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ARTICLE

Artisanal Spearfishery in Temperate Nearshore Ecosystems of Chile: Exploring the Catch Composition, Revenue, and Management Needs

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Abstract
We used extensive field data on catch and effort as well as fisher interviews to characterize the catch composition and revenue associated with the unregulated artisanal spearfishery in Chile (18–33°S). Sampling was performed on commercial spearfishing trips (snorkel and hookah diving gear) between spring 2010 and summer 2011. Two-way crossed ANOVA showed significant effects of region (latitude) and dive gear on fishery variables such as biomass CPUE ($CPUE_b$), numeric CPUE ($CPUE_n$), catch species richness, fishing depth, cost, and income. Catches included 22 fish species from 15 families. Among the 23 species, 17 were associated with temperate rocky reef habitats: 14 carnivorous species, 2 omnivorous species, and 1 herbivorous species. Our results indicated that smaller, less-valuable rocky reef fishes (e.g., Peruvian Morwong *Cheilodactylus variegatus*, Chilean Sandperch *Pinguipes chilensis*, and Peruvian Rock

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Seabass *Paralabrax humeralis*) supported higher CPUE$_b$ and CPUE$_n$ than large, high-value, emblematic rocky reef species (e.g., Vieja *Graus nigra*, Galapagos Sheephead Wrasse *Semicossyphus darwini*, and Acha *Medialuna ancietae*). The CPUE$_b$ was significantly higher for hookah fishers than for snorkel fishers. Our results revealed that artisanal spearfishing activities provide important revenue for the fishers (2–3 times the minimum monthly wage in Chile), thereby incentivizing a rapid expansion of this unregulated fishery. Management options based on territorial user rights and catch and size restrictions are discussed in light of these findings.

Many studies have indicated concern over the detrimental effects of spearfishing on reef fish populations in temperate and tropical nearshore ecosystems (Bohnsack 1982; Sluka and Sullivan 1998; Lowry and Suthers 2004; Lloret et al. 2008; Januchowski-Hartley et al. 2011; Frisch et al. 2012; Lindfield et al. 2014). Despite the global popularity of spearfishing, information related to artisanal yield is scarce. Spearfishing catch and effort data are limited; when available, such data mostly refer to tropical reef spearfisheries (Meyer 2007; Chavarro et al. 2014). The scarcity of data—particularly of the type needed to estimate stock abundance, productivity trends, and heterogeneity in reef fishing effort—coupled with the high costs associated with the collection of data at meaningful scales has resulted in a distinct lack of management action in many countries where spearfishing is prevalent, thus increasing the risk of overfishing (Gillet and Moy 2006; Godoy et al. 2010).

Studies on the management of artisanal reef fisheries have shown that from an economic and environmental standpoint, catch information is a critically important input for management (Page 1998; Cinner et al. 2009; Chavarro et al. 2014; Leleu et al. 2014). Catch data facilitate an understanding of (1) the potential impacts of fishing activities on reef fish populations, and (2) the resources' importance for the livelihood of artisanal fishers and for the economy (Brewer et al. 2012).

In temperate nearshore ecosystems of Chile, artisanal spearfishing is an important component of the overall fishing effort in rocky reefs (Godoy et al. 2010). This fishery has operated for at least four decades without regulations on minimum size, sexual maturity, or reproductive periods (Godoy et al. 2010). Additionally, there are no gear or catch share regulations despite local awareness that effort has increased while landings have dramatically declined (Moreno 1972; Fuentes 1985; Pequeño and Olivera 2005; Godoy et al. 2010). Catch, CPUE, and revenue associated with the Chilean rocky reef spearfishery remain largely unknown.

To contribute to a better understanding of the Chilean artisanal spearfishery, we conducted catch surveys and fisher interviews aimed at examining the rocky reef fish catch composition and spearfishing cost and revenue. To characterize artisanal spearfishing activities, we specifically examined the number of species caught, biomass CPUE (CPUE$_b$), numeric CPUE (CPUE$_n$), effort (number of fishing trips per month), fishing depth, diving time, cost, and revenue. Mean CPUE$_b$ and CPUE$_n$ were obtained over a wide geographic scale, enabling us to explore the potential effects of latitude (administrative region) and diving gear (snorkel and hookah) on fishery variables by use of two-way crossed ANOVA. The overall aim of this study was to provide a baseline against which future changes can be quantified and to promote discussions about rocky reef fish management policies. Such policies are particularly timely for application to temperate ecosystems, which have recently been proposed as a new global hotspot for rocky reef fish diversity (Stuart-Smith et al. 2013).

METHODS

Research setting.—In Chile, artisanal spearfishers are part of the artisanal commercial diving fleet, which mainly targets shellfish resources (Bustamante and Castilla 1987). The artisanal spearfishery can operate (1) from deckless boats (powered by outboard engines) in which fishers use hookah diving equipment (hookah fishers), or (2) from the shore with snorkel diving gear (snorkel fishers). In Chile, hookah diving equipment is the most widely used, but the costs to enter the snorkel fishery are lower. The artisanal spearfishery operates along approximately 2,000 km of coastline, spanning more than 15° of latitude between the cities of Arica and Valparaíso (~18–33°S). Administratively, the country is divided into 15 regions (designated by Roman numerals), with regions XV and I–V roughly corresponding to the so-called North Zone (Figure 1). In general, artisanal fishers are entitled to operate only within the region where they are registered. The Chilean National Artisanal Fishery Registry (Registro Pesquero Artesanal [RPA]) shows that currently there are 2,978 registered active spearfishers based in about 115 artisanal landing ports known as "caletas" (sensu Castilla et al. 1998). In Chile, active fishers are those who declare their daily catches to the National Fisheries Service (Servicio Nacional de Pesca [SERNAPESCA]). Artisanal fishers obtain their catches from daily fishing trips. Currently, Chilean spearfishing operates in de facto open-access areas and has an RPA open to any fisher that wishes to target rocky reef fishes. Spearfishing can be sporadically allowed in areas that are designated as "management and exploitation areas for benthic resources," in which exclusive territorial user rights over benthic resources are assigned to fisher organizations. This type of extraction is uncommon and can only take place if an agreement is reached among fisher organization members.

