic source. This likely reflects the fact that suspension feeders at both sites use other ¹³C-enriched organic matter sources (e.g., macroalgae and epilithic microalgae) and phytoplankton-derived organic matter or a mixture of sources. In addition, selective (bivalves and gastropods) and nonselective feeding (ascidians and sponges) mechanisms of suspension feeders can affect their broad isotopic range [23,46,48]. Similarly, the δ^{13} C ranges for the groups of herbivores and deposit feeders were relatively wide compared to those of the macroalgae and epilithic microalgae as benthic sources, with the largest differences between their minimum and maximum mean values. These results suggest that consumers ultimately use more organic matter derived from diverse primary producers rather than the collected organic matter sources. Some studies have reported broad ranges of δ^{13} C for macroalgae of diverse species in the eastern coasts of the Korean peninsula [23,24]. Therefore, such wide δ^{13} C ranges of primary producers (suspension feeders, herbivores, and deposit feeders) at both the artificial and natural sites likely reflect their direct or indirect consumption of a variety of primary producers and/or their mixed organic matter, suggesting the similarity of the trophic structure between the restored and natural habitats associated with the trophic function of primary producers, in terms of carbon flow, within the natural macroalgal system.

Omnivores at the artificial and natural sites exhibited a relatively wide range of δ^{13} C ranges among species (-17.7 to -12.5 and -21.3 to -10.2, respectively), suggesting a feeding plasticity that utilizes the most easily accessible nutritional sources across sites [18,49]. The omnivore groups comprising the taxonomic diversity of invertebrate species at both the sites are characterized by opportunistic feeders resulting in their wide range of δ^{13} C values, suggesting the consumption of both benthic and pelagic prey items as nutritional sources. In contrast, carnivores at both artificial and natural sites showed relatively narrow isotopic ranges (-18.0 to -16.9 and -17.0 to -14.0 for δ^{13} C; 9.3 to 10.5 and 9.9 to 11.4 for δ^{15} N, respectively) compared to the other feeding groups. The carnivore groups at both the sites consist of gastropods and polychaetes, known as top predators on rocky reef communities [18,23,50]. Such isotopic ranges of carnivores indicate that they mainly fed on invertebrates linked to the benthic-derived organic matter (macroalgae and epilithic microalgae) rather than pelagic-derived organic matter. Moreover, the relatively low isotopic enrichments of carnivores compared to the primary consumer groups may be related to the trophic redundancy caused by the major consumption of similar prey items

as the low trophic level consumers, and this phenomenon has been previously reported in kelp bed ecosystems [5,51,52].

The isotopic niche indices quantify the trophic diversity or redundancy of consumer species based on evaluating the degree of dietary niche overlap [35,53]. In our study, the isotopic characteristics exhibited by different functional feeding groups were similarly reflected by the isotopic niche indices estimated from the consumer's isotope values. For the herbivore group, the high niche overlap (70%) with wide and similar TA and SEAc values of the artificial and natural sites clearly suggests similar diversified trophic pathways based on macroalgal production at the sites [54,55]. The degree of isotopic niche overlap exceeding 60% is generally considered to be indicative of high dietary similarity or overlap among consumer species [56]. Furthermore, the other feeding groups had relatively high niche indices at the artificial site compared to those at the natural site, suggesting that the deployment of AMRs can play critical ecological roles on the trophic structure as complex as those at the natural kelp bed [18,23].

Relatively narrow isotopic ranges and niche indices of all feeding groups at the barren site compared to those at the artificial and natural sites may be closely related to a simple trophic pathway caused by being free of macroalgae. Given the isotopic ranges of the feeding groups at the barren site, the trophic structure was likely established by the major contribution of pelagic sources (i.e., SPOM) for suspension feeders and benthic sources (i.e., epilithic microalgae) for herbivores to higher trophic levels. Some herbivores and suspension feeders at the barren site had relatively enriched-¹³C and -¹⁵N values, suggesting a high availability of macroalgal-derived organic matter as drifting algae to the nutrition of primary consumers, even on the barren ground [23,57]. Nevertheless, the food web similarity observed between the artificial and natural sites, as discussed above, indicated the trophic importance of macroalgal-derived organic matter as nutritional sources for macrobenthic consumers, resulting in increased trophic diversity by their wider isotopic niche indices in the artificial and natural kelp beds.

