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Mollusc shell fisheries in coastal Kenya: Local ecological knowledge reveals overfishing

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ABSTRACT

There is limited documentation on the status and dynamics of fished marine shelled mollusc species in many countries. Some of the challenges are due to obscure documentation of species, extensive unregulated and unrecorded fishing and unawareness of drivers behind declining stocks. The lack of understanding makes it difficult to formulate effective management plans. Here, we assess the fishers' perceptions on changes in abundance of targeted marine shelled mollusc species and status of associated fished habitats. We interviewed 132 marine shelled mollusc gleaners (fishing by walking) at five sites in coastal Kenya. We established that a multispecies marine shelled mollusc fishery is present in Kenya and that this fishery is conducted by both women and men. We distinguished 158 different shelled mollusc species being targeted. The gleaners perceived a temporal decline of gleaned species. The main causes for the decline were perceived to be overfishing of shells, elevated sea-surface temperature and habitat destruction. The more experienced gleaners perceived a greater decline indicating a baseline shift in perceptions. Our findings suggest that local ecological knowledge is useful to understand historic changes in fisheries lacking long-term scientific data. Furthermore, it highlights the potential benefits of a collaboration between ecologists and gleaners to improve our understanding of the status and dynamics of fishing of marine shelled molluscs as well as other types of fishing.

1. Introduction

Marine shelled mollusc fisheries is an ancient and common activity around the globe (de Boer et al., 2000; Jerardino, 2010; Nordlund et al., 2018; Andrus, 2011), yet it remains among the most understudied and least understood fisheries along marine shorelines (Kowalewski et al., 2014). For many countries, marine shelled mollusc fisheries are missing from official catch statistics as well as historical baseline data (Edgar and Samson, 2004; Anderson et al., 2011; Nijman et al., 2015; Bao and Drew, 2017). Given the market growth for shell fishery across the globe in the past decades, many of these fisheries are overfished, collapsed, or closed (Anderson et al., 2011). Therefore, it is vital to gain a better understanding of marine shelled mollusc fisheries to enable a sustainable fishery.

Marine shelled mollusc fisheries are often conducted by gleaning (sometimes called invertebrate harvesting), i.e. walking in shallow waters and fishing with bare hands or with simple gear (Fig. 1). Gleaning is especially important and common in the tropics, where it provides a source of protein and income for fishing families (Gössling et al., 2004; Dias et al., 2011; Nordlund et al., 2018; Unsworth et al., 2019). However, given that gleaning is often conducted by women and children, it is often overlooked in management and lacks ecosystem-impact assessments because it is not considered fishing (Nordlund et al., 2010; Fröcklin et al., 2014; Kleiber et al., 2015; Harper et al., 2017; Unsworth et al., 2019).

Although seemingly benign and difficult to assess, gleaning can

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Fig. 1. A woman gleaning shells in Mkwiro village, Kenya.

result in a sudden decrease in population size over a short time threatening the sustainability of the fishery (Nordlund et al., 2010; Fröcklin et al., 2014). Many examples exist where the population of commercially important marine species have severely been depleted partly because of human activities (Anderson et al., 2011; Peters et al., 2013, 2015). For example, in Tanzania, overfishing due to increased tourism led to the decline of commercially valuable *Cypraea* species by between five and eighteen times (Newton et al., 1993). Clam species severely declined due to overfishing in New Caledonia and Iberian beaches (Jimenez et al., 2011; Kowalewski et al., 2014).

However, even though overfishing is assumed to be the primary driver of loss of marine shelled molluscs, other threats such as habitat loss, which involves a deterioration of habitat quality, are important factors contributing towards species declines and change in composition structure. For instance, in Moreton Bay, Australia, a population decline of up to 83% of mollusc species and the alteration of species composition was attributed to habitat loss (Skilleter and Warren, 2000). Habitat loss significantly altered the composition of mollusc species with conspicuous preferences for specific coral reef habitats in the northern Red Sea (Zuschin et al., 2001). Additionally, ocean acidification is likely to exacerbate the threats impacting on the growth and production of many ecologically and economically important shelled molluscs (Gazeau et al., 2013; Melatunan et al., 2013). The potential losses to the local, national, regional and global economy could be substantial (Mangi et al., 2018). Many countries have introduced regulations on minimum shell gleaning sizes, capture quotas and specific collection periods to control harvest and export of native species and those listed in the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES) (Dias et al., 2011; Nijman et al., 2015).

Illegal and indiscriminate gleaning of shells protected from overfishing persist in countries such as Indonesia and Brazil (Dias et al., 2011; Nijman et al., 2015). Nevertheless, the absence of reliable data and baseline information on marine shelled mollusc fisheries have made it difficult to determine their status. Historical data sources can improve understanding of past ecosystem dynamics and its drivers helping fill conservation data gaps (Thurstan et al., 2015). Hence, they can be utilized in reconstructing baselines of marine species currently or previously fished (Jackson et al., 2001; Saenz-Arroyo et al., 2005; Buckley et al., 2019).

However, in the absence of ecological baseline studies, local ecological knowledge (LEK) can be used to reconstruct past abundances of species that have undergone historic declines over a long period (Johannes et al., 2000; O'Donnell et al., 2010, 2012). This includes past abundances of species with very low densities (Anadón et al., 2009) and drivers of loss (Turvey et al., 2013) overlooked by scientific data due to its short sampling duration (Moller et al., 2004; Berkström et al., 2019). This is because LEK depends on personal observations and experiences over a long period (Moller et al., 2004). LEK is therefore reliable because it spans several decades and different spatial scales (Thurstan et al., 2016). In addition to conducting quantitative approaches to LEK data collection (Rehage et al., 2019), key informant interviews, which focus on the most knowledgable experts, can also be used to shed additional light on shifting baselines in LEK (Kroloff et al., 2019). Hence, LEK can boost information exchange and knowledge for conservation and management of fished stocks (Johannes et al., 2000; Lozano-Montes et al., 2008; Bender et al., 2014).

Studies show declining diversity, abundance and size of fished marine shelled molluscs since the 1970s along the Kenyan coast (Evans et al., 1977). In addition, the habitats for the shells are continually degraded particularly by human activities (Cinner, 2009). To improve the conservation and management of marine shelled mollusc species and their habitats, it is important to study shifting environmental baselines since community perceptions could be changing (Katikiro, 2014)..The present study was carried out to establish a baseline for the data limited marine shelled mollusc fisheries in coastal Kenya. Marine shelled mollusc gleaners with different levels of gleaning experience were interviewed to understand their perceptions on the dynamics of targeted shell species and their habitats over time. In specific, gleaning habitat preferences and changes in habitat distribution, gleaned mollusc species, changes in landings as well as perceptions of threats was investigated. The implications of utilizing LEK to expand our understanding of gleaning and the gleaning practice are then discussed.

2. Materials and methods

2.1. Study area

Kenya has a coastline of about 600 km stretching from 1°40S to 4°41′S bordering Somalia in the north and Tanzania in the south (Fig. 2). Fringing coral reefs run parallel to the coastline enclosing extensive seagrass meadows. Mangroves dominate the northern part of the coast (Kirui et al., 2013). Two monsoon seasons occur, the southeast monsoon and the northeast monsoon, driving differences in physical, biological and chemical oceanographic conditions of the coastal waters (McClanahan, 1988). The Kenya coast has a tidal range of 4m at spring. During spring-tide, extensive seagrass meadows located in the intertidal zone are exposed, providing suitable ground for marine shelled mollusc gleaning by women and children while walking in shallow waters. Gleaning occurs throughout the year although it is more prevalent during the southeast monsoon (Le Manach et al., 2015).

Five study sites were selected hinged on their history of gleaning marine shelled molluscs (Evans et al., 1977). The sites, as shown in Fig. 1, are Kiunga (1° 44′ 40.92″ S; 41° 29′ 54.96″ E), Kuruwitu (3° 49′ 12″ S; 39° 49′ 48″ E), Kanamai (3° 55′ 12″ S; 39° 47′ 2.4″ E), Mkwiro (4° 40′ 30″ S; 39° 23′ 60″ E) and Vanga (4° 39′ 0″ S; 39° 14′ 16.8″ E).

