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Comparative feeding ecology of two fish species bluestripe herring, *Herklotsichthys quadrimaculatus* Ruppel (Clupeidae) and big eye scad, *Selar crumenophthalmus* Bloch (Clupeidae) caught in the stilt fishery in southern Sri Lanka

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Abstract
The dietary habits and food resources partitioning of *H. quadrimaculatus* and *S. crumenophthalmus* caught by stilt fishing in southern Sri Lanka were studied. Food particles found in the gut contents of 112 specimens of *H. quadrimaculatus* and 166 specimens of *S. crumenophthalmus* were identified. Different food categories were sorted by taxonomic groups to calculate food electivity, overlap, trophic niche breadth and food preference of each fish species. *H. quadrimaculatus* fed on both phytoplankton and zooplankton while *S. crumenophthalmus* solely fed on zooplankton. Gut content of *H. quadrimaculatus* consisted of 46 food items and it preferred diatoms, dinoflagellates and calanoid copepods. *S. crumenophthalmus* preferred calanoid copepods, cyclopoid copepods and crustacean larvae (protozoea and nauplii) and it consumed 41 food items. Two fish species had low dietary overlap (16%) and their niche breadth was significantly different ($p < 0.05$). Therefore, these two fish species can aggregate with minimum competition for food and that may be one of the reasons for their seasonal congregation on shallow reef areas in the Southern coast of Sri Lanka.

Keywords: dietary overlap, niche breadth, tropic ecology, reef fishery

1. Introduction
Bluestripe herring (*Herklotsichthys quadrimaculatus*) is a short-lived tropical herring found in East Africa to Japan and throughout the western Indo-Pacific Oceans [19, 21, 30]. Big eye scad (*Selar crumenophthalmus*) is a small coastal pelagic fish, which is common in the tropical and subtropical belt of all oceans [16]. These two species often coexist (i.e. sympatric) in the shallow reef and shelf areas, where they likely share the same food resources. They are fished either for human consumption or as bait for tuna fishing [6, 11, 12, 24, 26]. Both species significantly contribute for subsistence and small commercial fisheries in all areas where they are relatively abundant and there is a potential to culture them in captivity [14].
Bluestripe herring and big eyed scad dominate the catch of still fishing which is a traditional artisanal fishing method practiced only in shallow coastal waters in Southern Sri Lanka. Fishermen sit on stilts planted on hard calcareous reef and practice pole-and-line fishing. Use of nets or any other means to catch migratory fishes in reef areas in Southern Sri Lanka have been forbidden by the law since 1912. Therefore, this unique fishing method offers a legal and socially acceptable way of catching fish. Stilt fishing season starts in October of a particular year and it lasts until July in the next year.
Seasonal migrations of small clupeid fishes in shallow waters has also been observed in Kaneohe Bay, Hawaii [32] and Reunion Island, southwest Indian Ocean [26]. These fish species migrate into coastal habitats during one or several parts of their life cycle [2] and it offers them protection against predation, substrates for spawning and generous food conditions [4-5]. These migrations are linked with the degree of dependence of these fish species on particular habitat and how it provides their biological requirements [31].
The growth and reproduction of *H. quadrimaculatus* and *S. crumenophthalmus* has been studied in number of oceanic areas including Indian and Pacific Oceans [6-18]. However, the comparative trophic ecology of *H. quadrimaculatus* and *S. crumenophthalmus* migrated into shallow coastal waters in the Indian Ocean has not been studied. The importance of the big eye scad and bluestripe herring in the food chain of coastal areas and the ability of these species to

use in aquaculture development prompted this study. It was hypothesized that the co-occurrence of these two fish species in the shallow coastal waters in Southern Sri Lanka was related to their different food preferences.

2. Materials and Methods

2.1 Sampling sites

The study was conducted at one of the stilt fishing sites at Talpe (5º 59`, 80º 24`) in the Galle district (Figure 1), Sri Lanka. The depth of water of the sampling site was 0.9 – 1.5m. Sampling site was weekly visited from March to May, 2014 to collect samples.