The Chilean spearfishery targets a rocky reef fish assemblage that is endemic to the southern temperate Pacific Ocean (Ojeda et al. 2000; Pequeño 2000). The three largest and more emblematic rocky reef fishes include the Vieja *Graus nigra*, Galapagos Sheephead Wrasse (Pejeperro) *Semicossyphus darwini*, and Acha *Medialuna ancietae*.

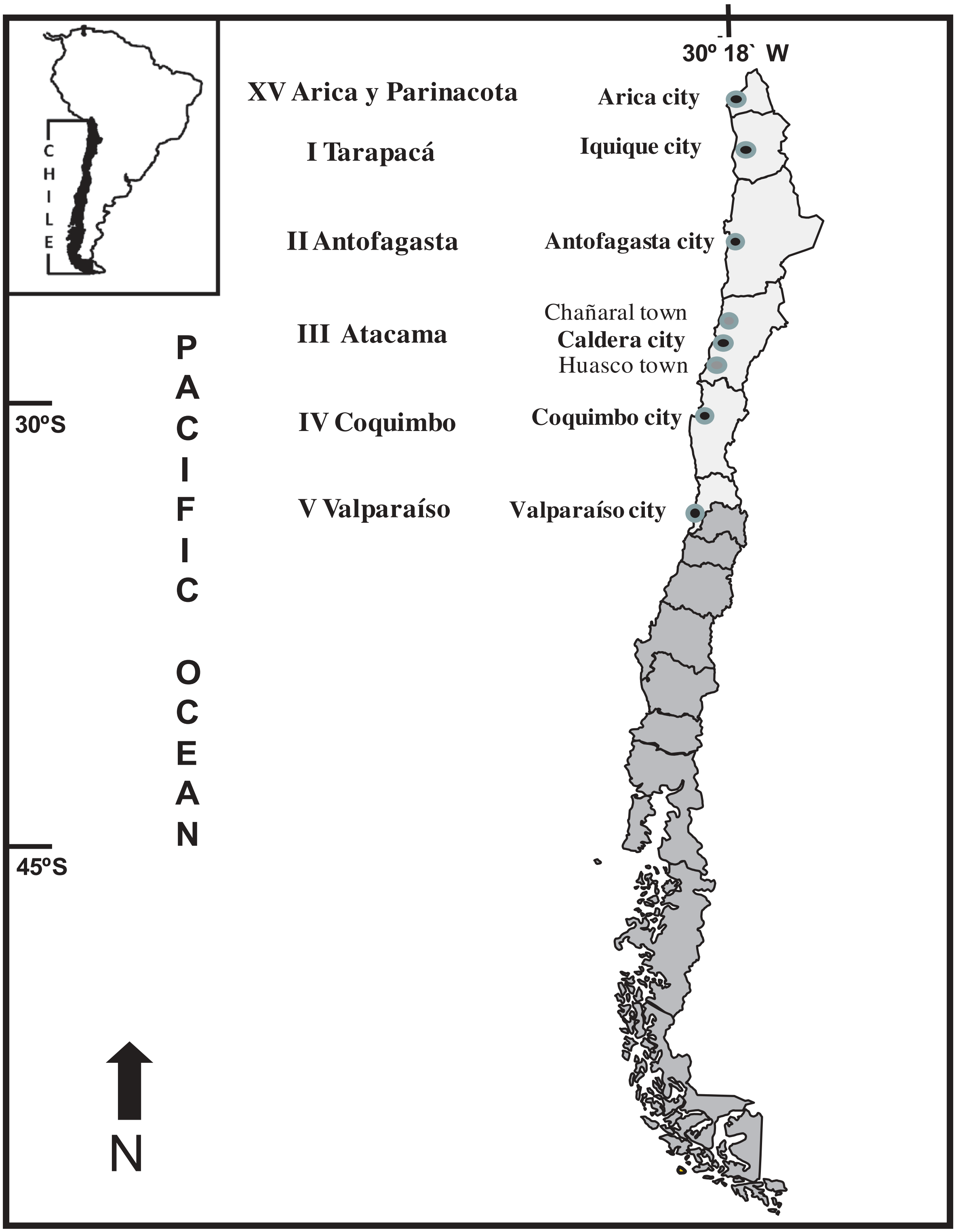

FIGURE 1. Map of the study area in northern Chile, showing the administrative regions (names preceded by Roman numerals) and cities or towns where sampling was conducted (black circles = cities; gray circles = towns).

Other, less-valuable rocky reef species include members of the families Cheilodactylidae, Serranidae, Aplodactylidae, and Pinguipedidae. Spearfishing activities are generally conducted in shallow water (<30 m depth) mostly over rocky bottoms that are dominated by kelp *Lessonia trabeculata* forest. The artisanal speargun is the main fishing gear, accounting for approximately 90% of the national landings of rocky reef fishes (SERNAPESCA 1998–2010).

Spearfishing operations on boats using hookah gear usually involve a crew of three people: the boat owner, the boat assistant, and the diver. Fishery revenues cover the cost of the fishing trip (gasoline and oil for the outboard motor and air compressor). The remaining revenues are divided among the crew members (40% to the boat owner, 40% to the diver, and 20% to the boat assistant). Snorkel spearfishing activities involve one to four fishers who travel to the fishing grounds by car or truck. Fuel costs for transport are equally divided among the spearfishers. On some occasions, the owner of the vehicle charges an additional monetary fee for transport.