2.2. Data collection

2.2.1. Interviews with marine shelled mollusc gleaners

A total of 132 respondents' (91 female and 41 male) were surveyed in northeast monsoon between December 2015 and February 2016 from the five study sites: 30 at Kiunga, 31 at Kuruwitu, 14 at Kanamai, 47 at Mkwiro, and 10 at Vanga. This sample size (132) represents about 34% of all gleaners recorded in Kenya by the State Department of Fisheries in 2016. Respondents were selected by snowball sampling by relying on referrals based on their involvement in gleaning marine shelled molluscs, willingness and availability to participate in the interviews as described in Fröcklin et al. (2014). All gleaners were interviewed individually during the daytime when they had completed the day's work at landing sites or at home. All interviews were conducted in Kiswahili language. Each interview took approximately 1 h. The interviewers had worked in the study sites for an extended period and were well known and trusted. At each site, interviewers worked with a well-known local community member selected by the chairman of the Beach Management

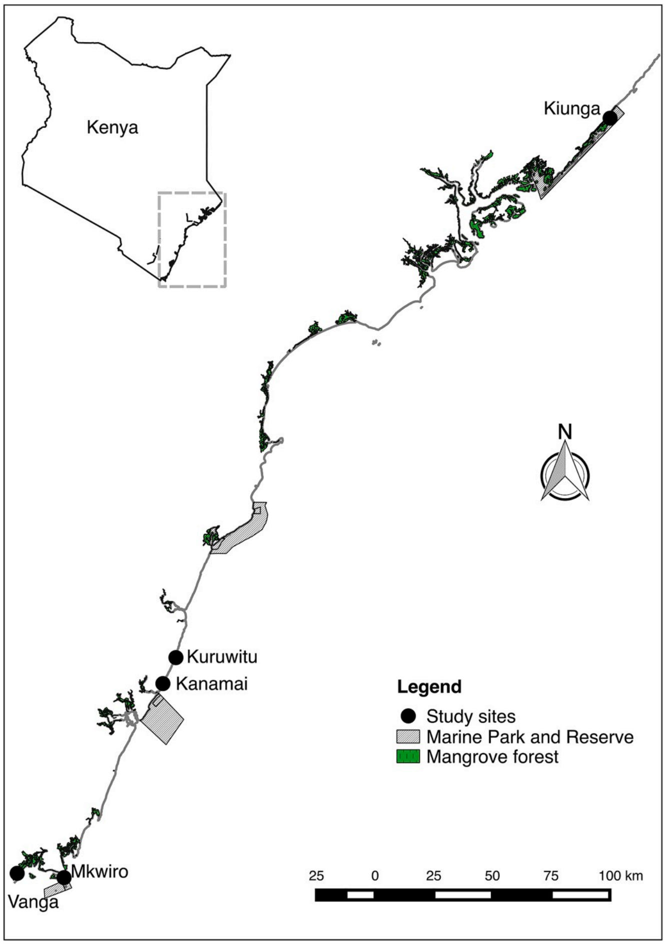

Fig. 2. Location of study sites.

Unit (BMU) to improve the trust in the process. A BMU refers to an organization of fishers, fish traders, boat owners, fish processors and other beach stakeholders who traditionally depend on fisheries activities for their livelihoods. The objectives of BMUs include *inter alia* strengthening the management of fish-landing stations, fishery resources and the aquatic environment and supporting the sustainable development of the fisheries sector.

Interviews were conducted to solicit information about age, gleaning experience, time spent on gleaning, fishing/gleaning grounds, and proportion of substrate preferred – including changes in the distribution of habitats they glean marine shelled molluscs and whether these changes affected their activities (Interview questions are available in Supplementary Material). Photographs of marine shelled molluscs derived from Richmond (1997) and other shells reported in East Africa (Newton et al., 1993; McClanahan, 2002; Nordlund et al., 2010) were then shown to respondents. Respondents were then asked about their catch (kg day^{-1}) early in their career or another year in which they had clear memory and the current or most recent year catch (O'Donnell et al., 2010, 2012). The gleaners were then asked about the monthly income generated from gleaning. In addition, they described the perceived causes for changes in marine shelled mollusc species abundance and distribution and ranked them in order of importance (high, medium and low). Conversation with key informants provided information on spatial changes in marine shelled molluscs abundance, fishing effort and trends in catches throughout history. Respondents were then categorized into three groups according to gleaning experience; low (<16 years of experience, n = 67), intermediate (16–30 years of experience, n = 31) and high (>30 years of experience, n = 34).

2.3. Data analysis

Summary statistics and frequency tables were used to describe the socio-demographic characteristics of the respondents and the effect of experience on perceived changes in marine shelled mollusc species and ecosystems. Kruskal-Wallis test was used to test for statistical differences among sites and the three categories of gleaners level of experience for income and weight of shells landed per gleaner per day. Where significant values were obtained, the Dunn's test for multiple comparisons was applied. Statistical and graphical data analysis was conducted using RStudio version 1.0.153 and Microsoft Excel 2011.

3. Results

3.1. Targeted species

Landed marine shelled mollusc species are shown in Table 1, together with perceptions of gleaners on the abundance of these exploited species in Kenya for each experience category. Analysis of gleaners target species show mixed opinions about the abundance and distribution of fished marine shelled mollusc species among experience categories of gleaners. All gleaners combined targeted a total of 158 different species belonging to 47 families of marine shelled molluscs. Less experienced gleaners targeted 114 different species (8.0 ± 6.1 species/gleaner) while those with intermediate experience targeted 122 species (11.2 ± 7.5 species/gleaner). Highly experienced gleaners targeted only 80 different species (10.0 ± 6.2 species/gleaner). Twenty-six percent (n = 67) of gleaners with low gleaning experience reported that 51% (n = 114) of species they fished were presently rare, when selecting between rarity and commonness of gleaned species. Seventy-four percent (n = 67) of less experienced gleaners perceived that 86% (n = 114) of the species they fished were plentiful. Forty percent (n = 31) of gleaners with intermediate gleaning experience perceived that 64% (n = 122) of the species they gleaned were presently rare while 60% of them believed that 75% (n = 122) of the species they gleaned were presently plentiful. Thirty-two percent (n = 34) of highly experienced gleaners reported that 50% (n = 80) of the species they targeted were presently rare while 68% of gleaners perceived that 80% (n = 80) of the species were presently plentiful (Table 1).

The list of landed marine shelled mollusc species, together with perceptions of gleaners on abundance of these exploited species in Kenya for each site is presented in Appendix A. Gleaners at Kanamai targeted 24 different species (3.8 ± 1.4 species/gleaner) while those at Kiunga targeted a total of 53 species (4.5 ± 1.0 species/gleaner). Gleaners at Kuruwitu targeted 88 different species (9.3 ± 1.1 species/gleaner) while those at Mkwiro targeted a total of 130 species (12.8 ± 0.8 species/gleaner). Gleaners at Vanga targeted 41 different species (9.4 ± 2.1 species/gleaner). Forty-five percent (n = 14) of gleaners in Kanamai reported that 67% (n = 24) of species they fished were presently rare, when selecting between rarity and commonness of gleaned species. Fifty-five percent (n = 14) of gleaners at Kanamai reported that 63% (n = 24) of species they fished were plentiful. Fifty-nine percent (n = 30) of gleaners at Kiunga perceived that 87% (n = 53) of the species they gleaned were presently rare while 41% of them believed that 28% (n = 53) of the species they gleaned were presently plentiful. Thirty-seven percent (n = 31) of gleaners at Kuruwitu perceived that 61% (n = 88) of the species they gleaned were presently rare while 63% of them believed that 74% (n = 88) of the species they gleaned were presently plentiful. Seventeen percent (n = 47) of gleaners at Mkwiro perceived that 38% (n = 130) of the species they gleaned were presently rare while 83% of them believed that 94% (n = 130) of the species they gleaned were presently plentiful. Sixty-four percent (n = 10) of gleaners at Vanga perceived that 83% (n = 41) of the species they gleaned were presently rare while 36% of them believed that 46% (n = 41) of the species they gleaned were presently plentiful.

Table 1
Landed marine shell mollusc species and perceptions of gleaners on abundance of these exploited species in Kenya. Left; list of all landed species in this study. "Plentiful" denotes species that are perceived to have constantly been abundant since the respondent started gleaning, while "Rare" denotes the species that were perceived plentiful in the past but are rare today. Numbers with decimal places indicate proportions (%) of responses by respondents that a species is either plentiful or rare. The total number of responses from which the proportions are derived is indicated in each column. Proportions in each column add up to 100%.

		Level of experience (years)					
		Low (<16) (n = 67)		Intermediate (16–30) (n = 31)		High (>30) (n = 34)	
Family	Species name	Plentiful (Total number of responses – 353)	Rare (Total number of responses – 124)	Plentiful (Total number of responses – 207)	Rare (Total number of responses – 139)	Plentiful (Total number of responses – 224)	Rare (Total number of responses – 104)
Arcidae	*Anadara antiquata*	2.27		0.97	1.44		
	Barbatia trapezina	0.28					
	Mosambicarca erythraeonensis	0.28	1.61	0.48			
Buccinidae	*Engina mendicaria*					0.89	
	Pollia fumosa				0.72		
Bullidae	*Bulla ampulla*		0.81	0.48			
Bursidae	*Bursa rosa*			0.48		0.45	
	Tutufa bubo	0.28		0.48			
Cancellariidae	*Merica melanostoma*	0.28					
Cardiida	*Maoricardium pseudolima*	0.57			0.72		
Cardiidae	*Tridacna maxima*	0.57		2.42	0.72	3.13	
	Tridacna squamosa	0.28		0.97	0.72	1.34	1.92
Cassidae	*Cassis cornuta*	2.83	8.06	4.35	3.60	6.70	4.81
3	*Cypraecassis rufa*	3.97	5.65	3.38	4.32	5.80	6.73
	Phalium glaucum	0.57				1.34	
Cerithiidae	*Cerithium caeruleum*	0.28	0.81				
	Clypeomorus bifasciata				0.72		
Chitonidae	*Acanthopleura brevispinosa*	1.70		1.93	0.72	1.34	
	Acanthopleura gemmata	1.42	0.81	0.48		0.45	
Columbellidae	*Pictocolumbella ocellata*			0.48			
Conidae	*Conus coronatus*			0.48			
	Conus ebraeus			0.48	0.72	0.89	
	Conus geographus			0.97	0.72		
	Conus imperialis				0.72		
	Conus litteratus		0.81				
	Conus marmoreus	0.57			0.72		
	Conus rattus	0.28					
	Conus striatellus	0.57		0.48			
	Conus striatus				0.72		
Cypraeidae	*Arestorides argus*		1.61	0.48	4.32	1.34	3.85
	Bistolida owenii	0.28	0.81				
	Bistolida stolida		0.81		1.44		
	Chelycypraea testudinaria	1.13	4.84	2.42	2.16	2.68	2.88
	Cribrarula cribraria	0.28	0.81				
	Cypraea pantherina	0.57		1.45			0.96
	Cypraea tigris	8.22	10.48	7.73	5.04	8.48	2.88
	Cypraeovula edentula	0.28		0.48	0.72		
	Erosaria erosa	1.98	0.81	0.97	0.72	0.45	0.96
	Erosaria gangranosa	0.28					
	Erosaria helvola		1.61	0.97		0.45	
	Erosaria lamarckii	0.28			0.72		
	Erosaria marginalis	0.57					
	Erosaria miliaris		1.61	0.48	0.72		0.96
	Erosaria nebrites	0.28		0.48	0.72		
	Erosaria poraria	0.57	0.81				
	Erosaria turdus			0.48			
	Erronea caurica	0.28	1.61		1.44	1.79	
	Erronea caurica		0.81	0.48	0.00	0.00	
	Erronea errones	0.85		0.48	0.72	1.34	
	Erronea onyx	0.28	0.81			0.89	0.96
	Leporicypraea mappa		0.81	0.48	1.44		0.96
	Luria isabella			0.97	1.44	0.45	0.96
	Lyncina carneola	0.57	0.81	0.48	1.44	0.45	
	Lyncina lynx	1.70	2.42	0.48	0.72	0.45	
	Lyncina vitellus	1.13	0.81		0.72		