In conclusion, our results demonstrated the important ecological function of AMRs in terms of supporting the macrobenthic food web structure, as shown by the high level of trophic complexity due to the similarity between resource diversity and resource use by consumers in the natural kelp bed. Our isotopic data showed the very similar, or relatively high, trophic niches of feeding groups at the artificial site compared to those at the natural site, indicating that the artificial kelp bed created by the development of AMRs can exhibit similar ecological functions and services as a natural counterpart. In addition, the present study revealed that the isotopic ranges and niche indices of the feeding groups were wider at the artificial and natural kelp beds than those at the barren site, suggesting the trophic importance of macroalgal-derived organic matter to consumer nutrition in coastal ecosystems. Although we did not compare the succession processes of the macroinvertebrate community during recovery after the development of AMRs, our results support the conclusion that the creation of an *Eisenia bicyclis* kelp bed by the AMRs may result in the restoration success of a macroalgal habitat through the recovery of an ecological function of the natural food web structure [45,58,59]. Further studies on the succession of epibenthic community composition by regular post-restoration monitoring, in addition to considering the ecological structure and function in natural macroalgal ecosystems, are needed to better understand habitat restoration for successful coastal management.

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References

- 1. Bender, D.J.; Contreras, T.A.; Fahrig, L. Habitat loss and population decline: A meta-analysis of the patch size effect. *Ecology* **1998**, 79, 517–533. [CrossRef]
- 2. Airoldi, L.; Beck, W.M. Loss, status and trends for coastal marine habitats of Europe. *Oceanogr. Mar. Biol. Annu. Rev.* 2007, 45, 345–405.
- Gedan, K.B.; Silliman, B.R.; Bertness, M.D. Centuries of human-driven change in salt marsh ecosystems. *Annu. Rev. Mar. Sci.* 2009, 1, 117–141. [CrossRef]
- 4. Steneck, R.S.; Graham, M.H.; Bourque, B.J.; Corbett, D.; Erlandson, J.M.; Estes, J.A.; Tegner, M.J. Kelp forest ecosystems: Biodiversity, stability, resilience and future. *Environ. Conserv.* **2002**, *29*, 436–459. [CrossRef]
- 5. Bode, A.; Alvarez-Ossorio, M.T.; Varela, M. Phytoplankton and macrophyte contributions to littoral food webs in the Galician upwelling estimated from stable isotopes. *Mar. Ecol. Prog. Ser.* **2006**, *318*, 89–102. [CrossRef]
- Fulton, C.J.; Berkström, C.; Wilson, S.K.; Abesamis, R.A.; Bradley, M.; Åkerlund, C.; Barrett, L.T.; Bucol, A.A.; Chacin, D.H.; Chong-Seng, K.M. Macroalgal meadow habitats support fish and fisheries in diverse tropical seascapes. *Fish Fish.* 2020, 21, 700–717.
 [CrossRef]
- 7. Seaman, W. Artificial habitats and the restoration of degraded marine ecosystems and fisheries. *Hydrobiologia* **2007**, *580*, 143–155. [CrossRef]
- 8. Caselle, J.E.; Rassweiler, A.; Hamilton, S.L.; Warner, R.R. Recovery trajectories of kelp forest animals are rapid yet spatially variable across a network of temperate marine protected areas. *Sci. Rep.* **2015**, *5*, 14102. [CrossRef]
- 9. Reed, D.C.; Schroeter, S.C.; Huang, D.; Anderson, T.W.; Ambrose, R.F. Quantitative assessment of different artificial reef designs in mitigating losses to kelp forest fishes. *Bull. Mar. Sci.* 2006, *78*, 133–150.