Study area and sampling design.—This study covered 11 caletas and five coastal cities over a wide geographic range of northern Chile (~18–33°S), including six administrative regions (Figure 1). Sampling was completed between spring 2010 and summer 2011. Study sites were selected to encompass caletas with relatively high landings of rocky reef fishes (SERNAPESCA 1998–2010). Artisanal catch, effort (number of spearfishing trips per month), and revenue were recorded by a group of four field research assistants. Two teams simultaneously recorded the catches obtained by snorkel and hookah fishers. Data were collected over 2–3-week periods for each selected site. In some cases, the data collection period was extended to 4 weeks because ocean conditions prevented commercial spearfishing activities.

We focused our study on 11 caletas for hookah catch composition analysis: Caleta Camarones (near the city of Arica), Caleta Los Verdes (near the city of Iquique), Caleta Riquelme (Iquique), Caleta Coloso (city of Antofagasta), Caleta Constitución (near Antofagasta), Caleta Pan de Azúcar (near the town of Chañaral), Caleta Chañaral de Aceituno (near the town of Huasco), Caleta Hornos (near the city of Coquimbo), Caleta Los Choros (near Coquimbo), Caleta Algarrobo (near Valparaíso), and Caleta Maitencillo (near Valparaíso; Figure 1). Initially, we visited each caleta to explore the fishery system and to identify local active hookah spearfishers. Once the fishers were identified, we asked for written permission to conduct our assessments based on their catches. Data were obtained by using catch surveys and interviews that were conducted upon the hookah fishers' return from their fishing grounds to the caleta.

Snorkel fishers do not use the caletas as the center of their fishing activities. Therefore, we conducted research based in five cities: Iquique, Antofagasta, Caldera, Coquimbo, and Valparaiso (Figure 1). We identified artisanal snorkel fishers through the Federación Chilena de Deportes Subacuáticos (FEDESUB), since many of these commercial fishers also compete in recreational underwater championships. In Chile, there are approximately 600 registered recreational snorkel divers. We visited each regional association affiliated with FEDESUB and identified artisanal snorkel divers with the potential for inclusion in our study. Once we had identified them, we asked for written permission to examine their catches. Catch information was obtained by field assistants who accompanied the snorkel divers during their fishing trips.

In total, 200 artisanal spearfishing trips were sampled: 40 fishing trips (20 snorkel trips and 20 hookah trips) were sampled per region (Table 1). All spearfishing trips occurred in de facto open-access areas where fishing is allowed. Data from regions XV and I were merged for analysis due to the low number of samples in Region XV. The following variables were recorded: species richness of the catch, relative abundance, total weight of the catch, weight of each fish species, and fish SL (cm). Additionally, from fisher interviews, we recorded information on diving time (h), diving depth (m), and fishing effort (number of fishing trips per month). Biomass CPUE (CPUE_b) and numeric CPUE (CPUE_n) were calculated for all fishing trips as

$$\mathrm{CPUE}_b = W/T \tag{1}$$

and

$$\mathrm{CPUE}_n = N/T, \tag{2}$$

where W is the total landing weight (kg) per trip per fisher, N is the total number of fish per landing, and T is the total fishing time (h) associated with the landing. Mean CPUE_b and CPUE_n were also calculated separately for each fish species.

We recorded the market price and local demand for rocky reef fishes to characterize the revenue and costs associated with artisanal spearfishing activities. For each study site, we estimated the rocky reef fish price based on fisher interviews and local fish market visits. Artisanal spearfishing revenues (R_{spear}) were calculated for all fishing trips as

$$R_{\mathrm{spear}} = W \times P_{\mathrm{market}}, \tag{3}$$

where P_{market} is the local market price per kilogram of fish (US\$1 ≈ 500 Chilean pesos). Different rocky reef fish species typically have different market prices. In these cases, we estimated total income as

$$R_{\mathrm{spear}} = \sum\nolimits_{a=sp1}^{n} W_a P_a, \tag{4}$$

where W_a is the total weight of fish species a and P_a is the local market price of fish species a. For hookah fishers, we

TABLE 1. Number of hookah and snorkel fishing trips and number of fishers interviewed at each city or caleta (administrative regions XV and I were combined for analysis).

Region	City or caleta	Dive gear	Fishers	Number of fishing trips
XV. Arica y Parinacota	Caleta Camarones	Hookah	1	2
I. Tarapaca	Iquique	Snorkel	5	20
	Caleta Los Verdes	Hookah	3	12
	Caleta Riquelme	Hookah	2	6
II. Antofagasta	Antofagasta	Snorkel	4	20
	Caleta Coloso	Hookah	3	12
	Caleta Constitución	Hookah	2	8
III. Atacama	Caldera	Snorkel	5	20
	Caleta Pan de Azúcar	Hookah	3	12
	Caleta Chañaral de Aceituno	Hookah	2	8
IV. Coquimbo	Coquimbo	Snorkel	10	20
	Caleta Los Choros	Hookah	4	12
	Caleta Hornos	Hookah	4	8
V. Valparaíso	Valparaíso	Snorkel	5	20
	Caleta Maitencillo	Hookah	2	8
	Caleta Algarrobo	Hookah	3	12
Total			58	200

estimated the per capita income as 40% of the total income for the fishing trip (see Research Setting). We witnessed commercial transactions between spearfishers and middlemen, which allowed us to confirm the market prices declared by the fishers.

The costs associated with spearfishing activities were also estimated from interviews with fishers upon their return from fishing grounds. Artisanal spearfishing costs (C) were calculated for all landings by using the following equation for hookah fishing:

$$C_{\text{hookah}} = G_{\text{ob}} + G_{\text{ac}} + O_{\text{ob}}, \tag{5}$$

where G_{ob} is the gasoline cost for the outboard motor; G_{ac} is the gasoline cost for the air compressor; and O_{ob} is the oil cost for outboard motor. We assumed that for hookah fishers, the per capita costs were one-third of the total fishing trip costs. We estimated the snorkel fishers' cost as

$$C_{\text{snorkel}} = G_t + M_f, \tag{6}$$

where G_t is the cost of gasoline for the truck and M_f is the monetary fee for transport. In this study, the maintenance costs of vessels and vehicles were not considered. Local demand was estimated as the proportion of fishing trips for which the catches were sold to middlemen or to a restaurant directly by artisanal spearfishers. The entire database is available separately online (Supplementary Tables S.1–S.3).