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Table 1 (*continued*)

		Level of experience (years)					
		Low (<16) (n = 67)		Intermediate (16–30) (n = 31)		High (>30) (n = 34)	
Family	Species name	Plentiful (Total number of responses – 353)	Rare (Total number of responses – 124)	Plentiful (Total number of responses – 207)	Rare (Total number of responses – 139)	Plentiful (Total number of responses – 224)	Rare (Total number of responses – 104)
	Mauritia arabica	0.57	0.81	0.48	1.44		0.96
	Mauritia depressa	0.57		0.48			0.96
	Mauritia histrio	0.57	0.81	0.48			0.96
	Mauritia mauritiana	2.27	0.81	0.97	0.72	1.79	1.92
	Mauritia scurra		0.81		0.72		0.96
	Melicerona felina	0.57	2.42			0.45	0.96
	Monetaria annulus	7.08	4.84	4.35	2.16	4.46	
	Monetaria caputserpentis	1.13	3.23	0.97		0.89	
	Monetaria moneta	6.23	5.65	4.83	2.88	4.02	
	Palmadusta asellus		1.61		0.72		
	Palmadusta clandestina	0.85			0.72	1.79	
	Palmadusta diluculum			0.81	0.48		
	Palmadusta ziczac	1.13		0.97	1.44	0.45	
	Purpuradusta fimbriata		0.81				
	Purpuradusta gracilis	0.28	0.81		1.44		
	Purpuradusta microdon	0.57	0.81				
	Pustalaria cicercula	0.28		0.48	0.72		
	Pustularia globulus	0.28			0.72		
	Ransoniella punctata	0.28	0.81		0.72		
	Staphylaea staphylaea	0.57					
	Talparia talpa		0.81	0.48	0.72		
Epitoniidae	*Acrilla acuminata*						0.96
	Janthina janthina	0.28					
Fasciolariidae	*Fusinus colus*	0.57		0.48		0.45	
	Latirus polygonus	0.57		0.48	0.72	0.45	
	Pleuroploca filamentosa	1.70	0.81	0.97	1.44	1.79	
	Pleuroploca trapezium	6.23	4.03	5.31	5.76	6.25	1.92
Ficidae	*Ficus subintermedia*					0.45	
Harpidae	*Harpa harpa*	0.57		0.48	1.44	1.34	1.92
	Harpa major	0.28	1.61				0.96
Hexabranchidae	*Hexabranchus sanguineus*			0.48			
Littorinidae	*Littoraria coccinea glabrata*		0.81	0.48			
	Littoraria pallescens				0.72		2.88
	Littoraria scabra		0.81		2.16		2.88
Lucinidae	*Codakia punctata*			0.48			
Mactridae	*Mactrotoma ovalina*	0.28					
Melongenidae	*Volema pyrum*	1.42	0.81	1.93		0.89	
Mitridae	*Pterygia nucea*					0.45	
Muricidae	*Chicoreus ramosus*	2.83	1.61	2.42	0.72	1.79	3.85
	Cronia konkanensis	0.28		0.48			
	Drupa morum			0.48			
	Drupa ricinus			0.48			
	Drupella cornus			0.48			
	Drupella margariticola	0.28					
	Drupella rugosa			0.48			
	Morula granulata	0.28		0.48			
	Murex brevispina	0.28		0.48			0.96
	Murex pecten	0.28		0.97		0.89	1.92
	Purpura persica			0.48	0.72		
	Semiricinula squamosa			0.48			
Mytilidae	*Brachidontes pharaonis*			0.48			
Nassariidae	*Nassarius olivaceus*				0.72		
Neritidae	*Nerita albicilla*	0.57					
	Nerita polita	0.85				0.45	
	Nerita textilis	0.57					

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Table 1 (*continued*)

		Level of experience (years)					
		Low (<16) (n = 67)		Intermediate (16–30) (n = 31)		High (>30) (n = 34)	
Family	Species name	Plentiful (Total number of responses – 353)	Rare (Total number of responses – 124)	Plentiful (Total number of responses – 207)	Rare (Total number of responses – 139)	Plentiful (Total number of responses – 224)	Rare (Total number of responses – 104)
	Nerita undata	0.57			0.72		
Olividae	*Oliva bulbosa*		0.81		0.72		
Ostreidae	*Striostrea margaritacea*					0.45	0.96
Ovulidae	*Calpurnus verrucosus*	0.28					
	Ovula ovum	0.28	0.81	1.45	1.44	2.23	2.88
Pharidae	*Siliqua radiata*			0.48	0.72		
Phasianellidae	*Phasianella nivosa*				0.72		
Pinnidae	*Atrina vexillum*	0.28		0.97		0.89	
	Pinna muricata				0.72		
Planaxidae	*Planaxis sulcatus*				0.72		
Potamididae	*Terebralia palustris*	1.42	0.81	0.48	2.16		
Pteriidae	*Isognomon ephippium*			0.48	0.72	0.45	
	Pinctada margaritifera	0.28	0.81	0.48	0.72		
Ranellidae	*Charonia lampas*	0.57	0.81	0.97		1.79	2.88
	Charonia tritonis	0.85	1.61	1.45	2.88	3.57	9.62
	Gutturnium muricinum					0.45	
	Lotoria lotoria					0.45	
	Monoplex gemmatus			0.48		0.45	
Strombidae	*Conomurex decorus*	0.57		0.48		0.89	
	Gibberulus gibberulus	1.70		1.45		0.89	
	Lambis chiragra arthritica	0.85	0.81	3.86	2.88	2.68	5.77
	Lambis crocata	0.85	1.61	0.48	0.72	0.89	
	Lambis lambis	3.68	0.81	3.38	2.16	3.57	8.65
	Lambis truncata	2.27		1.93	0.72	2.23	4.81
	Lentigo lentiginosus	0.57		0.97	0.72	1.79	
Tegulidae	*Tectus mauritianus*	0.28					
Terebridae	*Hastula lanceata*	0.28			0.72		
	Oxymeris crenulata				0.72	0.45	
	Oxymeris dimidiata	0.28			1.44	0.89	0.96
Tonnidae	*Tonna canaliculata*			0.97		0.45	
	Tonna galea	0.85	1.61		0.72		0.96
	Tonna perdix			0.97		0.45	
Triviidae	*Trivirostra oryza*	0.85					0.96
Trochidae	*Agagus agagus*	0.28					
	Clanculus puniceus			0.48			0.96
	Monodonta labio			0.48		0.45	
	Oxystele tabularis			0.48			0.96
	Stomatella auricula	0.28					
	Trochus maculatus	0.85		0.48			
Turbinellidae	*Vasum ceramicum*	1.42		0.48	0.72		
	Vasum rhinocerus	0.28			0.72		
	Vasum turbinellus	0.57			0.72		
Turbinidae	*Lunella coronata*			0.48		0.89	
	Turbo argyrostomus		1.61	0.48	0.72	0.45	
	Turbo marmoratus	0.28	0.81	1.45	2.16	1.79	5.77
Turridae	*Lotyrris cingulifera*				0.72		
Veneridae	*Chione toreuma*	0.28		0.48			
	Venus sinuosa					0.45	

3.2. Past and current weights of gleaned marine shelled molluscs

Past daily weight of selected families of marine shelled molluscs landed per respondent from interviews held with 132 gleaners is shown in Fig.3. The gleaners perceived that shells landed by each gleaner per day between the 1970s and 2010s declined by about 54% (Fig. 3f). Gleaners with low gleaning experience thought that shells were more abundant in 2010. Gleaners with high gleaning experience reported high abundance of shells between 1970 and 1980. The gleaners perceived a declining trend in abundance of shell families between the 1970s and 2010s (Fig. 3a–e).

For example, the abundance of Fasciolaridae, Cassidae and Strombidae decreased between 1980 and 2010 (Fig. 3b, c, e). Ranellidae showed a declining trend in abundance between 1970 and 2000 and a sudden increase in 2010 (Fig. 3d). The abundance of Cypraeidae declined in 1980 and remained relatively stable between 1980 and 2000 (Fig. 3a). A Kruskal-Wallis test showed a significant difference (χ^2 [4] = 119.60, P = <0.001) in weight of shells landed per gleaner per day (Fig. 3f).