- 10. Campos, L.; Ortiz, M.; Rodríguez-Zaragoza, F.A.; Oses, R. Macrobenthic community establishment on artificial reefs with *Macrocystis pyrifera* over barren-ground and soft-bottom habitats. *Glob. Ecol. Conserv.* **2020**, *23*, e01184. [CrossRef]
- Tsiamis, K.; Salomidi, M.; Gerakaris, V.; Mogg, A.; Porter, E.; Sayer, M.; Küpper, F. Macroalgal vegetation on a north European artificial reef (Loch Linnhe, Scotland): Biodiversity, community types and role of abiotic factors. *J. Appl. Phycol.* 2020, *32*, 1353–1363. [CrossRef]
- 12. Jung, S.; Chau, T.V.; Kim, M.; Na, W.-B. Artificial seaweed reefs that support the establishment of submerged aquatic vegetation beds and facilitate ocean macroalgal afforestation: A review. *J. Mar. Sci. Eng.* **2022**, *10*, 1184. [CrossRef]
- 13. Choi, C.G.; Takeuchi, Y.; Terawaki, T.; Serisawa, Y.; Ohno, M.; Sohn, C.H. Ecology of seaweed beds on two types of artificial reef. *J. Appl. Phycol.* **2002**, *14*, 343–349. [CrossRef]
- 14. Endo, H.; Nishigaki, T.; Yamamoto, K.; Takeno, K. Subtidal macroalgal succession and competition between the annual, *Sargassum horneri*, and the perennials, *Sargassum patens* and *Sargassum piluliferum*, on an artificial reef in Wakasa Bay, Japan. *Fish. Sci.* **2019**, *85*, 61–69. [CrossRef]
- 15. Graham, M.H. Effects of local deforestation on the diversity and structure of southern California giant kelp forest food webs. *Ecosystems* **2004**, *7*, 341–357. [CrossRef]
- 16. Boaventura, D.; Moura, A.; Leitao, F.; Carvalho, S.; Curdia, J.; Pereira, P.; Fonseca, L.C.D.; Santos, M.N.D.; Monteiro, C.C. Macrobenthic colonisation of artificial reefs on the southern coast of Portugal (Ancão, Algarve). *Mar. Biodivers.* **2006**, 335–343.
- 17. Santos, M.N.; Monteiro, C.C. A fourteen-year overview of the fish assemblages and yield of the two oldest Algarve artificial reefs (southern Portugal). *Hydrobiologia* **2007**, *580*, 225–231. [CrossRef]
- 18. Kang, H.Y.; Lee, B.-G.; Park, H.J.; Yun, S.-G.; Kang, C.-K. Trophic structures of artificial reef communities off the southern coast of the Korean peninsula as determined using stable isotope analyses. *Mar. Pollut. Bull.* **2021**, *169*, 112474. [CrossRef]
- 19. Park, H.J.; Park, T.H.; Kang, H.Y.; Lee, K.-S.; Kim, Y.K.; Kang, C.-K. Assessment of restoration success in a transplanted seagrass bed based on isotopic niche metrics. *Ecol. Eng.* **2021**, *166*, 106239. [CrossRef]
- Dunton, K.; Schell, D. Dependence of consumers on macroalgal (*Laminaria solidungula*) carbon in an arctic kelp community: δ¹³C evidence. *Mar. Biol.* 1987, 93, 615–625. [CrossRef]
- Jennings, S.; Reñones, O.; Morales-Nin, B.; Polunin, N.V.; Moranta, J.; Coll, J. Spatial variation in the ¹⁵N and ¹³C stable isotope composition of plants, invertebrates and fishes on Mediterranean reefs: Implications for the study of trophic pathways. *Mar. Ecol. Prog. Ser.* **1997**, *146*, 109–116. [CrossRef]
- 22. Layton, C.; Shelamoff, V.; Cameron, M.J.; Tatsumi, M.; Wright, J.T.; Johnson, C.R. Resilience and stability of kelp forests: The importance of patch dynamics and environment-engineer feedbacks. *PLoS ONE* **2019**, *14*, e0210220. [CrossRef]
- 23. Kang, C.K.; Choy, E.J.; Son, Y.; Lee, J.Y.; Kim, J.K.; Kim, Y.; Lee, K.S. Food web structure of a restored macroalgal bed in the eastern Korean peninsula determined by C and N stable isotope analyses. *Mar. Biol.* **2008**, *153*, 1181–1198. [CrossRef]
- 24. Kim, M.J.; Yun, H.Y.; Shin, K.-H.; Kim, J.H. Evaluation of food web structure and complexity in the process of kelp bed recovery using stable isotope analysis. *Front. Mar. Sci.* 2022, *9*, 885676. [CrossRef]

