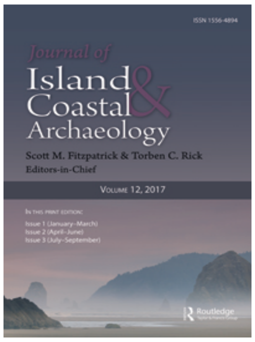

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Seasonal Patterns of Coastal Exploitation on the Farasan Islands, Saudi Arabia

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ABSTRACT

Here we present the results of the analysis of coastal exploitation patterns in the southern Red Sea during the Middle Holocene. We focus on the shell midden cluster of the Farasan Islands, Saudi Arabia, which comprises over 3,000 shell midden sites. These sites date from 6,500 to 4,500 cal BP and are part of an arid landscape. We focus on one site, JW1727, which provides a snapshot of marine exploitation and will help to understand the use of food resources within the region. Stable isotope values ($\delta^{18}O$) were collected from the marine gastropod Conomurex fasciatus *(Born 1778), which represents 72% of shell weight of JW1727, in order to reconstruct the season of capture. Results demonstrate that 1) every season is represented within the dataset; and 2) there is increased* C. fasciatus *deposition during the summer and autumn months. This indicates a diet consisting of* C. fasciatus *throughout the year in combination with other food sources and an increase of the* C. fasciatus *component during the arid seasons, possibly linked to the unavailability of vegetation. Additionally, size measurements of* C. fasciatus *were carried out to examine changes in size distribution throughout the occupation of the site that could be related to overexploitation of* C. fasciatus*. However, no significant trends could be observed. In sum, the results suggest a sustainable and constant habitation of the Farasan Islands despite the highly arid conditions.*

Keywords Arabia, coastal archaeology, oxygen isotopes, seasonality, shell midden

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Color versions of one or more of the figures in the article can be found online at http://www.tandfonline.com/uica.

INTRODUCTION

Shell middens are one of the main sources of archaeological evidence along the Red Sea coastline of southern Arabia. Despite this, they are seldom the subject of intensive study and their role in the subsistence of prehistoric coastlines is not yet understood. In this paper we focus on shell deposits from the Farasan Island archipelago in the southern Red Sea (Figure 1). During the Middle Holocene (6,500–4,500 cal BP) the Farasan Islands were a place for the intense exploitation of marine mollusks, which resulted in over 3,000 shell midden sites that remain a dominant feature of the modern coastline (Alsharekh and Bailey 2014; Bailey et al. 2013; Meredith-Williams et al. 2014).

During the Middle Holocene a change in the solar insolation and a corresponding southward movement of the Intertropical Convergence Zone (ITCZ) between 8,000 and 6,000 cal BP (Fleitmann et al. 2003; Lézine et al. 2014) caused a weakening of the summer monsoon in Arabia. The lack of rain had a drastic impact on the climate and likely caused a shift in subsistence strategies. As the climate deteriorated, reliable food sources became more important. For the Red Sea coastline, which has a more arid climate than the temperate mountains nearby, the subsistence strategies are largely unknown. Earlier research (Boivin and Fuller 2009; Durrani 2005; Khalidi 2005; Tosi 1985, 1986a, 1986b; Zarins et al. 1980) showed the prevalence of shell midden sites along the coastline but was not able to comprehensively link the use of marine resources to any form of subsistence strategy. Because the Farasan Island shell mounds are unequaled in their preservation, size, and concentration, due to the remoteness of the islands and the lack of building developments, they are a prime example for the analysis of coastal exploitation, studies of seasonality, and the sustainability of large-scale mollusk consumption.

Here we use stable oxygen isotope values ($\delta^{18}O$) to determine the season of collection, a method that has successfully been applied to shell midden sites around the world (Burchell 2013; Colonese et al. 2012; Eerkens et al. 2013; Mannino et al. 2003; Prendergast et al. in press; Schweikhardt et al. 2011). The seasonally changing $\delta^{18}O$ values relate to changes in temperature as well as the isotope composition of the ambient water that the shells grow in, which itself is controlled by evaporation, precipitation, and freshwater inflow (Leng and Lewis 2014). Measuring the stable oxygen isotope values of mollusk shell carbonate thus potentially provides information on the seasonal changes in the local environment. Additionally, the terminal data points from the very edge of the shell can be used to determine the season when the animal stopped precipitating carbonate (i.e., the time of death and collection by humans). Based on this principle, this study makes use of the seasonally changing $\delta^{18}O$ values in *Conomurex fasciatus* (Born 1778; Hausmann et al. 2015a), the most abundant shell species of the JW1727 shell mound (72%), to reconstruct exploitation patterns that resulted in shell accumulation. In addition, we analyzed the species composition of JW1727 as well as the shell size distribution of *C. fasciatus* to explore the possibility of impact of human predation on the mollusk population. This allows us for the first time to draw conclusions about the role of shellfish in the diets of people inhabiting Farasan and about the sustainability of the coastal environment of the southern Red Sea during the Middle Holocene.