The decadal median daily weight of shelled molluscs landed per respondent for each site is shown in Appendix B. The abundance of marine shelled molluscs in Kiunga declined in 1980 and remained

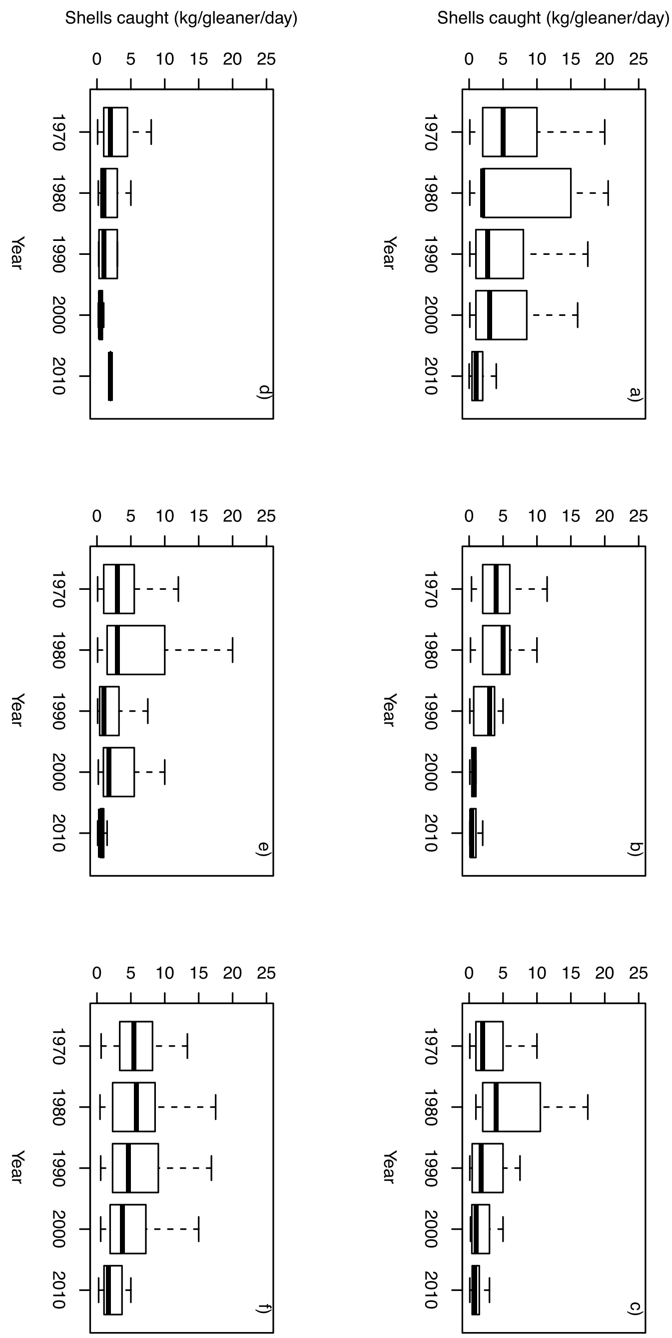

Fig. 3. Past daily weight (with minimum, interquartile range, median and maximum) of marine shelled molluscs landed per respondent for the families a) Cypraeidae, b) Cassidae, c) Fasciolariidae, d) Ranellidae, e) Strombidae, and f) All families combined from interviews held with 132 gleaners. Sample size for 1970 period = 24; 1980 = 16; 1990 = 24; 2000 = 23; 2010 = 45; total = 132.

relatively stable between 1990 and 2000. Marine shelled molluscs in Mkwiro showed a declining trend in abundance between 1980 and 2010. A significant difference in weight of marine shelled molluscs landed was found among study sites for each period.

3.3. Gleaners habitat preference

The most preferred benthic habitat for gleaning marine shelled molluscs among all gleaners was seagrass (56.0%, n = 74), followed by seagrass mixed with coral reefs (15.6%, n = 21), coral reefs (13.7%, n = 18), bare areas (12.7%, n = 17), any habitat (1.5%, n = 2) and mangrove (0.5%, n = 1). Moderate and extensive seagrass patches were preferred over smaller seagrass patches especially among intermediate and highly experienced gleaners (Fig. 4). Moderate coral patches and extensive coral reef habitats were to a lesser extent preferred. Mangroves were the least preferred habitat.

The perceptions of gleaners for the size of habitat per site are presented in Appendix C. Moderate and smaller seagrass patches were preferred over extensive seagrass meadows among gleaners at Mkwiro. Gleaners at Vanga preferred moderate coral patches and extensive coral reef habitats over extensive seagrass meadows. Moderate seagrass patches and seagrass mixed with coral reefs were preferred over extensive seagrass meadows among gleaners at Kanamai. Gleaners at Kiunga preferred extensive seagrass meadows while those in Kuruwitu preferred 100% bare areas over extensive seagrass meadows.

3.4. Perceptions of historical changes to the most preferred gleaning habitats (seagrass meadows)

Perceptions of gleaners on seagrass meadows distribution changes is shown in Table 2. More than half of the gleaners with high experience (56%, n = 19) and those with intermediate gleaning experience (55%, n = 17) reported a decline in seagrass meadow distribution over time. On the other hand, 57% (n = 38) of gleaners with low experience reported no changes in seagrass distribution. Of the respondents that reported changes (n = 59), more than 75% (n = 47) noted a decrease in seagrass distribution. Furthermore, about 66% (n = 39) of the gleaners that perceived changes in seagrass distribution (n = 59) believed that catches declined due to a decrease in seagrass cover.

Respondent perceptions on seagrass habitat distribution per site is presented in Appendix D. More than half of the gleaners at Kiunga (77%, n = 30), Mkwiro (54%, n = 47) and those at Vanga (100%, n = 10) reported changes in seagrass habitat cover over time. On the other hand, 75% (n = 14) of gleaners at Kanamai and 73% (n = 31) of those at Kuruwitu reported no changes in seagrass distribution. Of those that reported changes in seagrass distribution, more than half at Kiunga (94%, n = 30), Kuruwitu (100%, n = 31, Mkwiro (67%, n = 47) and Vanga (60%, n = 10) reported a decline in seagrass habitat distribution over time.

3.5. Perceptions on threats to marine shelled mollusc abundance and distribution

Perceptions on threats to marine shelled mollusc abundance and distribution for respondents in each experience category are shown in Table 3. Respondents in the three gleaning experience categories (low, intermediate and high) mentioned eight threats that, they perceived, influence marine shelled mollusc abundance and distribution. These are ranked from the most mentioned: overfishing; elevated sea surface temperatures; habitat destruction; sea urchin herbivory of seagrass meadows; predation by fish and sting rays; disregard of traditional taboo practices and beliefs; weak law enforcement; and migrant fishers. Overfishing was perceived as the single greatest threat to marine shelled mollusc populations. Most gleaners with high gleaning experience (50%, n = 34), intermediate gleaning experience (32.1%, n = 31), and low gleaning experience (45.2%, n = 67) responded that the level of threat to overfishing posed to marine shelled molluscs was moderate to high.

The second greatest threat to marine shelled mollusc populations was perceived to be elevated sea surface temperatures. The most experienced gleaners (21.4%, n = 34), those with intermediate gleaning experience (18.8%, n = 31), and low gleaning experience (37%, n = 67), reported that they thought elevated sea surface temperatures posed a moderate to high level of threat to marine shelled mollusc species abundance and distribution. Fewer gleaners with intermediate experience (13.2%, n = 31) and high experience (9.5%, n = 34) considered sea urchin herbivory of seagrass meadows to pose a moderate to high level of threat to marine shelled mollusc species abundance and distribution.