- Fry, B.; Sherr, E.B. δ¹³C measurements as indicators of carbon flow in marine and freshwater ecosystems. *Contrib. Mar. Sci.* 1984, 27, 13–47.
- Bearhop, S.; Adams, C.E.; Waldron, S.; Fuller, R.A.; Macleod, H. Determining trophic niche width: A novel approach using stable isotope analysis. J. Anim. Ecol. 2004, 73, 1007–1012. [CrossRef]
- Boecklen, W.J.; Yarnes, C.T.; Cook, B.A.; James, A.C. On the use of stable isotopes in trophic ecology. *Annu. Rev. Ecol. Evol. Syst.* 2011, 42, 411–440. [CrossRef]
- 28. Layman, C.A.; Araujo, M.S.; Boucek, R.; Hammerschlag-Peyer, C.M.; Harrison, E.; Jud, Z.R.; Post, D.M. Applying stable isotopes to examine food-web structure: An overview of analytical tools. *Biol. Rev.* **2012**, *87*, 545–562. [CrossRef]
- 29. Peterson, B.J.; Fry, B. Stable isotopes in ecosystem studies. Annu. Rev. Ecol. Syst. 1987, 18, 293–320. [CrossRef]
- Post, D.M. Using stable isotopes to estimate trophic position: Models, methods, and assumptions. *Ecology* 2002, *83*, 703–718. [CrossRef]
- Wozniak, A.S.; Roman, C.T.; Wainright, S.C.; McKinney, R.A.; James-Pirri, M.J. Monitoring food web changes in tide-restored salt marshes: A carbon stable isotope approach. *Estuar. Coast.* 2006, 29, 568–578. [CrossRef]
- 32. Eger, A.M.; Marzinelli, E.M.; Christie, H.; Fagerli, C.W.; Fujita, D.; Gonzalez, A.P.; Hong, S.W.; Kim, J.H.; Lee, L.C.; McHugh, T.A. Global kelp forest restoration: Past lessons, present status, and future directions. *Biol. Rev.* **2022**, *97*, 1449–1475. [CrossRef]
- Anderson, M.J.; Clarke, K.R.; Gorley, R.N. PERMANOVA+ for Primer: Guide to Software and Statistical Methods; University of Auckland and PRIMER-E Ltd.: Plymouth, UK, 2008.
- Jackson, A.L.; Inger, R.; Parnell, A.C.; Bearhop, S. Comparing isotopic niche widths among and within communities: SIBER–Stable Isotope Bayesian Ellipses in R. J. Anim. Ecol. 2011, 80, 595–602. [CrossRef]
- Layman, C.A.; Arrington, D.A.; Montaña, C.G.; Post, D.M. Can stable isotope ratios provide for community-wide measures of trophic structure? *Ecology* 2007, *88*, 42–48. [CrossRef] [PubMed]
- Catry, T.; Lourenco, P.M.; Lopes, R.J.; Carneiro, C.; Alves, J.A.; Costa, J.; Rguibi-Idrissi, H.; Bearhop, S.; Piersma, T.; Granadeiro, J.P. Structure and functioning of intertidal food webs along an avian flyway: A comparative approach using stable isotopes. *Funct. Ecol.* 2016, *30*, 468–478. [CrossRef]
- 37. Rooney, N.; McCann, K.S.; Moore, J.C. A landscape theory for food web architecture. Ecol. Lett. 2008, 11, 867–881. [CrossRef]
- Taormina, B.; Claquin, P.; Vivier, B.; Navon, M.; Pezy, J.-P.; Raoux, A.; Dauvin, J.-C. A review of methods and indicators used to evaluate the ecological modifications generated by artificial structures on marine ecosystems. *J. Environ. Manag.* 2022, 310, 114646. [CrossRef] [PubMed]
- van Katwijk, M.M.; Thorhaug, A.; Marbà, N.; Orth, R.J.; Duarte, C.M.; Kendrick, G.A.; Althuizen, I.H.J.; Balestri, E.; Bernard, G.; Cambridge, M.L.; et al. Global analysis of seagrass restoration: The importance of large-scale planting. *J. Appl. Ecol.* 2016, 53, 567–578. [CrossRef]
- 40. Wortley, L.; Hero, J.M.; Howes, M. Evaluating ecological restoration success: A review of the literature. *Restor. Ecol.* 2013, 21, 537–543. [CrossRef]
- Vander Zanden, M.J.; Olden, J.D.; Gratton, C. Food-web approaches in restoration ecology. In *Foundations of Restoration Ecology*; Falk, D.A., Palmer, M., Zedler, J., Eds.; Island Press: Washington, DC, USA, 2006; pp. 165–189.
- Park, H.J.; Kwak, J.H.; Kang, H.Y.; Kwon, K.-Y.; Lim, W.; Kang, C.-K. Incorporation of *Cochlodinium* bloom-derived organic matter into a temperate subtidal macrobenthic food web as traced by stable isotopes. *Mar. Pollut. Bull.* 2020, 154, 111053. [CrossRef] [PubMed]
- 43. Kang, H.Y.; Lee, Y.-J.; Kim, C.; Kim, D.; Kim, D.-H.; Kim, J.-H.; Choi, D.-L.; Kang, C.-K. Food web trophic structure at marine ranch sites off the East coast of Korea. *Front. Mar. Sci.* **2021**, *8*, 653281. [CrossRef]
- 44. Shin, D.; Park, T.H.; Lee, C.I.; Jeong, J.M.; Lee, S.-J.; Kang, S.; Park, H.J. Trophic ecology of largehead hairtail *Trichiurus japonicus* in the South Sea of Korea revealed by stable isotope and stomach content analyses. *Front. Mar. Sci.* **2022**, *9*, 910436. [CrossRef]
- James, W.R.; Lesser, J.S.; Litvin, S.Y.; Nelson, J.A. Assessment of food web recovery following restoration using resource niche metrics. *Sci. Total Environ.* 2020, 711, 134801. [CrossRef] [PubMed]
- 46. Grall, J.; Le Loc'h, F.; Guyonnet, B.; Riera, P. Community structure and food web based on stable isotopes (δ¹⁵N and δ¹³C) analysis of a North Eastern Atlantic maerl bed. *J. Exp. Mar. Biol. Ecol.* **2006**, *338*, 1–15. [CrossRef]
- Park, H.J.; Han, E.; Lee, W.C.; Kwak, J.H.; Kim, H.C.; Park, M.S.; Kang, C.-K. Trophic structure in a pilot system for the integrated multi-trophic aquaculture off the east coast of Korean peninsula as determined by stable isotopes. *Mar. Pollut. Bull.* 2015, 95, 207–214. [CrossRef] [PubMed]
- 48. Petersen, J.K. Ascidian suspension feeding. J. Exp. Mar. Biol. Ecol. 2007, 342, 127–137. [CrossRef]
- 49. Rezek, R.J.; Lebreton, B.; Roark, E.B.; Palmer, T.A.; Pollack, J.B. How does a restored oyster reef develop? An assessment based on stable isotopes and community metrics. *Mar. Biol.* **2017**, *164*, 54. [CrossRef]
- 50. Ruppert, E.; Fox, R.; Barnes, R. Invertebrate Zoology, 7th ed.; Brooks/Cole Thompson Learning: Belmont, CA, USA, 2004.
- Kaehler, S.; Pakhomov, E.; McQuaid, C. Trophic structure of the marine food web at the Prince Edward Islands (Southern Ocean) determined by δ¹³C and δ¹⁵N analysis. *Mar. Ecol. Prog. Ser.* 2000, 208, 13–20. [CrossRef]
- Fredriksen, S. Food web studies in a Norwegian kelp forest based on stable isotope (δ¹³C and δ¹⁵N) analysis. *Mar. Ecol. Prog. Ser.* 2003, 260, 71–81. [CrossRef]
- Newsome, S.D.; Martinez del Rio, C.; Bearhop, S.; Phillips, D.L. A niche for isotopic ecology. Front. Ecol. Environ. 2007, 5, 429–436. [CrossRef]