ARCHAEOLOGICAL BACKGROUND

The Neolithic in the Tihamah Coastal Plain

The Red Sea coastal plain of Saudi Arabia and Yemen, termed Tihamah (Figure 1), mainly consists of fluvial deposits from the Holocene and is crossed by wadis that only seasonally carry water. Knowledge of the occupation of the Tihamah during the Neolithic period is based on only a few sites, which are roughly divided into the Jizan group in the North and the Hodeidah group in the South (Durrani 2005).

The Jizan and Hodeidah site clusters contain characteristic flakes that are typical

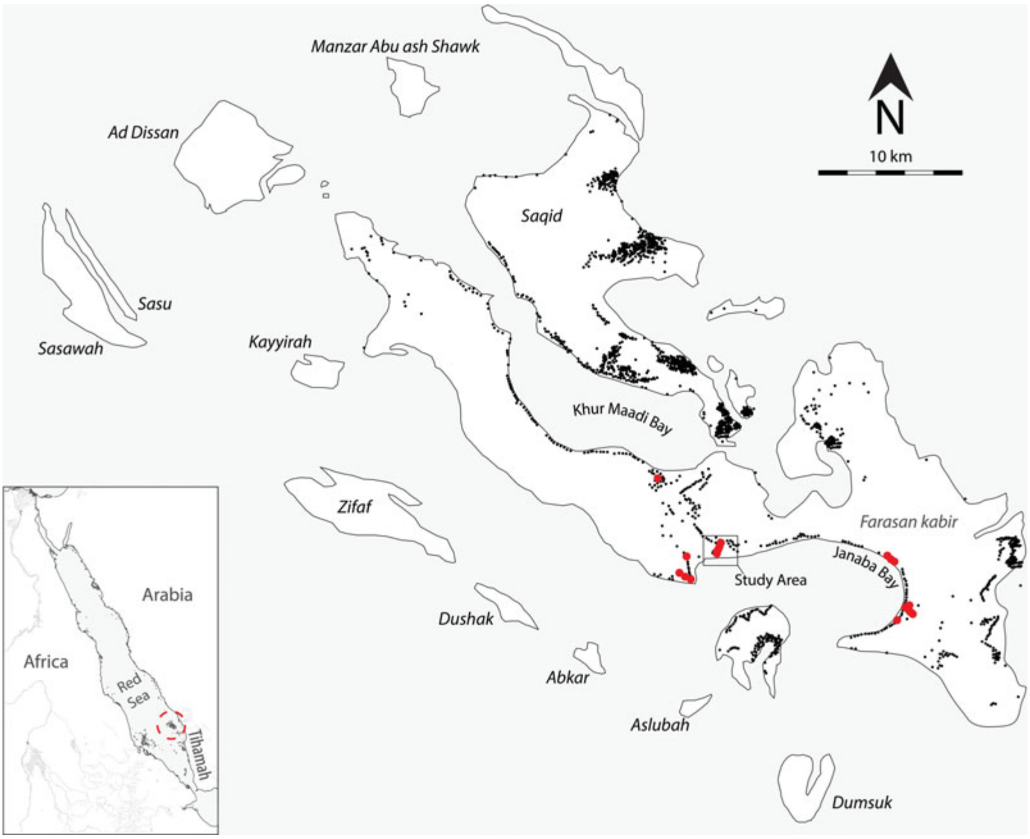

Figure 1. *Location of Farasan Islands within the Red Sea (red circle), and location of study area on Farasan (black rectangle). Black dots indicate surveyed shell midden sites; red dots indicate excavated sites.*

for the Arabian bifacial group (Zarins et al. 1980) dating to the Early Holocene 9,000–5,000 cal BP (Sanlaville 1992). The majority of sites from this period consist of shell middens of *Terebralia palustris* and lithic scatters with little depth and a general lack of stratified material, which makes them difficult to date accurately. The shell middens in the Jizan area were radiocarbon dated from between 7,000 and 5,000 cal BP (Grigson et al. 1989; Zarins and al-Badr 1986). However, the dated material was shell carbonate sampled at the surface of middens without stratigraphic context. Faunal material consisted of some heavily abraded mammal bones and ostrich eggshell, but also marine shells, indicating a subsistence strategy that integrated marine and terrestrial resources (Durrani 2005; Tosi 1985, 1986b).