Effects of latitude and gear on catch, effort, and revenue.— We used a two-way crossed ANOVA model to explore the potential effects of latitude (region) and dive gear on the following fishery variables: CPUE$_b$, CPUE$_n$, catch species richness, fishing depth (m), diving time (h/trip), number of fishing trips per month, cost per capita (US$ per trip), and gross income per capita (US$ per trip). The analysis was performed in R software (R Development Core Team, Vienna; Bates and Watts 1988), and the design included region (five levels) and diving gear (two levels) as fixed factors.

RESULTS

The spearfishing catch included 23 species from 15 families (Figure 2). Two species were associated with nearshore pelagic habitat (Yellowtail Jack *Seriola lalandi* and Corvina Drum *Cilus gilberti*), two were associated with sandy bottom habitat (Fine Flounder *Paralichthys adspersus* and Small-eye Flounder *Paralichthys microps*), two were associated with demersal habitat (Red Cusk-eel *Genypterus chilensis* and Pink Cusk-eel *Genypterus blacodes*), and 17 were associated with rocky reef habitat. The Yellowtail Jack, Corvina Drum, Peruvian Grunt *Anisotremus scapularis*, Acha, and Small-eye Flounder were exclusively caught by snorkel fishers. Catches included 14 carnivorous fish species, 2 omnivorous species (Sea Chub *Girella laevifrons* and Acha), and 1 herbivorous species (Jerguilla *Aplodactylus punctatus*).

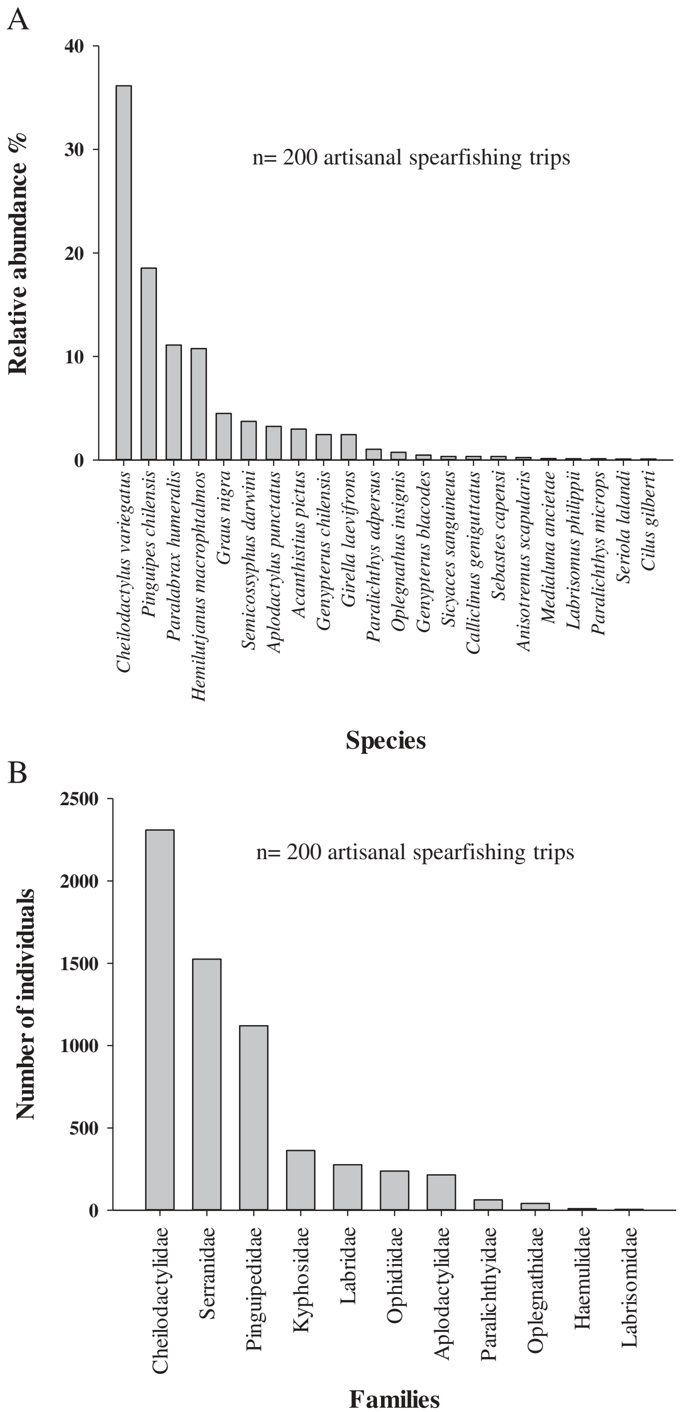

FIGURE 2. Relative abundances of **(A)** fish species (including the Yellowtail Jack *Seriola lalandi*, Corvina Drum *Cilus gilberti*, Chilean Clingfish *Sicyases sanguineus*, Tomoyos *Calliclinus geniguttatus*, and Cape Redfish *Sebastes capensis*; see Table 2 for common names of the remaining species) and **(B)** fish families targeted by artisanal spearfishers in Chile.

The CPUE$_n$ data revealed that three smaller rocky reef species (Peruvian Morwong *Cheilodactylus variegatus*, Chilean Sandperch *Pinguipes chilensis*, and Peruvian Rock Seabass *Paralabrax humeralis*) made up 50% of the total catch for both types of diving gear (Table 2). The three large, emblematic species (Vieja, Galapagos Sheephead Wrasse, and Acha) had low numeric representation in the catch (Figure 2; Table 2). Snorkel fishing obtained high CPUE$_b$ values for Peruvian Morwong, Chilean Sandperch, and Vieja. Hookah catch biomass had strong contributions from the Peruvian Morwong, Galapagos Sheephead Wrasse, and Vieja (Table 2).