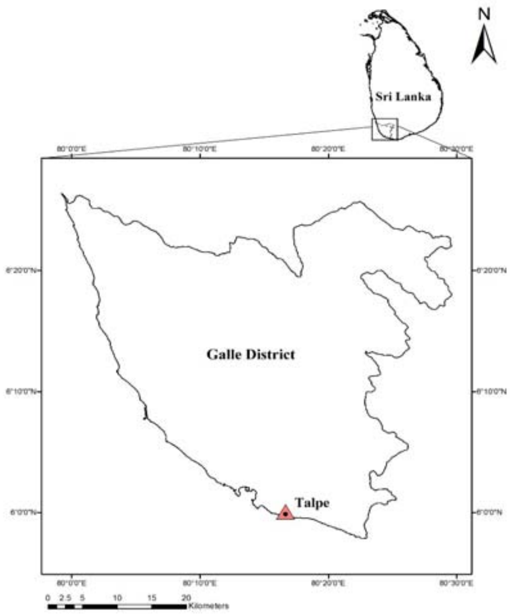


Fig. 1: Location of stilt fishing site at Galle district, Sri Lanka

2.2 Gut content analysis

According to preliminary observations gut fullness of fish was higher in the early morning hours and therefore all the samples were collected between 4.00 – 6.00hrs. Hundred and twelve specimens of *H. quadrimaculatus* and 166 specimens of *S. crumenophthalmus* caught by pole and line method were randomly selected for the study. Fish were immediately dissected and the entire gut from the esophagus to pylorus was preserved in 8% formalin in sea water. Total lengths of *H. quadrimaculatus* and *S. crumenophthalmus* varied between 9 – 12cm and 7 – 20cm, respectively. Evidence of regurgitation was not observed in any sampled fish.

Prey taxa were identified at least to genus (and to species where possible) and enumerated under binocular microscope using Sedgewick rafter cell. For prey counting, each individual was considered as an item, except for colonial organisms or algae, which were counted as one item per colony. Some parts of copepods and phytoplankton were decayed to the level that they could not be identified consistently to species or genus level. Those particles were recorded as unidentified copepod (UIC) and unidentified phytoplankton (UIP) particles. Two penaeid larval forms found in the fish guts were recorded as protozoea and nauplii.

2.3 Food overlap among fish species

The food overlap among fish species were calculated using of Schoener's [29] equation.

$$S = 1 - 0.5\ (\Sigma^{n}_{i=1}\ |\ P_{Xi} - P_{yi}\ |)$$

Here, S is the overlap of species x on species y. P_{Xi} is the proportion of the resource category i used by species x and P_{yi} is the proportion of the same resource category used by species y. Food overlap among two species as determined by this formula is range from 0.00 to 1.00 indicating significantly no overlap to complete overlap. In the analysis, food overlap values of >0.66, 0.33-0.66 and <0.33 were considered high, moderate and low, respectively. This analysis was performed for the gut composition of *H. quadrimaculatus* and *S. crumenophthalmus* taking the proportion of food items pooled and the mean value was considered as the index of dietary overlap (S).

2.4 Determination of the trophic niche breadth

Trophic niche breadth was measured by the diversity of food items ingested by species using Shannon diversity index (H). This index combines two quantifiable measures: species richness and species evenness. The form of the index appropriate for a finite community is,

$$H = -\Sigma\ P_i\ (\ln P_i)$$

Where, H = Breadth of the trophic niche and P_i = the proportion of each species found in the population [17].

2.5 Food preference of fish species

The preference for different food items by each fish species was determined by calculating the coefficient of electivity (E) using the following equation,

$$E = (r^1 - P_1) / (r^1 + P_1)$$

Here, r^1 is the relative importance of any food item in the gut expressed as percentage of the total gut contents and P_1 is the relative importance of same food item in the environment. The values for coefficient of electivity range from +1.00 to -1.00. The positive values indicate selection of a certain food item and negative indicate avoidance and zero indicating random selection from the environment.

2.6 Water sampling and identification of plankton

Water samples were collected 50m away from the coast by towing the plankton net (mesh size of 250μm) to a length of 100m at night to investigate the plankton abundance. Plankton collected twice a month were preserved in 5% formalin and 10% lugol solution for identification and enumeration. The plankton were identified to species or nearest taxonomic level using standard keys and enumerated under binocular microscope using Sedgewick rafter cell.