The shell middens of the Hodeidah group lie in western Yemen. There are few radiocarbon dates from these shells. Dates from the site of Gahabah ranged from 8,000 to 7,500 cal BP and dates from sites in the Wadi Surdud ranged from 7,000 to 5,500 cal BP (Durrani 2005). Bifacial arrowheads indicate a Neolithic tradition for some of the shell middens.

The overall preservation of the Tihamah middens and also the uncertain connection to inland sites (Khalidi et al. 2010) make it difficult to ascertain other activities that might have taken place in the vicinity of the sites. However, some indicators might point to a more diversified diet and lifestyle than solely shellfish consumption. Net weights were found as well as several ground stones (Durrani 2005). Additionally, several sites of the Hodeidah group, namely Ash Shumah, Gahabah, and Surdud-1 have faunal assemblages containing a mixture of bones from cattle (*Bos*), wild donkey (*Equus africanus*), and ass (*Equus asinus*). A comprehensive interpretation of these sites is problematic as the preservation and low visibility lead to only a small number of viable identifications and thus generate blurred and distorted views (Wilkinson 2010).

Farasan

General background. Today the Farasan Islands have a subtropical desert climate. The only water they receive is some precipitation from December to April with a maximum monthly rainfall of 22 mm during February. Evaporation is much higher than rainfall, but the groundwater levels are high enough to sustain some vegetation (Mutairi et al. 2012). Plants are also supported by the condensation of water from the very humid air.

The marine ecosystem around the Farasan Islands has extraordinarily favorable conditions for shellfish exploitation; the waters are warm and rich in nutrients providing a good environment for marine fauna (Gladstone 2000). The number of human inhabitants increased following the closure of a military base, and the islands became more accessible. This increased the development of infrastructure and tourism, which in turn led to the discovery of archaeological sites. Within a few years, this almost unknown region transformed to a key area to investigate coastal archaeology of the region, which has one of the highest concentrations of shell mounds worldwide (Bailey et al. 2013).

During 2013, 18 shell middens were excavated in different parts of Farasan Kabir (Meredith-Williams et al. 2013) (Figure 1). This included larger shell mounds with heights between 4 and 5 m and diameters of ca. 30 m, as well as smaller shell scatters of under 0.5 m in height and less than 10 m in diameter. Both types occurred in clusters as well as in rows along palaeo-shorelines.

Radiocarbon dates on charcoal and shells suggest that the majority of shellfish exploitation occurred over a 2,000-year period, with single sites indicating different lengths of exploitation and few sites indicating a continuation of small-scale exploitation into historic times (Bailey et al. 2013). For the majority of the sites, shells were clast supported and lacked signs of being crushed or having been exposed for longer periods. The opposite of long exposure can be assumed; these well-preserved shells were quickly covered by new shell deposits and because of that were immediately protected.

During the excavations, few artifacts were found (Hausmann et al. 2015b). Pottery was present on the surface of or in the upper layers of several middens. However, observed bioturbation suggests that these artifacts may have been accidentally introduced into the deposit and thus it is likely that pottery remains are more recent than the shell middens.

JW1727. The focus of this study is the shell mound JW1727. The site is located in the north-western part of Janaba Bay and is now at ca. 0.75 km away from the sea due to tectonic uplift (Figure 2). The shell mound has a dominant position in the landscape as it sits on a distinct palaeo-shoreline, visible as a sand ridge, in line with several dozen similar shell middens. Because of its size, approximately 2 m in height and 30 m across, it provided a good opportunity to access a detailed stratigraphy of shell deposition. In addition, together with the sites JW1705, JW5694, JW5719, and JW5697, which show some changes in size and composition, it forms a transect following the direction of the shift in shoreline with the changing position of relative sea-level change and provides some insight into the change of coastal exploitation in this part of the bay. In Figure 2, note the general connection between occupation date and distance to the modern shoreline.