Effects of Latitude and Gear on Catch, Effort, and Revenue

Two-way crossed ANOVA performed on the data set showed significant region and gear effects on CPUE$_b$ and CPUE$_n$ (Table 3). Our results also revealed that in general, hookah divers fished deeper and obtained higher CPUEs than snorkel divers (Figure 3A, B). Region and gear effects on CPUE$_n$ were significant for regions III, IV, and V (Figure 3B). Geographic patterns of the catch suggested a strong correspondence between CPUE$_b$ or CPUE$_n$ and the biogeographic distribution of targeted rocky reef fishes (Table 4). Our results showed higher CPUEs in northern regions for rocky reef fishes with a northerly distribution range, such as the Acha (18–20°S), Pacific Beakfish (~18–26°S), and Galapagos Sheephead Wrasse (~18–33°S). The CPUEs for rocky reef fishes with southern distributions extending to 40°S (e.g., Vieja and Chilean Sandperch) increased with latitude. The small, carnivorous Peruvian Morwong supported high CPUEs in most of the regions analyzed (Region III was the exception). The ANOVA showed significant region effects (regions II, III, IV, and V) on the species richness of the catch (Table 3; Figure 3C). Results also indicated significant effects of gear on diving depth (Table 3). Hookah fishers reached depths greater than those of snorkel fishers in all of the regions studied (Figure 3D). We detected no significant region or gear effects on diving time or the number of fishing trips per month (Table 3; Figure 3E, F). Fishing effort was similar among regions, averaging 15 d/month (Figure 3F).

The costs associated with hookah fishing included fuel and oil for the outboard motor and air compressor. The only cost associated with snorkel fishing was the fuel required for terrestrial transportation. The ANOVA demonstrated significant effects of region and gear on the cost of spearfishing trips (Table 3). Hookah fishing incurred greater costs than snorkel fishing in all of the regions studied. Regions II and III had significant effects on the cost of fishing trips (Figure 3G).

The data on local market prices for rocky reef fishes indicated that the commercial value of fish ranged between \$2.50 and \$6.00 per kilogram depending on the species (i.e., the large, emblematic species were worth more than the smaller species), and the average value was \$3 per kilogram. Region, gear, and the region × gear interaction had significant effects on gross income (Table 3). Higher gross incomes were recorded for hookah divers in northern regions (Figure 3H). Local buyers for rocky reef fishes were mainly middlemen and restaurants (Figure 3I).

TABLE 2. Composition of the catch obtained by artisanal snorkel and hookah spearfishers in Chile: average biomass CPUE ($CPUE_b$; kg·fisher^{-1}·trip^{-1}), numeric CPUE ($CPUE_n$; number of individuals·fisher^{-1}·trip^{-1}), fish SL, and total weight (SD in parentheses; NR = no record).

Fish species	$CPUE_b$		$CPUE_n$		Fish SL (cm)		Fish total weight (kg)	
	Snorkel	Hookah	Snorkel	Hookah	Snorkel	Hookah	Snorkel	Hookah
Vieja *Graus nigra*	3.56 (3.67)	7.93 (6.14)	1.38 (1.42)	2.4 (1.75)	48.12 (10.70)	57.64 (9.88)	2.73 (1.60)	4.04 (1.64)
Galapagos Sheephead Wrasse *Semicossyphus darwini*	1.97 (3.26)	9.50 (9.96)	0.6 (0.95)	3.62 (3.98)	50.71 (10.83)	47.86 (8.11)	2.93 (1.74)	2.04 (1.16)
Grape-eye Seabass *Hemilutjanus macrophthalmos*	3.04 (4.50)	7.13 (10.12)	2.7 (3.81)	8.2 (12.89)	38.19 (8.20)	29.36 (3.85)	1.12 (0.76)	0.56 (0.24)
Peruvian Morwong *Cheilodactylus variegatus*	6.45 (4.42)	15.46 (12.95)	9.59 (7.08)	22.54 (17.51)	34.08 (3.83)	32.89 (3.15)	0.67 (0.21)	0.56 (0.15)
Jerguilla *Aplodactylus punctatus*	0.62 (1.80)	1.55 (3.32)	0.71 (2.06)	2.18 (4.26)	35.17 (3.56)	37.11 (1.36)	0.77 (0.18)	0.78 (0.13)
Acha *Medialuna ancietae*	0.41 (1.65)	NR	0.1 (0.30)	NR	56.8 (16.09)	NR	4.5 (3.71)	NR
Pacific Beakfish *Oplegnathus insignis*	0.23 (0.78)	0.25 (1.99)	0.26 (0.81)	0.21 (1.49)	29.23 (4.7)	27.31 (6.98)	0.71 (0.31)	0.65 (0.21)
Brick Seabass *Acanthistius pictus*	1.38 (3.68)	1.28 (4.13)	1.12 (2.84)	1.37 (4.30)	36.00 (1.41)	39.04 (2.58)	0.89 (0.07)	1.08 (0.14)
Red Cusk-eel *Genypterus chilensis*	0.49 (1.91)	8.51 (10.85)	0.15 (0.53)	2.56 (3.20)	87.12 (28.74)	83.33 (22.98)	3.18 (2.05)	3.07 (1.64)
Pink Cusk-eel *Genypterus blacodes*	0.52 (2.01)	0.78 (3.29)	0.18 (0.75)	0.48 (2.49)	63.65 (10.45)	59.76 (19.89)	2.53 (1.08)	3.14 (0.89)
Peruvian Rock Seabass *Paralabrax humeralis*	3.77 (4.31)	3.68 (6.91)	4.92 (5.93)	5.72 (10.45)	39.53 (0.98)	37.56 (3.34)	0.98 (0.43)	0.81 (0.19)
Fine Flounder *Paralichthys adspersus*	0.73 (1.57)	1.26 (2.52)	0.44 (1.38)	0.39 (0.75)	56.57 (32.22)	70.80 (9.00)	2.2 (1.12)	2.9 (0.92)
Small-eye Flounder *Paralichthys microps*	0.13 (0.62)	NR	0.06 (0.23)	NR	50.18 (22.13)	NR	2.5 (0.98)	NR
Chilean Sandperch *Pinguipes chilensis*	4.51 (3.19)	7.18 (6.99)	5.61 (3.74)	9.92 (10.02)	38.48 (3.64)	34.67 (4.77)	0.79 (0.25)	0.55 (0.26)
Sea Chub *Girella laevifrons*	1.05 (2.65)	0.01 (0.13)	1.08 (2.56)	0.01 (0.1)	36.90 (2.05)	40.00 (1.63)	1.13 (0.21)	1.33 (0.28)
Peruvian Grunt *Anisotremus scapularis*	0.11 (0.33)	NR	0.2 (0.56)	NR	28.89 (6.87)	NR	0.87 (0.34)	NR
Tomoyos *Calliclinus geniguttatus*	0.09 (0.33)	NR	0.1 (0.36)	NR	27.74 (4.12)	NR	0.98 (0.56)	NR