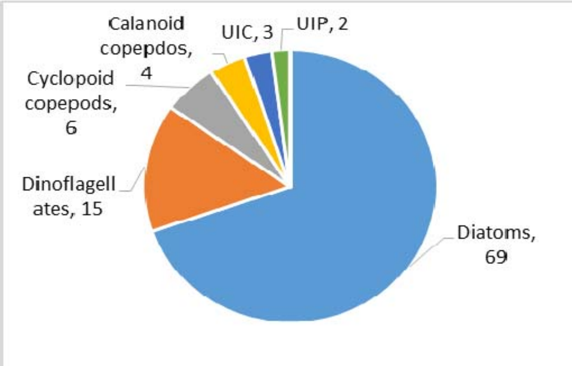
3. Results

3.1 Gut contents

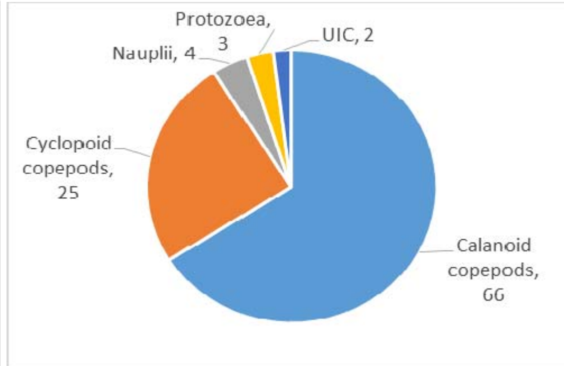
All of the guts examined were found to contain food in them. The food found in the guts of both species was only composed of plankton. No mineral material (sand, shell fragments), algae, fish or benthic animals were found.

A total of 46 different prey items were recorded in the gut Contents of *H. quadrimaculatus* (Table 1). These belongs to six major taxonomic groups namely, diatoms, dinoflagellates, calanoid copepods, cyclopoid copepods and UIC and UIP with frequency of occurrence of 69, 15, 4, 6, 3 and 2%, respectively (Figure 2). Among the prey items of *H. quadrimaculatus* nine taxons, *Phaeocystis, Leptocylindricus, Nitzchia, Rhizosolenia, Leptocylindricus mediterraneus, Scytonema, Proboscia arcuatum* and *Bellerochea* were found to be dominant.

Gut contents of *S. crumenophthalmus* consisted of a total of 41 different prey items belonging to five major taxonomic groups (Table 2) namely, calanoid copepods (66%), cyclopoid copepods (25%), crustacean nauplii (4%), protozoea (3%) and UIC (2%). Among those *Calanus finmarchicus*, *Pseudocalanus*, *Oithona helgolandica*, *Rhincalanus*, *Acartia clause*, *Micro calanus*, *Calacalanus*, *Pseudocalanus Temora longicornis*, *Nanocalanus minor*, *Candacia* and *Labidocera* were dominant.



(A)



(B)

Fig. 2: Percentage occurrence of different food items in the gut of *H. quadrimaculatus* (A) and *S. crumenophthalmus* (B)

Table 1: Prey items found in the gut contents of *H. quadrimaculatus*

Diatoms	Copepods	Dinoflagellates	Unidentified particles
Order Bacillariales	**Order Calanoida**	**Order Dinophysiales**	Plankton
Bleakeleya notate	*Calanus finmarchicus*	*Amphisolenia*	Copepod
Nitzchia amphibian	*C. gracilis*	*Dinophysis*	
N. obtuse	*C. minor*	*Citharistes apsteinii*	
Petrodictyon	*Calocalanus pavo*	*Dinophysis caudate*	
Order: Biddulphiales	Centropages furcatus	**Order Gymnodiniales**	
Cyclotella	*Eucalanus sp.*	*Gymnodinium simplex*	
Leptocylindrus danicus	*E. pileatus*	*G. splendens*	
Leptocylindrus minimus	*E. subtenuis*	**Order Perennials**	
Proboscia alata	*Lucicutia flavicornis*	Diplopsalis lenticular	
Skeletonema costatum	*Pleuromamma gracilis*	D. globula	
Order Chaetocerotales	Rhincalanus rostrifrons		
Chaetoceros	*R. nasutus*		
Order Hemiaulales			
Bellerochea	**Order Cyclopoida**		
Order Naviculales	Calocalanus		
Caloneis	*Halicyclops*		
Diploneis ovalis	*Microcyclops varicans*		
D. subovalis	*Oithona helgolandica*		
Pinnularia			
Order Phaeocystales			
Phaeocystis			
Order Rhabdonematales			
Rhabdonema arcuatum			
Order Rhizosoleniales			
Proboscia alata			
Rhizosolenia			
Order Thalassionematales			
Thalassiothrix longissima			