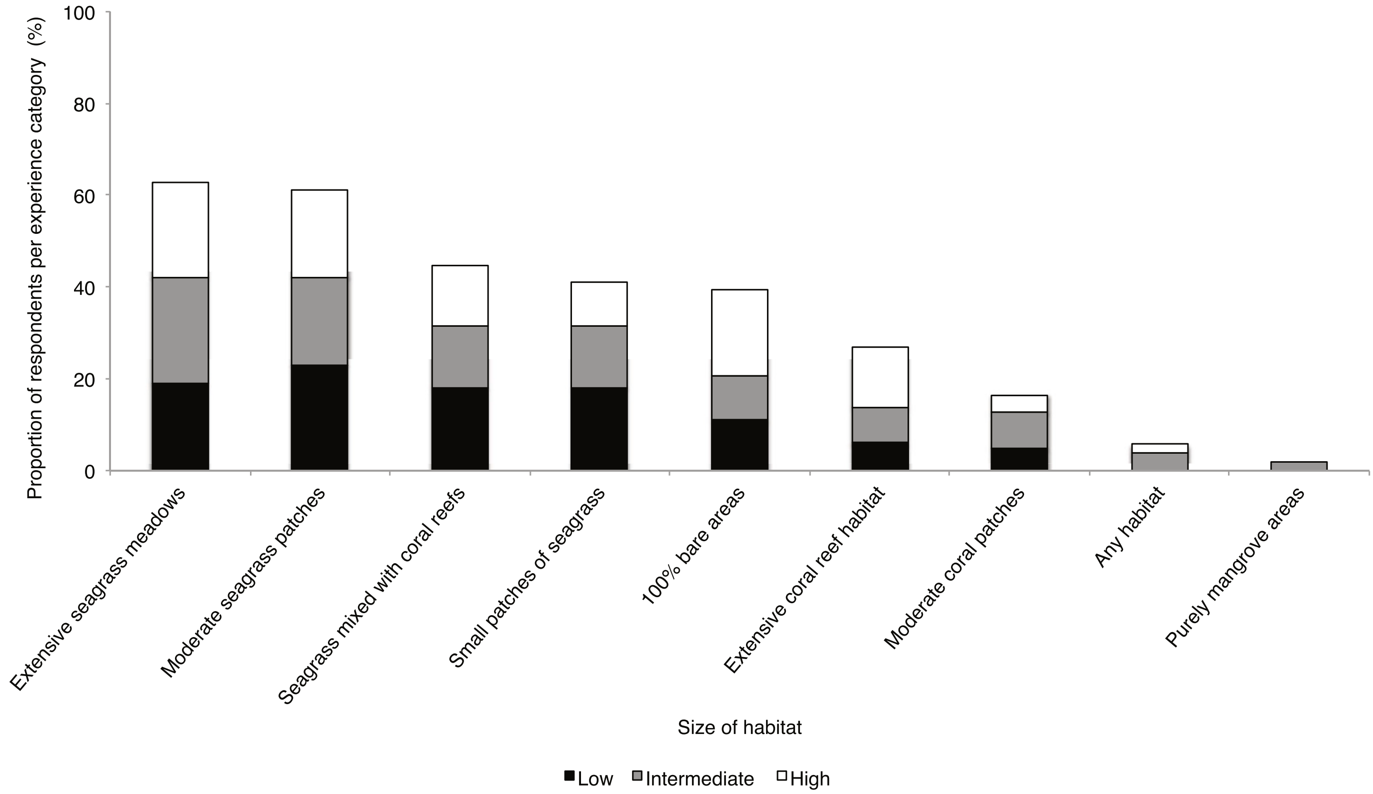

Fig. 4. Preference of gleaners for the size of habitat. Proportions in a gleaning experience category add up to 100%. Gleaning experience categories include low (<16 years of experience, n = 67), intermediate (16–30 years of experience, n = 31) and high (>30 years of experience, n = 34).

Table 2
Respondent perceptions on seagrass habitat distribution. (Numbers represent proportion of respondents by experience). Proportions in a category add up to 100% (low (<16 years of experience, n = 67), intermediate (16–30 years of experience, n = 31) and high (>30 years of experience, n = 34)).

Question	Answer	Low	Intermediate	High
Have there been any changes in seagrass distribution?	Don't know	3	8	12
	No	57	37	32
	Yes	40	55	56
If yes, what changes?	Decrease	77	81	85
	Dynamic	12	6	15
	Increase	12	13	0
Have these changes affected your collection activities negatively?	Don't know	0	0	5
	No	33	35	29
	Yes	68	65	67

The most experienced gleaners (7.1%, n = 34) perceived that weak law enforcement presented a high level of threat to marine shelled mollusc abundance and distribution. Gleaners with low experience (2.7%, n = 67) reported that they thought disregard of traditional taboo practices and beliefs by gleaners caused a low level of threat to marine shelled mollusc species abundance and distribution.

The perceptions of respondents on threats to marine shelled mollusc abundance and distribution in each village are presented in Appendix E. Overfishing was cited as the single greatest threat to marine shelled mollusc populations in all sites except Kiunga. Most gleaners at Kanamai (62.5%, n = 14), Kuruwitu (62.7%, n = 31), Mkwiro (38.5%, n = 47) and Vanga (24%, n = 10) believed the level of threat to overfishing posed to marine shelled molluscs was moderate to high. The second greatest threat to marine shelled mollusc populations in all sites except Kiunga was elevated sea surface temperatures. Gleaners at Kanamai (25%, n = 14), Kuruwitu (19.6%, n = 31), Mkwiro (38.5%, n = 47) and Vanga (36%, n = 10) reported that they thought elevated sea surface temperatures posed a moderate to high level of threat to marine shelled mollusc species abundance and distribution. Gleaners at Kiunga reported that they thought the level of threat posed by sea urchin herbivory of seagrass meadows (64.7%, n = 30) and habitat destruction (17.6%, n = 30) to marine shelled molluscs was high.

Gleaners reported that gleaning was mainly conducted for sale of shells to tourists and export (74.7%), food (24.7%) and fish bait (0.5%). Key informants perceived that habitat destruction was caused by interacting factors such as boating activities, trampling on seagrass beds and sea urchin herbivory. Both elevated sea surface temperatures and habitat destruction caused marine shelled mollusc species to move deeper. These areas are usually inaccessible by female gleaners and male foot fishers.

3.6. Respondent characteristics

General characteristics of each experience category of respondents interviewed in terms of gender, age, gleaning experience, duration spent gleaning, and monthly income is shown in Table 4. Respondents with low and intermediate gleaning experience were mostly female representing 86.6% and 67.7% respectively, in comparison to high gleaning experience which included 64.7% male respondents (Table 4). A significant difference in income was established among gleaning experience categories (southeast monsoon - Kruskal-Wallis $\chi^2 = 10.9811$, df = 2, p-value = 0.004126; northeast monsoon - Kruskal-Wallis $\chi^2 = 10.2253$, df = 2, p-value = 0.00602).

The general characteristics of respondents interviewed in each village is shown in Appendix F. Respondents at Kiunga (76.7%, n = 30), Kanamai (69.2%, n = 14) and Mkwiro (96.2%, n = 47) were mostly female while at Kuruwitu (57.1%, n = 31) they were mostly male. All respondents at Vanga were male (100%, n = 10). No difference in income was observed between seasons. Similarly, no difference in

Table 3
Perceived threats to mollusc shells grouped by level of threat and per experience category. Proportions of respondents per experienced category (low (<16 years of experience, n = 67), intermediate (16–30 years of experience, n = 31) and high (>30 years of experience, n = 34)) indicated by – None – no respondent (0%), Very few <5% of respondents, Few 5–10% of respondents, several 11%–20% of respondents, and many >20% of respondents.

Perceived threat	Level of threat	Low gleaning experience	Intermediate gleaning experience	High gleaning experience
Overexploitation	High	Many	Many	Many
	Moderate	Few	Few	Several
	Low	None	Very few	Very few
Elevated sea surface temperatures (SST)	High	Several	Several	Several
	Moderate	Several	Few	Few
	Low	Very few	Very few	Very few
Sea urchin herbivory of seagrass beds	High	Very few	Several	Few
	Moderate	None	Very few	None
	Low	None	Very few	None
Habitat destruction	High	Very few	Very few	Very few
	Moderate	Very few	Few	None
	Low	Very few	Very few	None
Predation by fish and stingrays	High	Very few	None	Very few
	Moderate	None	Very few	Very few
	Low	None	Few	None
Disregard of traditional taboo practices and beliefs[a]	High	Very few	Very few	None
	Moderate	Very few	None	None
	Low	Very few	None	None
Migrant fishermen	High	None	None	None
	Moderate	None	None	None
	Low	None	Very few	None
Weak enforcement of fisheries rules and regulations	High	None	None	Few
	Moderate	None	None	None
	Low	None	None	None

[a] Disregard of traditional taboo practices and beliefs includes indecent dressing by women gleaners and unaccepted gleaning tool handling.

gleaning time was observed among gleaning experience categories. No difference in age, gleaning experience, income and time (days and hours) spent gleaning was found among sites.

4. Discussion

This study highlights that a multispecies marine shelled mollusc fishery is present in Kenya and that this fishery is conducted by both women and men. From 132 interviews with gleaners we were able to distinguish 158 different shelled mollusc species being targeted. This high diveristy of target species is similar to findings from Zanzibar, Tanzania (Nordlund et al., 2010; Fröcklin et al., 2014) and Kenya (McClanahan, 2002), suggesting that there is a need to expand our understanding of gleaning as it may have large environmental impacts. Recent studies have highlighted the importance of seagrass as a circumglobal fishery habitat, its high productivity and support for very diverse fishery (Nordlund et al., 2018; Unsworth et al., 2018). This study shows that gleaning is conducted in all habitats in the nearshore area, but that seagrass was cleary the most preferred habitat for shelled molluscs among the gleaners in Kenya.

Scientific data about gleaning is scarce globally and Local Ecological Knowledge (LEK) is one way to expand our understanding of gleaning and the gleaning practice. This study, investigating gleaners' LEK is therefore useful for obtaining information to develop a baseline for the occurrence and abundance of fished marine shelled mollusc species useful for management of coastal fisheries. In accordance with Bao and Drew (2017), results demonstrate the existence of overfishing and changing human perceptions of the environment. This may be caused by the loss of experience about past conditions due to the shifting baseline syndrome (Pauly, 1995). Moreover, this paper shows, in-line with Ainsworth et al.(2008), how each gleaner experience category accepts the shell abundance during the beginning of their careers as normal abundance. When the next gleaner experience category begins their career, shells have further declined but shell stocks at that time would now function as a new baseline (Pauly, 1995). To understand changes in abundance of marine shelled mollusc species it is therefore important to include people with high levels of experience as large declines may have happened before gleaners with less experience started to glean.