TABLE 3. Results of two-way crossed ANOVA examining differences in biomass CPUE ($CPUE_b$; kg·fisher^{-1}·trip^{-1}), numeric CPUE ($CPUE_n$; number of individuals·fisher^{-1}·trip^{-1}), species richness of the catch, fishing depth (m), diving time (h/trip), number of fishing trips per month, cost (US$) per capita per trip, and gross income (US$) per capita per trip (SS = sum of squares; MS = mean square).

Source of variance	df	SS	MS	*F*	*P*
		$CPUE_b$			
Region (latitude)	4	21,254	5,314	26.26	<0.001
Gear	1	56,226	56,226	277.86	<0.001
Interaction (Region × Gear)	4	12,102	3,025	14.95	<0.001
Residual	190	38,447	202		
		$CPUE_n$			
Region	4	42,084	10,521	38.22	<0.001
Gear	1	46,208	46,208	167.87	<0.001
Interaction (Region × Gear)	4	20,023	5,006	18.18	<0.001
Residual	190	52,301	275		
		Catch species richness			
Region	4	102.53	25,633	16,020	<0.001
Gear	1	3.38	3,380	2,112	0.1478
Interaction (Region × Gear)	4	17.27	4,317	2,698	0.0321
Residual	190	304.00	1,600		
		Catch species richness			
Region	4	18	4	0.459	0.7655
Gear	1	3,987	3,987	412,230	<0.001
Interaction (Region × Gear)	4	80	20	2,058	0.0879
Residual	190	1,838	10		
		Diving time			
Region	4	9.27	2,317	2.42	0.0499
Gear	1	0.00	0.005	0.005	0.9425
Interaction (Region × Gear)	4	0.97	0.2425	0.253	0.9074
Residual	190	181.95	0.9576		
		Number of fishing trips per month			
Region	4	4,520	1,130	0.643	0.632
Gear	1	0.180	0.180	0.102	0.749
Interaction (Region × Gear)	4	2,120	0.530	0.302	0.877
Residual	190	333,800	1,757		
		Cost per capita per trip			
Region	4	2,624	656	17,689	<0.001
Gear	1	19,464	19,464	524,861	<0.001
Interaction (Region × Gear)	4	699	175	4,709	<0.005
Residual	190	7,046	37		
		Gross income per capita per trip			
Region	4	191,287	47,822	26.26	<0.001
Gear	1	506,035	506,035	277.86	<0.001
Interaction (Region × Gear)	4	108,916	27,229	14.95	<0.001
Residual	190	346,025	1,821		

DISCUSSION

In Chile, artisanal spearfishing activities targeted approximately 90% of the most common carnivorous and herbivorous rocky reef fish species that inhabit nearshore subtidal habitats. We found that artisanal spearfishers caught 17 rocky reef species from among the 19 fish species that have been described as occurring in *L. trabeculata* kelp forests (Perez-Matus et al. 2007). The *L. trabeculata* kelp ecosystems are among those most commonly found along northern and southern Chile (~20–40°S; Villouta and Santelices 1984) and represented the main habitat used as fishing grounds by artisanal spearfishers. Our results provide evidence that targeted fish