Table 2: Prey items found in the gut contents of *S. crumenophthalmus*

Order Calanoida	Order Cyclopoida	Crustacean larvae	Unidentified
Acartia clausi	*Candacia*	*Penaeid nauplii, Sp. 1*	copepod particles
C. calaninus	*Ectocyclops*	*Penaeid protozoea, Sp. 1*	
C. gracilis	*Halicyclops sp.*		
Calanus finmarchicus	*H. paralongicirrus*		
Calanus minor	*Haloptilus longicornis*		
Calocalanus	*Heterostylites*		
Calocalanus pavo	*Lucicutia clausi*		
Canthocalanus pauper	*L. flavicornis*		
Centropages furcatus	*L. gaussae*		
Clausocalanus furcatus	*Microcyclops varicans*		
Cyclospina	*Oithona helgolandica*		

Eucalanus attenuates	*Pachyptilus pacificus*		
E. pileatus			
E. subtenuis			
Labidocera			
Lucicutia sp.			
Lucicutia flavicornis			
Microcalanus			
Nannocalanus minor			
Pseudocalanus			
Rhincalanus gigas			
Rhincalanus rostrifrons			
R. nasutus			
Scolecithrix danae			
S. bradyi			
Temora			

3.2 Relative importance of food items
Relative importance of food items were calculated to quantify the dietary overlap between *H. quadrimaculatus* and *S. crumenophthalmus*. They did not compete for diatoms, dinoflagellates, UIP, protozoea and nauplii larvae (Table 3). Their feeding competition mainly occurred for calanoid, cycloid and unidentified particles of copepods.

Table 3: Relative importance of food items of *H. quadrimaculatus* and *S. crumenophthalmus*

Fish species	Diatoms	Dinoflagellates	Calanoid copepods	Cyclopoid copepods	UIC	UIP	Protozoea	Nauplii larvae
H. quadrimaculatus	68.4	15.4	4	6.3	3.3	2.4	-	-
S. crumenophthalmus	-	-	66.6	24.2	2.0	-	3.14	4.1

3.3 Food overlap
Food overlap among the two species according to Schoener's overlap index was 16.5%. Therefore, there was a very low dietary overlap among *H. quadrimaculatus* and *S. crumenophthalmus* that migrated into shallow coastal waters in Southern Sri Lanka.

3.4 Trophic niche breadth
Trophic niche breadth of *H. quadrimaculatus* and *S. crumenophthalmus* are given in tables 4 and 5. Trophic niche breadth of *H. quadrimaculatus* was significantly different from *S. crumenophthalmus* ($t = 2.80$, $p = 0.005$).

Table 4: Trophic niche breadth of *H. quadrimaculatus*

Food item	No. of particles	Pí	ln Pí	Pí(ln Pí)
Diatom	51248	0.68	-0.38	-0.262
Dinoflagellates	11971	0.15	-1.89	-0.284
Calanoid copepods	2996	0.04	-3.21	-0.128
Cyclopoid copepods	4749	0.06	-2.81	-0.168
UIC	3479	0.03	-3.51	-0.105
UIP	1797	0.02	-3.91	-0.078
Trophic niche breadth				1.025

Table 5: Trophic niche breadth of *S. crumenophthalmus*

Food item	No. of particles	Pí	ln Pí	Pí(ln Pí)
Calanoid copepods	42344	0.66	-0.415	-0.274
Cyclopoid copepods	15264	0.241	-1.42	-0.342
Penaeid protozoea	1997	0.031	-3.473	-0.107
Penaeid nauplies	2607	0.041	-3.194	-0.131
UIC	1272	0.023	-3.77	-0.086
Trophic niche breadth				0.94

3.5 Co-efficient of food electivity
H. quadrimaculatus preferred diatoms and calanoid copepods. Those were actively selected or preferred food intakes as they were found in greater proportion in the gut than available in the environment (Table 6).