- 54. Rigolet, C.; Thiébaut, E.; Brind'Amour, A.; Dubois, S.F. Investigating isotopic functional indices to reveal changes in the structure and functioning of benthic communities. *Funct. Ecol.* **2015**, *29*, 1350–1360. [CrossRef]
- 55. Quillien, N.; Nordström, M.C.; Schaal, G.; Bonsdorff, E.; Grall, J. Opportunistic basal resource simplifies food web structure and functioning of a highly dynamic marine environment. *J. Exp. Mar. Biol. Ecol.* **2016**, 477, 92–102. [CrossRef]
- Guzzo, M.M.; Haffner, G.D.; Legler, N.D.; Rush, S.A.; Fisk, A.T. Fifty years later: Trophic ecology and niche overlap of a native and non-indigenous fish species in the western basin of Lake Erie. *Biol. Invasions* 2013, 15, 1695–1711. [CrossRef]
- 57. Bustamante, R.H.; Branch, G.M. The dependence of intertidal consumers on kelp-derived organic matter on the west coast of South Africa. J. Exp. Mar. Biol. Ecol. 1996, 196, 1–28. [CrossRef]
- 58. Moseman, S.M.; Levin, L.A.; Currin, C.; Forder, C. Colonization, succession, and nutrition of macrobenthic assemblages in a restored wetland at Tijuana Estuary, California. *Estuar. Coast. Shelf Sci.* **2004**, *60*, 755–770. [CrossRef]
- 59. Nordström, M.C.; Demopoulos, A.W.J.; Whitcraft, C.R.; Rismondo, A.; McMillan, P.; Gonzalez, J.P.; Levin, L.A. Food web heterogeneity and succession in created saltmarshes. *J. Appl. Ecol.* **2015**, *52*, 1343–1354. [CrossRef]

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