Our results indicate that many marine shelled mollusc species that were once plentiful have experienced a severe decline between the 1970s and 2010s along the Kenyan coast. This includes sites that are located close to Kisite-Mpunguti and Mombasa Marine Protected Areas (MPAs) notably Mkwiro and Kanamai, respectively. Tourism activities in sites close to MPAs may have provided ready markets for marine shelled molluscs leading to these observed declines in comparison to sites located in relatively remote areas such as Kiunga and Vanga. Many species are currently perceived to be rare, therefore, they could be at risk to local extinction. Moreover, gleaning of more, smaller shells due to the shifting baseline syndrome could lead to population depletion (Bao and Drew, 2017). Selective fishing of larger, mature individuals may lead to species extinction since gamete densities get too low to produce positive recruitment values (Neo et al., 2015). Turvey et al. (2010) showed how species that are no longer encountered regularly are deemed to have disappeared due to the shifting baseline syndrome.

Here, the personal experiences of gleaners show differences in perceptions about the loss of marine shelled mollusc species. Gleaners with high gleaning experience observed a greater number of species being rare as well as a greater decline in shell populations compared to gleaners with low experience. A greater proportion of gleaners with low experience did not observe temporal changes in shell species abundance.

Table 4
General characteristics of respondents interviewed (n = 132). NEM = Northeast monsoon and SEM = Southeast monsoon; Low (<16 years of experience, n = 67), intermediate (16–30 years of experience, n = 31) and high (>30 years of experience, n = 34).

Experience category	Gender (%)		Age (±SD)	Gleaning experience (years)± SD	Days spent gleaning per week. Hours/day in parenthesis (±SD)		Monthly income (USD± SD)	
	Female	Male			SEM	NEM	SEM	NEM
Low (n = 67)	86.6	13.4	34.25 ± 11.19	5.76 ± 4.71	5.22 ± 1.69 (3.45 ± 1.43)	5.45 ± 1.67 (3.40 ± 1.18)	44.85 ± 39.68	42.64 ± 36.18
Intermediate (n = 31)	67.7	32.3	43.20 ± 10.62	22.42 ± 4.75	5.27 ± 1.48 (3.50 ± 1.20)	5.34 ± 1.24 (3.84 ± 1.35)	94.63 ± 182.33	72.19 ± 53.58
High (n = 32)	35.3	64.7	59.29 ± 9.39	42.39 ± 8.26	5.19 ± 1.69 (3.10 ± 1.43)	5.97 ± 1.29 (3.53 ± 1.18)	72.73 ± 70.48	72.75 ± 62.24
Total (n = 132)	68.9	31.1	42.81 ± 14.72	19.46 ± 16.24	5.22 ± 1.66 (3.37 ± 1.27)	5.56 ± 1.48 (3.55 ± 1.33)	64.58 ± 104.15	58.15 ± 50.48

This is likely because they started gleaning when stocks had reduced or depleted. Bao and Drew (2017) have recently shown in their study, in Fiji, that gleaners with low experience may readily accept that shell stocks naturally occur in low population abundance. Furthermore, intergenerational changes in perception of the natural status of marine shelled mollusc stocks have been shown to lead to shifting environmental baselines elsewhere (Edgar and Samson, 2004; Saenz-Arroyo et al., 2005; Bender et al., 2014). The present results show similar trends, that gleaners' environmental baselines could have been affected by the difference in years of gleaning experience.

Since marine shelled mollusc fishery is missing in Kenyan official statistics (Le Manach et al., 2015), it is difficult to analyse time trends and evaluate the status of this mollusc fishery. Hence, by utilizing the LEK held by 132 gleaners, this study reconstructs past populations of fished marine shelled mollusc in coastal Kenya. This could help in avoiding the loss of marine shelled mollusc species due to the shifting baseline syndrome by identifying threatened species. These findings may increase understanding and support for species conservation and restoration (Soga and Gaston, 2018). The study forms the first step towards avoiding overfishing since it provides status information of marine shelled molluscs at a national scale.

Given the limited resources available for government agencies to monitor and control the harvesting of these species, a co-management approach is recommended to complement and share responsibilities in managing and controlling fishery resources (Cinner et al., 2012; Matsue et al., 2014; Hunter et al., 2018). In this way, the Beach Management Units (BMUs), which consist of local resource users at the landing sites, can be more involved in the enforcement of regulations and the monitoring and recording of landings to play a more central role in the protection of species most at risk and at the same time minimize conflicts (Hunter et al., 2018). In this case, we know that the abundance of several of the species are much lower than just a few decades ago and there might have been several great declines or collapses before the 1970s, but this kind of data is not available. One conservation target could be to use at least the 1970s and 1980s as a reference point upon which recovery targets should be based for most fished shells. After this period, the rate of decline of marine shelled mollusc catches increased. It can be assumed that the absence of historical data and the belief that contemporary marine shelled mollusc abundance is natural may have led to the continued decline of shell species. Therefore, it is likely that less experienced gleaners were tolerant of the collapse of the fishery. It also seems plausible that scientific baseline studies view the stocks observed at the beginning of their surveys as natural since they are unable to incorporate past observation into the current thinking (Pauly, 1995; Saenz-Arroyo et al., 2005).

The results emphasize the dissimilarities in the way gleaners perceive and subsequently rank major threats to marine shelled molluscs. Newton et al. (1993) and Gössling et al. (2004) have shown that overfishing mainly for sale to tourists and export is the primary cause for the decline in marine shelled molluscs abundance and diversity in East Africa. However, when viewing this by experience, perceptions of the gleaners with high and low experiences seem to be different from those with intermediate experience. This suggests an adaptation to gleaning in response to their population decline. In their study in Fiji, Bao and Drew (2017) demonstrated that as gleaners increase because of the growing demand for shells, smaller sized shells are increasingly collected because of a shift in perceptions of baselines resulting in overfishing. Like in Fiji (Bao and Drew, 2017), many young and less experienced gleaners in Kenya could have lacked knowledge about marine shelled molluscs life-history traits, optimal collection methods and suitable gleaning seasons.

Similarly, elevated sea surface temperature was perceived as another important threat. Indeed, increased sea surface temperatures is likely to lead to redistribution of mollusc species and a lower survival, growth and development (Kroeker et al., 2013). The responses based on experience indicate elevated sea surface temperatures was perceived to be a major threat to marine shelled molluscs by gleaners of all experience categories. Additionally, climate related affects on the coastal seas could potentially increase the number of gleaners as coral reefs gets devastated and forces people to find new fishing grounds. Furthermore, increased storminess could also limit fishers to go further from the shore and thus increase the number of gleaners (Unsworth et al., 2018). Seagrass habitat destruction through sea urchin herbivory was also perceived to cause major declines in marine shelled molluscs by the intermediate and experienced gleaners. Mangi et al. (2018) demonstrated that the associated economic losses due to each threat could be substantial. Globally, elevated sea surface temperatures and habitat destruction were shown to lead to a significant decline and possible depletion of marine shelled mollusc species (Nordlund and Gullström, 2013; Peters et al., 2013; Fröcklin et al., 2014). In this study, reports of weak enforcement of fisheries rules and regulations by experienced gleaners signify poor compliance of locally accepted measures by other experience categories.

Key informants attributed the loss of marine shelled mollusc species to be as a result of interacting threats. Key informants were shown to give important insights about drivers of species decline and shifts as a result of the decline as has been shown elsewhere (Kroloff et al., 2019). The perceptions of gleaners on the major drivers of loss of shells may differ between sites as was observed at Kiunga (sea urchin herbivory and habitat destruction) compared to the other sites (overexploitation and elevated sea surface temperatures). We report that fished marine shelled mollusc species have not completely disappeared or become locally extinct, yet. Consistent monitoring and enforcement of locally accepted measures such as species restriction and area-based conservation, however, will promote conservation of declining shell species and their habitats.

Gleaning occurred primarily in moderate to extensive sized seagrass meadows. Intertidal seagrass meadows are easily accessible to gleaners. Nordlund and Gullström (2013) have shown fragmentation and attenuation of seagrass meadows to have negative impacts on targeted marine shelled mollusc species. This study has shown that individuals with high gleaning experience perceive a greater decline in seagrass distribution compared to those with low gleaning experience. The reduction in seagrass distribution could have contributed to the decrease in the number of gleaned shells. A decrease in seagrass cover in just two decades was perceived to greatly reduce catch weights and gleaners' income by approximately 1.5–2.5 times in Zanzibar (Nordlund et al., 2010).

Gleaners' experience of the fishery could have resulted in more pessimistic perceptions. The current study overcame the issue of uncertainty in the reliability of the data by interviewing many gleaners and using in-depth interviews, and questionnaires, and identification guides as suggested by Anadón et al. (2009), Daw (2010) and Daw et al.(2011). The interviewers were well known and trusted in the community. In addition, community members with good knowledge of resource use in the area were involved in the data collection. Hence, it is assumed that the ability of respondents to recall was improved. As Jones et al. (2008) posits, this provides an accurate estimate of the status of the resource underutilization.

5. Conclusion

The study shows that where scientific information is lacking, it is possible to use local ecological knowledge to expand our understanding of marine shelled mollusc fisheries, and help avoid the shifting baseline syndrome in the management of invertebrate fisheries. It also reveals a multispecies marine shelled mollusc fishery that is conducted by both men and women. Therefore, this study is valuable to the conservation and management efforts of marine shelled mollusc species. The rarity of many of these species could be an indication that they could be at a high risk of local extinction. Information on rare species can be used in setting up local management goals and plans for sustainable management. The study points to the need for incorporating shifting baselines in marine resource management programmes to contribute to the long-term conservation and management of fisheries resources. Moreover, Beach Management Units can be used as platforms upon which shell fisheries management goals can be entrenched in the existing management plans.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix G. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2020.105285.