During the excavation, a 1 m wide trench was cut into the midden from the rim towards the center. This exposed the stratigraphic sequence in three sections, two

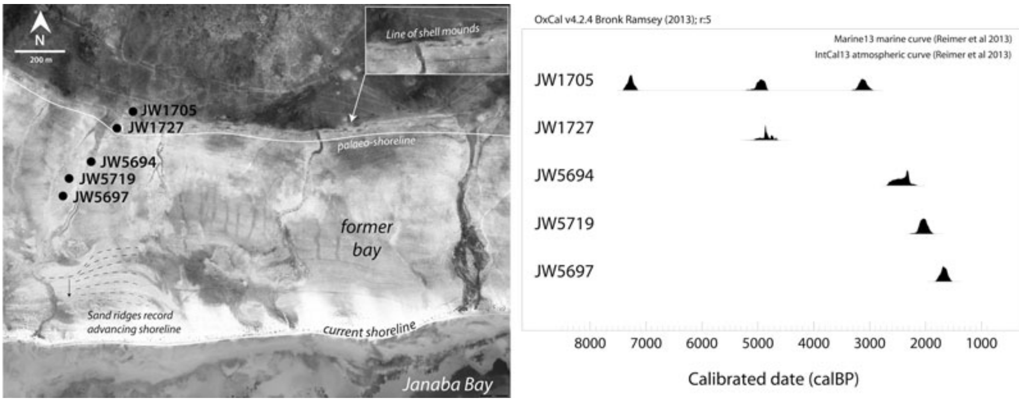

Figure 2. *Location of JW1727 and nearby excavated midden sites with radiocarbon dates. Note the short occupation period of JW1727. Radiocarbon dates can be found in the supplementary material (available online).*

long lateral sections, and one short section in the center of the mound. The exposed stratigraphy showed well-defined layers of *C. fasciatus* often mixed with other shell species, as well as ash and charcoal, suggesting the remains of processing areas in the form of hearths. Apart from a single potsherd no artifacts were found during the excavation that could give insight into the activities at the site. Layers were least disturbed at the central column and signs of erosion and mixing of layers on the slopes were observed.

Radiocarbon dates from the central column of JW1727 were taken at the base, the center and the top of the midden. Despite the size of the mound ($\sim$160 m^3), the dates are very close to each other and suggest a very short occupation period (Hausmann and Meredith-Williams 2016).

METHODS

Analysis of Bulk Samples for Species Composition and Size Distribution

A column of bulk samples was analyzed to determine the species composition and change in size of *C. fasciatus* shells throughout the deposit (Figure 3). Bulk samples were taken from the central column of JW1727 (Table 1). Using a dustpan and trowel, blocks of 25 $\times$ 25 cm were taken with a thickness of 10 cm, where the layers allowed it. The thickness was reduced accordingly when layers were thinner than 10 cm. All samples were sieved with 4 mm and 1 mm mesh screens to account for any smaller fragments in the material such as fish bones.

For the analysis of shell size, we measured a distinct part at the lip of 2,816 *C. fasciatus* shells. Specifically, we measured the distance between the posterior canal and the stromboid notch (Figure 4A) (hereafter "aperture-size"). Since the lip-parts are often better preserved than the main body of the shell, this method allowed us to measure a larger number of mollusks than would otherwise have been possible. A small number of shells ($n = 100$) was used to establish the relationship between total length and aperture-size (1 to 1.8 $\pm$ 0.1). Changes in shell sizes and age as well as in species composition are often associated with human exploitation because the human predation can be more efficient than the reproduction of the targeted animal.

Seasonality Study

Modern reference for Conomurex fasciatus. *Conomurex fasciatus* is a small (3–5 cm adult size), herbivorous conch