Table 6: Food electivity of *H. quadrimaculatus* and *S. crumenophthalmus*

Fish species	Diatoms	Dinoflagellates	Calanoid copepods	Cyclopoid copepods	Protozoa	Nauplii larvae
H. quadrimaculatus	0.06	-0.06	0.1	-0.29	-	-
S. crumenophthalmus	-	-	0.91	0.11	1.0	1.0

The food items that were eaten in lesser proportions than available in the environment were dinoflagellates and cyclopoid copepods. The prey items of *S. crumenophthalmus* that indicated positive values were calanoid copepod, cyclopoid copepods, protozoea and nauplii larvae. Those are actively selected or preferred food in a greater proportion than available in the environment.

4. Discussion
Gut content analysis of present study indicates that *H. quadrimaculatus* fed mainly on phytoplankton, although they can be broadly defined as omnivores since a significant proportion of their diet (13%) consisted of animal material. Diatoms composed of the highest portion (68%) of the diet of *H. quadrimaculatus*. This is in disagreement with the amount of diatoms detected (14%) in the diet of *H. quadrimaculatus* in the Central Pacific Sea [22]. *H. quadrimaculatus* was found feeding on harpacticoid copepods, calanoid copepods, brachyuran zoea and megalopae in Gazi Bay, Kenya [31] and on small zooplankton (such as copepods), as juveniles and considerably larger prey (chaetognaths, polychaetes, shrimp and fish) as adults in Hawaiian waters [33]. As the adult length of *H. quadrimaculatus* was 21.5cm in the Indian Ocean [26], the fish sampled in the present study can be considered as juveniles (9 – 15cm). Therefore, the higher amount of

phytoplankton found in the gut of *H. quadrimaculatus* may be attributed to its dietary shifts in different life stages [3, 21].

According to the co-efficient of food electivity *H. quadrimaculatus* preferred diatoms and calanoid copepods. In contrast to the results of the present study calanoid copepods were negatively selected while Brachyura and teleost larvae were positively selected by *H. quadrimaculatus* from the plankton in the Kiribati, Central Island [22]. The variable composition of prey items found in the guts of *H. quadrimaculatus* caught in different oceanic areas including present study suggests that they exhibit considerable feeding flexibility. Fish diet is influenced by changes in the quality and quantity of food in the environment and the fishes' migratory patterns [25] and timing of these changes varies from species to species and is often associated with changes in life style and habitats [3, 23]. Differences in diet composition among species and even within species among different seasons have been observed in fish communities in tropical areas [8, 10, 13, 24]. *Atherinomorus lacunosus* (Atherinidae) fed mostly on phytoplankton, copepods and nematodes during the North East Monsoon. However, its diet was dominated by nematodes during the South East Monsoon [24].

S. crumenophthalmus was zooplanktivorous [15, 27, 28] and the major food items ingested were calanoid and cyclopoid copepods. According to co-efficient of electivity its preferred food items was crustacean larvae. It has been reported that this fish also fed on small fishes such as anchovies and juvenile holocentrids, together with copepods, crab megalops, stomatopods, shrimps and other free swimming crustacea [16].

Unidentifiable food particles were frequently found in the stomachs of *H. quadrimaculatus* and *S. crumenophthalmus* with an occurrence of 5.7 and 2%, respectively. However, as these items were identified as copepods and phytoplankton, the failure to identify this material was unlikely to introduce any significant bias into the diet description of either species, as copepods and phytoplankton were already well represented. Diets of both fishes reflect characteristics typical to shallow tropical coastal habitats by having calanoid copepods as one of the dominant food items [10].

Dietary overlap between *H. quadrimaculatus* and *S. crumenophthalmus* was in a lower range (16%) and therefore, these two fish species could live in the same habitat with a minimum competition for food. As food segregation plays a more important role than habitat or temporal separations within many fish assemblages [13, 27], minimum competition for food may be one of the major reasons for seasonal congregation of *H. quadrimaculatus* and *S. crumenophthalmus* in shallow coastal areas in Southern Sri Lanka.

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