Appendix A. Landed marine shelled mollusc species and perceptions of gleaners on abundance of these exploited species in Kenya. Left; list of all landed species in this study. “plentiful” denotes species that are perceived to have constantly been abundant since the respondent started gleaning, while “rare” denotes the species that were perceived plentiful in the past but are rare today. Numbers with decimal places indicate proportions (%) of responses by respondents that a species is either plentiful or rare. The total number of responses from which the proportions are derived is indicated in each column. Proportions in each column add up to 100%

		Site									
		Kanamai		Kiunga		Kuruwitu		Mkwiro		Vanga	
Family	Species name	Plentiful (Total number of responses – 24)	Rare (Total number of responses – 20)	Plentiful (Total number of responses – 55)	Rare (Total number of responses – 78)	Plentiful (Total number of responses – 191)	Rare (Total number of responses – 114)	Plentiful (Total number of responses – 484)	Rare(Total number of responses – 100)	Plentiful (Total number of responses – 31)	Rare (Total number of responses – 54)
Arcidae	*Anadara antiquata*							2.07			3.70
	Barbatia trapezina							0.21			
	Mosambicarca erythraeonensis							0.41	2.00		
Buccinidae	*Engina mendicaria*					1.05					
	Pollia fumosa				1.28						
Bullidae	*Bulla ampulla*							0.21	1.00		
Bursidae	*Bursa rosa*					0.52		0.21			
	Tutufa bubo							0.41			
Cancellariidae	*Merica melanostoma*							0.21			
Cardiida	*Maoricardium pseudolima*							0.41			1.85
Cardiidae	*Tridacna maxima*	8.33				5.76		0.21			1.85
	Tridacna squamosa	4.17				2.62	0.88				3.70
Cassidae	*Cassis cornuta*	4.17			8.97	6.28	3.51	3.93	7.00	6.45	3.70
	cypraecassis rufa	4.17	5.00		5.12	6.28	5.26	3.72	5.00	9.68	7.41
	Phalium glaucum					1.05		0.62			
Cerithiidae	*Cerithium caeruleum*						0.88	0.21			
	Clypeomorus bifasciata										1.85
Chitonidae	*Acanthopleura brevispinosa*							2.69	1.00		
	Acanthopleura gemmata							1.45	1.00		
Columbellidae	*Pictocolumbella ocellata*							0.21			
Conidae	*Conus coronatus*					0.52					
	Conus ebraeus					0.52	0.88	0.21		3.23	
	Conus geographus					0.52	0.88	0.21			
	Conus imperialis										1.85

(*continued on next page*)

(*continued*)

		Site									
		Kanamai		Kiunga		Kuruwitu		Mkwiro		Vanga	
Family	Species name	Plentiful (Total number of responses – 24)	Rare (Total number of responses – 20)	Plentiful (Total number of responses – 55)	Rare (Total number of responses – 78)	Plentiful (Total number of responses – 191)	Rare (Total number of responses – 114)	Plentiful (Total number of responses – 484)	Rare(Total number of responses – 100)	Plentiful (Total number of responses – 31)	Rare (Total number of responses – 54)
	Conus litteratus										1.85
	Conus marmoreus				1.28			0.41			
	Conus rattus							0.21			
	Conus striatellus							0.62			
	Conus striatus						0.88				
Cypraeidae	*Arestorides argus*		5.00		1.28	1.05	5.26	0.41	1.00		5.56
	Bistolida owenii					0.52	0.88				
	Bistolida stolida						1.75		1.00		
	Chelycypraea testudinaria	4.17	15.00		1.28	3.14	4.39	1.45	1.00	3.23	3.70
	Cribrarula cribraria							0.21	1.00		
	Cypraea pantherina			1.82		0.52		0.62	1.00		
	Cypraea tigris	4.17	5.00	23.64	12.82	7.33	2.63	6.61	6.00	12.90	5.56
	Cypraeovula edentula				1.28	0.52		0.21			
	Erosaria erosa		5.00		1.28	1.57		1.45	1.00		
	Erosaria gangranosa							0.21			
	Erosaria helvola			1.82		0.52	1.75	0.21			
	Erosaria lamarckii							0.21	1.00		
	Erosaria marginalis							0.41			
	Erosaria miliaris				2.56		1.75	0.21			
	Erosaria nebrites							0.41	1.00		
	Erosaria poraria						0.88	0.41			
	Erosaria turdus							0.21			
	Erronea caurica			1.82	1.28	0.52	2.63	0.62			
	Erronea caurica							0.21	1.00		
	Erronea errones			1.82	1.28	1.57		0.62			
	Erronea onyx		5.00	1.82		1.05			1.00		
	Leporicypraea mappa				1.28	0.52	0.88		1.00		1.85
	Luria isabella				1.28		0.88	0.62	1.00		
	Lyncina carneola				1.28	0.52		0.62	1.00		1.85
	Lyncina lynx				2.56	0.52	0.88	1.45	1.00		
	Lyncina vitellus				1.28		0.88	0.83			
	Mauritia arabica						0.88	0.62	3.00		
	Mauritia depressa			1.82				0.41	1.00		
	Mauritia histrio						0.88	0.62	1.00		
	Mauritia mauritiana			5.45		2.09	1.75	1.45	2.00		
	Mauritia scurra				1.28		1.75				
	Melicerona felina			1.82	1.28		0.88	0.41	2.00		
	Monetaria annulus	25.00	10.00	20	3.85	4.71	1.75	3.72	1.00		1.85
	Monetaria caputserpentis					0.52		1.45	4.00		
	Monetaria moneta	12.50		16.36	1.28	2.09	1.75	5.17	8.00		
	Palmadusta asellus						1.75		1.00		
	Palmadusta clandestina			1.82	1.28	1.05		0.83			
	Palmadusta diluculum				1.28			0.41			
	Palmadusta ziczac	4.17		1.82		0.52		0.83	1.00		1.85
	Purpuradusta fimbriata				1.28						

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		Site									
		Kanamai		Kiunga		Kuruwitu		Mkwiro		Vanga	
Family	Species name	Plentiful (Total number of responses – 24)	Rare (Total number of responses – 20)	Plentiful (Total number of responses – 55)	Rare (Total number of responses – 78)	Plentiful (Total number of responses – 191)	Rare (Total number of responses – 114)	Plentiful (Total number of responses – 484)	Rare(Total number of responses – 100)	Plentiful (Total number of responses – 31)	Rare (Total number of responses – 54)
	Purpuradusta gracilis	4.17			1.28		1.75				
	Purpuradusta microdon				1.28			0.41			
	Pustalaria cicercula				1.28			0.41			
	Pustularia globulus				1.28			0.21			
	Ransoniella punctata				1.28		0.88	0.21			
	Staphylaea staphylaea							0.41			
	Talparia talpa				1.28			0.21	1.00		
Epitoniidae	*Acrilla acuminata*								1.00		
	Janthina janthina							0.21			
Fasciolariidae	*Fusinus colus*					0.52		0.62			
	Latirus polygonus				1.28	0.52		0.62			
	Pleuroploca filamentosa		5.00		1.28	1.57		1.86	1.00		
	Pleuroploca trapezium	4.17	5.00	16.36	2.56	5.24	1.75	5.17	6.00	6.45	7.41
Ficidae	*Ficus subintermedia*					0.52					
Harpidae	*Harpa harpa*		5.00			1.57	1.75	0.41		3.23	1.85
	Harpa major							0.21	2.00		1.85
Hexabranchidae	*Hexabranchus sanguineus*							0.21			
Littorinidae	*Littoraria coccinea glabrata*							0.21	1.00		
	Littoraria pallescens						1.75		1.00		1.85
	Littoraria scabra						2.63		2.00		3.70
Lucinidae	*Codakia punctata*							0.21			
Mactridae	*Mactrotoma ovalina*							0.21			
Melongenidae	*Volema pyrum*	4.17				0.52		1.86	1.00		
Mitridae	*Pterygia nucea*					0.52					
Muricidae	*Chicoreus ramosus*		5.00				1.75	3.31	2.00	9.68	3.70
	Cronia konkanensis							0.41			
	Drupa morum							0.21			
	Drupa ricinus							0.21			
	Drupella cornus							0.21			
	Drupella margariticola							0.21			
	Drupella rugosa							0.21			
	Morula granulata							0.41			
	Murex brevispina						0.88	0.41			
	Murex pecten					0.52	1.75	0.83			
	Purpura persica						0.88	0.21			
	Semiricinula squamosa					0.52					
Mytilidae	*Brachidontes pharaonis*					0.52					
Nassariidae	*Nassarius olivaceus*				1.28						
Neritidae	*Nerita albicilla*							0.41			
	Nerita polita					0.52		0.62			
	Nerita textilis							0.41			
	Nerita undata						0.88	0.41			
Olividae	*Oliva bulbosa*						1.75				