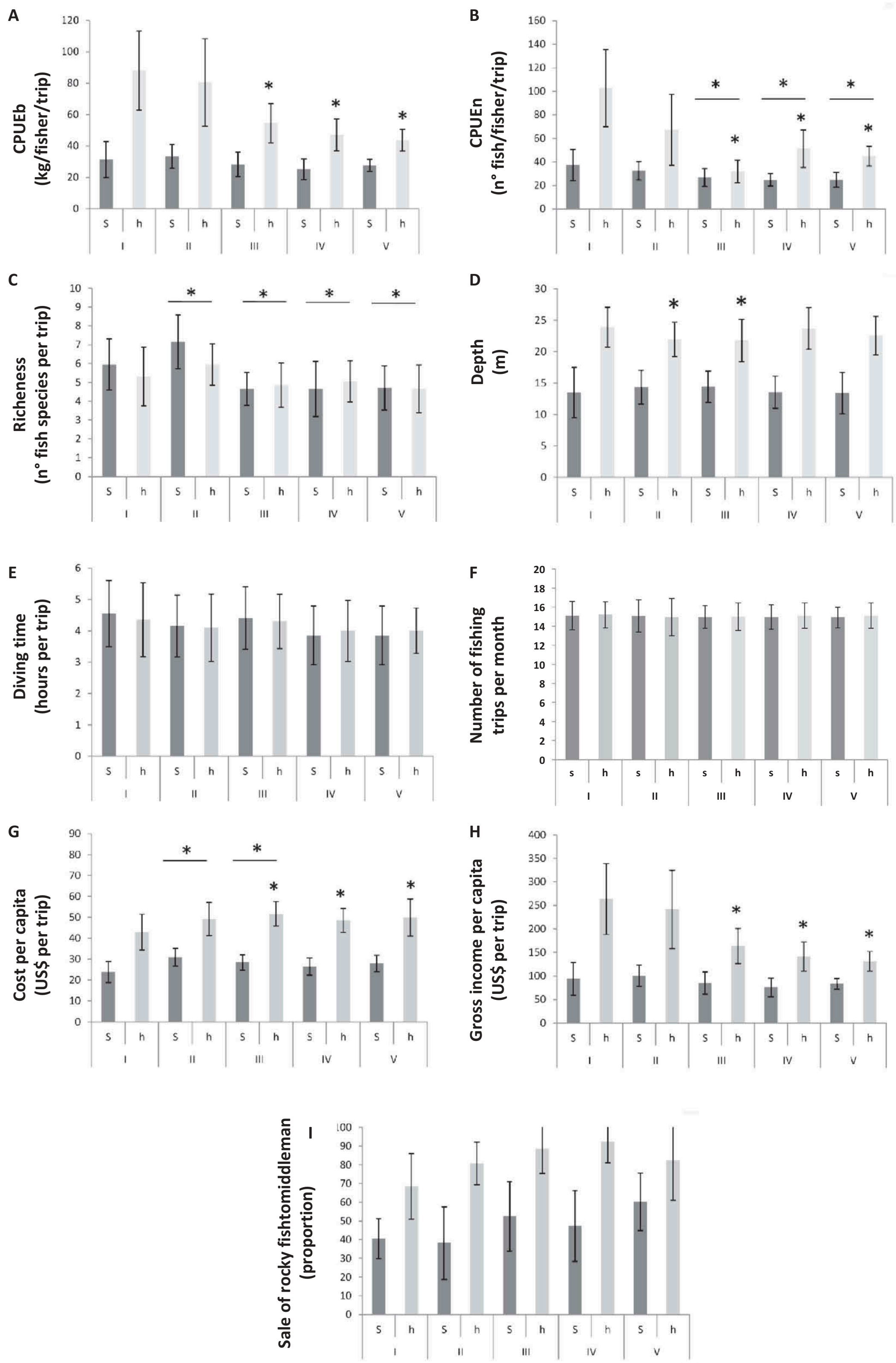

FIGURE 3. Catch, effort, and revenues from the artisanal spearfishery (s = snorkel; h = hookah) in Chile: **(A)** biomass CPUE (CPUE$_b$); **(B)** numeric CPUE (CPUE$_n$); **(C)** species richness of the catch; **(D)** diving depth; **(E)** diving time; **(F)** number of fishing trips per month; **(G)** cost per capita per trip; **(H)** gross income per capita per trip; **(I)** sale of rocky reef fish to middlemen (the remaining proportion was for sale at restaurants). Roman numerals indicate the administrative region (latitude). Values are means ± SD. Asterisks indicate significant effects of gear type ($P < 0.05$; region effects are indicated by asterisks above horizontal lines).

TABLE 4. Geographical patterns of catch composition in terms of average biomass CPUE ($CPUE_b$; kg·fisher^{-1}·trip^{-1}) and numeric CPUE ($CPUE_n$; number of individuals·fisher^{-1}·trip^{-1}) for artisanal spearfishers in northern Chile (SD in parentheses; NR = no record). Data are presented for administrative regions (see Table 1 for region names).

	Regions XV and I		Region II		Region III		Region IV		Region V	
Fish species	$CPUE_b$	$CPUE_n$	$CPUE_b$	$CPUE_n$	$CPUE_b$	$CPUE_n$	$CPUE_b$	$CPUE_n$	$CPUE_b$	$CPUE_n$
Vieja	3.54 (5.09)	1.47 (2.07)	5.97 (6.07)	2.1 (1.91)	7.90 (5.92)	2.3 (1.43)	5.58 (5.48)	1.7 (1.52)	5.77 (4.09)	1.87 (1.22)
Galapagos Sheephead Wrasse	5.41 (7.75)	2.17 (3.49)	9.59 (9.64)	3.52 (3.48)	10.08 (10.07)	3.95 (4.15)	2.59 (5.02)	0.62 (1.07)	1.00 (1.99)	0.27 (0.55)
Grape-eye Seabass	8.75 (12.32)	10.8 (15.87)	8.27 (8.82)	8 (11.23)	6.81 (5.86)	7.15 (5.61)	0.93 (1.51)	0.75 (1.03)	0.68 (1.28)	0.55 (0.98)
Peruvian Morwong	20.55 (16.20)	29.62 (21.42)	10.45 (10.28)	16.05 (14.68)	4.48 (4.30)	6.57 (6.28)	9.43 (6.10)	15.4 (9.35)	9.87 (3.82)	12.67 (5.07)
Jerguilla	0.48 (1.79)	0.75 (2.75)	NR	NR	0.25 (1.10)	0.22 (0.99)	2.09 (3.39)	2.72 (4.03)	2.63 (3.96)	3.52 (4.73)
Acha	0.58 (1.97)	0.15 (0.36)	0.45 (1.70)	0.1 (0.30)	NR	NR	NR	NR	NR	NR
Pacific Beakfish	0.95 (3.22)	0.92 (2.50)	0.27 (0.74)	0.25 (0.63)	NR	NR	NR	NR	NR	NR
Brick Seabass	4.29 (7.07)	4.2 (6.62)	2.35 (3.54)	1.92 (3.02)	0.02 (0.14)	0.02 (0.15)	NR	NR	NR	NR
Red Cusk-eel	3.74 (7.41)	1.2 (2.31)	6.88 (12.14)	1.5 (2.63)	5.49 (9.67)	2.17 (3.82)	3.92 (7.72)	1.12 (2.00)	2.47 (4.79)	0.77 (1.47)
Pink Cusk-eel	1.11 (2.79)	1.05 (3.76)	2.15 (5.12)	0.6 (1.49)	NR	NR	NR	NR	NR	NR
Peruvian Rock Seabass	8.42 (7.50)	13.05 (11.26)	7.21 (6.08)	10.5 (8.92)	0.89 (1.99)	1.05 (2.35)	1.05 (2.73)	1.07 (2.40)	1.08 (2.47)	0.92 (2.00)
Fine Flounder	0.42 (1.03)	0.55 (1.98)	0.95 (2.01)	0.32 (0.72)	0.92 (2.17)	0.27 (0.59)	1.25 (2.59)	0.47 (0.93)	1.43 (2.35)	0.45 (0.74)
Small-eye Flounder	0.14 (0.51)	0.1 (0.30)	0.07 (0.45)	0.025 (0.15)	NR	NR	NR	NR	0.11 (0.72)	0.02 (0.15)
Chilean Sandperch	2.42 (2.96)	3.12 (4.39)	2.69 (2.68)	4.5 (4.40)	4.24 (3.03)	5.2 (3.58)	8.36 (5.86)	13.02 (10.53)	11.52 (5.92)	12.9 (7.55)
Sea Chub	0.20 (1.18)	0.45 (2.68)	0.10 (0.41)	0.1 (0.37)	0.24 (1.08)	0.22 (0.91)	1.36 (3.49)	1.1 (2.44)	0.74 (1.79)	0.85 (1.81)
Peruvian Grunt	0.12 (0.33)	0.25 (0.63)	0.16 (0.40)	0.25 (0.63)	NR	NR	NR	NR	NR	NR
Tomoyos	0.15 (0.45)	0.12 (0.40)	0.07 (0.24)	0.12 (0.40)	NR	NR	NR	NR	NR	NR

species accounting for higher catches are vulnerable to spearfishing activities (Lowry and Suthers 2004). We suggest that artisanal spearfishing in Chile has the potential to affect the structure of subtidal temperate rocky reef ecosystems in a manner similar to that reported for other artisanal spearfisheries (Chavarro et al. 2014).

In the present study, rocky reef fishes such as the Peruvian Morwong, Chilean Sandperch, and Peruvian Rock Seabass supported higher $CPUE_b$ and $CPUE_n$ than the large, emblematic species—the Vieja, Galapagos Sheephead Wrasse, and Acha. These results are in close agreement with previous studies suggesting that overfishing can lead to a change in catch composition from large, emblematic rocky reef fish species to smaller species (Godoy et al. 2010; Godoy 2013). We recognize that our study was temporally limited and that our results might contain bias associated with seasonal changes. However, informal conversations with artisanal spearfishers during the study suggested that catch composition shows little seasonality.

Although we did not investigate the specific factors that lead people to engage in spearfishing as a livelihood strategy, our results indicate that artisanal spearfishing plays an important economic and social role for artisanal fishers whose income from benthic resources has been reduced due to market fluctuations and accessibility (Godoy et al. 2010). The prices paid by consumers (domestic, middlemen, and restaurants) showed that artisanal spearfishing is a profitable activity. We estimated that the average net revenue from spearfishing was $1,500 per month per fisher (based on gross income per trip = $137.38 ± 76.09 [mean ± SD]; cost per trip = $37 ± 12.24; and effort = 15.03 ± 1.41 fishing trips/month). Thus, revenues received by spearfishers were two to three times higher than the current minimum monthly wage in Chile (~$440 per month). The similarity in effort between regions is probably related to the similarity in environmental conditions across northern Chile and to the strategy used by fishers in deciding where to go diving. The strategy involves an assessment of ocean conditions and the exposure of fishing grounds. Fishers can optimize their workdays by prioritizing fishing efforts in exposed areas (which are generally more productive) when ocean conditions are good and to dive in more protected coves when ocean conditions are suboptimal (Godoy 2013).

Our results demonstrated that hookah fishers obtained higher $CPUE_b$ and $CPUE_n$ than snorkel fishers; this is probably due to the hookah fishers' diving autonomy and improved access to deeper habitat (Lindfield et al. 2014). Unfortunately, in Chile, there are no management regulations on the spearfishing gear or on the number and size of rocky reef fish species caught—despite awareness of scuba and hookah spearfishing's detrimental effects on reef fish populations and the wider ecosystem (Sadovy et al. 2003; Gillett and Moy 2006). Several of the rocky reef fishes recorded in Chilean spearfishing catches are particularly vulnerable to spearfishing exploitation due to such attributes as endemicity, slow growth, residency, and sex change (e.g., Lowry and Suthers 1998; Topping et al. 2005, 2006).

Our results allowed us to compare current $CPUE_b$ with historical records on Galapagos Sheephead Wrasse catch within Region I in northern Chile. Fuentes (1985) reported that the Galapagos Sheephead Wrasse $CPUE_b$ for snorkel divers ranged between 10 and 15 $kg \cdot fisher^{-1} \cdot h^{-1}$, whereas our estimate of $CPUE_b$ for this species was 1.17 $kg \cdot fisher^{-1} \cdot h^{-1}$. This pattern is consistent with the historical decline in landings of Galapagos Sheephead Wrasse (SERNAPESCA 1998–2010; Godoy et al. 2010; Godoy 2013).

Management of reef fish species at appropriate spatial scales has been proposed as a critical element of success (Gunderson et al. 2008). One possibility for initiating the management of rocky reef fish species at small spatial scales in Chile builds upon fishery legislation passed in 1991, which enables fishing organizations to apply for exclusive "territorial user rights for fisheries" (TURFs) in well-defined inshore coastal areas (Castilla 1994). Protection of benthic resources within TURFs has conservation effects in addition to benefits for fish species richness and abundance (Gelcich et al. 2008, 2012). The hundreds of established TURFs in Chile have the potential to provide conservation benefits for rocky reef fishes. We suggest that the inclusion of these species into TURF management plans would represent an important step toward sustainability while biological regulations (e.g., catch limits, size limits, and/or reproductive season bans) are negotiated. We hope that the information and warning signals reported herein may trigger and support the necessary policy discussions leading to the regulation of commercial spearfishing activities.

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