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		Site									
		Kanamai		Kiunga		Kuruwitu		Mkwiro		Vanga	
Family	Species name	Plentiful (Total number of responses – 24)	Rare (Total number of responses – 20)	Plentiful (Total number of responses – 55)	Rare (Total number of responses – 78)	Plentiful (Total number of responses – 191)	Rare (Total number of responses – 114)	Plentiful (Total number of responses – 484)	Rare(Total number of responses – 100)	Plentiful (Total number of responses – 31)	Rare (Total number of responses – 54)
Ostreidae	*Striostrea margaritacea*					0.52	0.88				
Ovulidae	*Calpurnus verrucosus*							0.21			
	Ovula ovum				1.28	1.57	1.75	0.83	3.00	6.45	
Pharidae	*Siliqua radiata*								1.00	3.23	
Phasianellidae	*Phasianella nivosa*						0.88				
Pinnidae	*Atrina vexillum*			1.82		0.52		0.41		3.23	
	Pinna muricata				1.28						
Planaxidae	*Planaxis sulcatus*										1.85
Potamididae	*Terebralia palustris*						0.88	1.24			5.56
Pteriidae	*Isognomon ephippium*							0.21		3.23	1.85
	Pinctada margaritifera							0.41			3.70
Ranellidae	*Charonia lampas*		5.00			1.57	2.63	1.03			
	Charonia tritonis		10.00		5.13	2.62	6.14	1.45	1.00	6.45	3.70
	Gutturnium muricinum					0.52					
	Lotoria lotoria					0.52					
	Monoplex gemmatus					0.52		0.21			
Strombidae	*Conomurex decorus*					0.52		0.83			
	Gibberulus gibberulus					0.52		2.07			
	Lambis chiragra arthritica	4.17	5.00		3.85	4.19	3.51	1.45	2.00	3.23	1.85
	Lambis crocata							1.24	2.00		1.85
	Lambis lambis	8.33			6.41	5.24	2.63	2.89	5.00	6.45	
	Lambis truncata	4.17	5.00			2.09	1.75	2.27	2.00	3.23	1.85
	Lentigo lentiginosus					1.05		1.03		3.23	1.85
Tegulidae	*Tectus mauritianus*							0.21			
Terebridae	*Hastula lanceata*				1.28			0.21			
	Oxymeris crenulata				1.28	0.52					
	Oxymeris dimidiata				1.28	1.05	0.88	0.21		3.23	
Tonnidae	*Tonna canaliculata*					0.52		0.41			
	Tonna galea							0.62	3.00		1.85
	Tonna perdix					0.52		0.41			
Triviidae	*Trivirostra oryza*					1.57	0.88				
Trochidae	*Agagus agagus*							0.21			
	Clanculus puniceus							0.21			1.85
	Monodonta labio					0.52		0.21			
	Oxystele tabularis					0.52	0.88				
	Stomatella auricula							0.21			
	Trochus maculatus							0.62		3.23	
Turbinellidae	*Vasum ceramicum*				1.28			1.24			
	Vasum rhinocerus				1.28			0.21			
	Vasum turbinellus				1.28			0.41			

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		Site									
		Kanamai		Kiunga		Kuruwitu		Mkwiro		Vanga	
Family	Species name	Plentiful (Total number of responses – 24)	Rare (Total number of responses – 20)	Plentiful (Total number of responses – 55)	Rare (Total number of responses – 78)	Plentiful (Total number of responses – 191)	Rare (Total number of responses – 114)	Plentiful (Total number of responses – 484)	Rare(Total number of responses – 100)	Plentiful (Total number of responses – 31)	Rare (Total number of responses – 54)
Turbinidae	*Lunella coronata*							0.62			
	Turbo argyrostomus					0.52	0.88	0.21	2.00		
	Turbo marmoratus		5.00			3.14	7.02	0.41			1.85
Turridae	*Lotyrris cingulifera*				1.28						
Veneridae	*Chione toreuma*							0.41			
	Venus sinuosa							0.21			

Appendix B. Decadal median daily weights (kg) of marine shelled molluscs landed per respondent for each site. Sample size for 1970 period = 24; 1980 = 16; 1990 = 24; 2000 = 23; 2010 = 45; total = 132. IQR = interquartile range

	Site						
	Kanamai(n = 14)Median (IQR)	Kiunga(n = 30)Median (IQR)	Kuruwitu(n = 31)Median (IQR)	Mkwiro(n = 47)Median (IQR)	Vanga(n = 10)Median (IQR)	*H*	*P*
1970	2.0(0.2–5.3)[a]	5.5(3.3–10.1)[b]	3.0(1.0–4.6)[a]	6.0(3.5–10.0)[b]		32.86	***
1980		2.0(1.3–11.8)[a]	3.0(2.0–5.0)[a]	5.5(3.0–15.0)[b]	1.0(0.2–10.0)[c]	15.83	**
1990		5.5(2.4–8.0)[a]	1.0(0.3–3.4)[b]	1.0(0.5–3.0)[b]	5.75(1.50–10.4)[a]	60.38	***
2000	0.5(0.4–0.7)[d]	6.0(1.0–14.0)[ab]	3.0(3.0–5.0)[ac]	1.0(0.5–3.0)[e]	5.0(1.5–12.5)[bc]	31.73	***
2010	3.0(1.0–4.0)[ab]	2.5(1.0–13.5)[ac]	0.6(0.5–1.5)[d]	0.7(0.4–2.0)[d]	2.5(2.0–4.1)[bc]	18.41	***

P values derived from Kruskal-Wallis tests; values that are significantly different have different superscript letters in each row following Dunn's multiple comparisons test. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, df = 4. Blank cells indicate no data was available.

Appendix C. Preference of gleaners for the size of habitat. Proportions in a site add up to 100%

	Kanamai	Kiunga	Kuruwitu	Mkwiro	Vanga
Moderate seagrass patches	27	23	16	28	12
Extensive seagrass meadows	8	53	16	20	8
Seagrass mixed with coral reefs	23	13	18	12	12
Small patches of seagrass	4	3	15	28	12
100% bare areas	19	–	23	4	8
Extensive coral reef habitat	12	7	4	6	24
Moderate coral patches	4	–	5	2	20
Any habitat	4	–	1	–	–
Purely mangrove areas	–	–	–	–	4

Appendix D. Respondent perceptions on seagrass meadow distribution. (Numbers represent proportion of respondents by site). Proportions in a category add up to 100%

Question	Answer	Kanamai	Kiunga	Kuruwitu	Mkwiro	Vanga
Have there been any changes in seagrass distribution?	Don't know	19	9	2	4	0
	No	75	14	73	42	0
	Yes	6	77	24	54	100
If yes, what changes?	Decrease	50	94	100	67	60
	Dynamic	50	0	0	24	0
	Increase	0	6	0	10	40
Have these changes affected your collection activities negatively?	Don't know	0	4	0	0	0
	No	0	9	25	43	44
	Yes	100	87	75	57	56

Appendix E. Perceived threats to marine shelled mollusc shells grouped by level of threat and per site. Proportions of respondents per site indicated by – None – no respondent (0%), Very few <5% of respondents, Few 5–10% of respondents, several 11%–20% of respondents, and many >20% of respondents

Perceived threat	Level of threat	Kanamai	Kiunga	Kuruwitu	Mkwiro	Vanga
Overcollection	High	Many	None	Many	Many	Many
	Medium	Several	None	Several	Few	None
	Low	None	None	Very few	Very few	None
Elevated temperatures	High	Several	Several	Few	Many	Several
	Medium	Few	None	Several	Several	Many
	Low	None	None	Very few	Very few	Very few
Sea urchin herbivory of seagrass meadows	High	None	Many	None	None	None
	Medium	None	None	Very few	None	None
	Low	None	None	Very few	None	None
Habitat destruction	High	None	Several	None	Very few	None
	Medium	None	None	Very few	Very few	Few
	Low	None	None	Very few	None	Several
Mollusc predation	High	Several	None	None	None	Very few
	Medium	None	Few	Very few	None	None
	Low	None	None	Very few	None	Few
Disregard of traditional taboo practices and beliefs*	High	None	None	None	Very few	None
	Medium	None	None	None	Very few	None
	Low	None	None	None	Very few	None
Migrant fishermen	Low	None	None	None	Very few	None
Poor law enforcement	High	None	None	None	Very few	Very few

*Disregard of traditional taboo practices and beliefs includes indecent dressing by women gleaners and unaccepted gleaning tool handling.

Appendix F. General characteristics of respondents interviewed in five sites (n = 132). NEM = Northeast monsoon and SEM = Southeast monsoon

Experience category	Gender (%)		Age (±SD)	Gleaning experience (years)± SD	Days spent gleaning per week. Hours/day in parenthesis (±SD)		Monthly income (USD± SD)	
	Female	Male			SEM	NEM	SEM	NEM
Kanamai	69.2	30.8	47.54 ± 16.63	14.65 ± 19.78	4.92 ± 2.33 (2.73 ± 1.86)	6.33 ± 1.23 (3.63 ± 1.82)	43.5 ± 64.36	48.1 ± 40.18
Kiunga	76.7	23.3	47.41 ± 16.37	23.13 ± 13.12	4.73 ± 1.36 (2.96 ± 0.77)	5.75 ± 0.60 (3.09 ± 0.83)	57.7 ± 37.66	66.1 ± 47.74
Kuruwitu	42.9	57.1	43.21 ± 14.03	19.80 ± 18.76	5.91 ± 1.85 (3.07 ± 1.25)	5.86 ± 1.96 (3.59 ± 1.59)	62.2 ± 59.65	64.1 ± 57.35
Mkwiro	96.2	3.8	39.51 ± 14.00	18.52 ± 16.20	5.06 ± 1.46 (3.91 ± 1.15)	5.09 ± 1.54 (3.74 ± 1.27)	76.2 ± 154.43	55.2 ± 52.98
Vanga	_	100	39.40 ± 9.47	18.40 ± 9.79	5.57 ± 0.53 (4.00 ± 0.00)	5.71 ± 1.54 (4.00 ± 1.27)	56.3 ± 40.24	42.4 ± 34.05

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