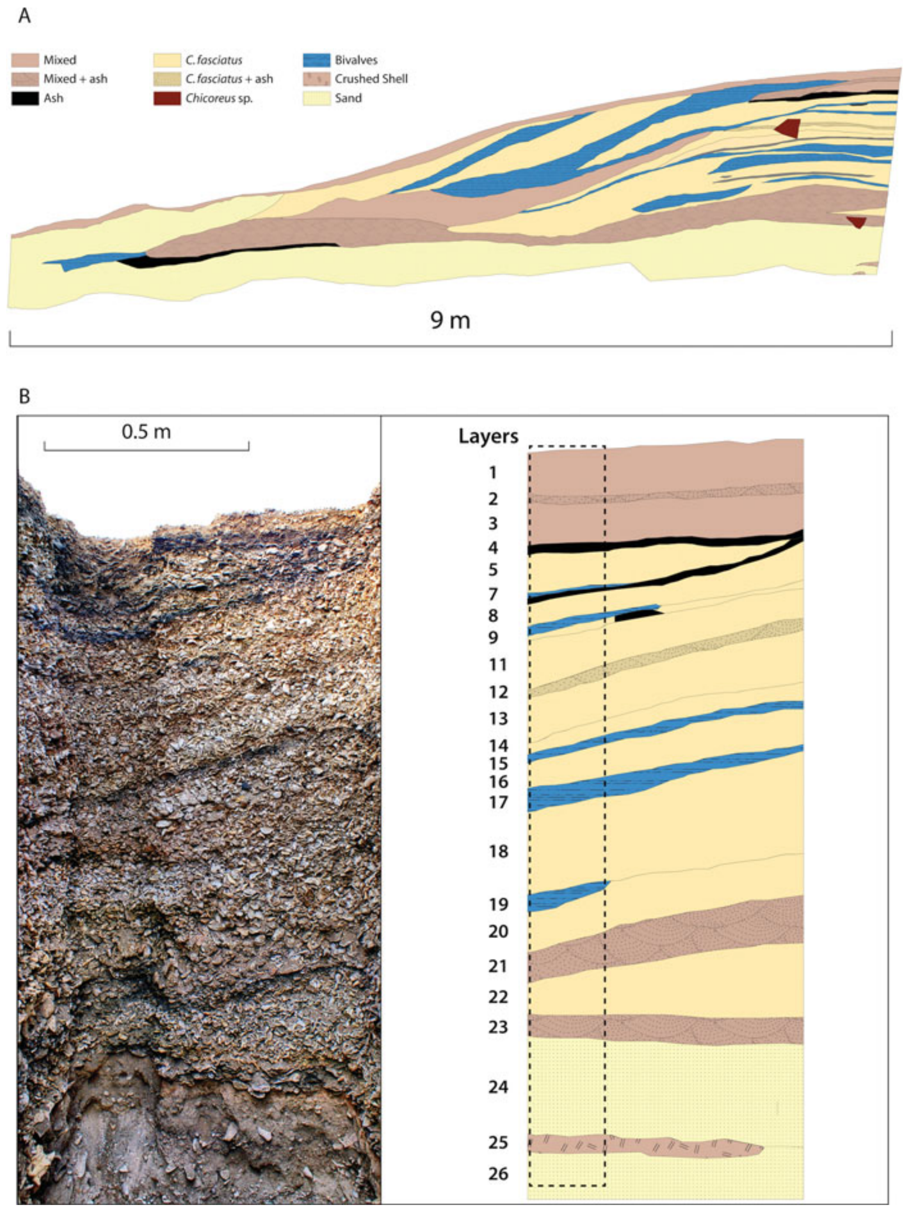

Figure 3. *A: Section drawing of the western section of JW1727. B: Photo of the central section after collection of bulk samples and corresponding section drawing with sampled area as indicated by the dotted line.*

that grazes on algae and detritus in tropical and subtropical waters. *C. fasciatus* grow quickly in their juvenile stage (~80 mm/year), with the growth rate slowing during the adult stage (~13 mm/year) (Hausmann et al. 2015a), when the shell develops a distinct lip on the aperture and only grows in thickness (Appeldoorn 1988).

Table 1. **Summary information of shell samples analyzed from the central column of JW1727.**

Layer	Samples taken	Total weight (g)
1	2	1107
2	1	1428
3	3	2057
4	1	1476
5	1	1158
6	1	965
7	1	568
8	1	1301
9	1	1477
11	2	1897
12	1	682
13	1	540
14	1	281
15	1	969
16	1	1107
17	1	2338
18	4	1989
19/20	2	1869
21	1	1857
22	1	1328
23	1	1075
24	2	631
26	1	72

While growth stops were apparent in some shells, they could not be linked to specific seasons. Neither did changes in growth rate relate to specific seasons (Hausmann et al. 2015a). While they were not encountered before, changes in growth patterns can still be a factor even if they are small and need further research of the species. Shells can vary in size at maturation as a result of biotic and abiotic factors, including nutrient availability, habitat suitability, and predator proximity. Thus, their growth is highly locational specific. *C. fasciatus* is found in subtidal shallow water areas around reefs, which includes clean sand, seagrass beds, and sand patches on reef flats. In some locations they can be encountered in the dozens (Bailey et al. 2013), but during our surveys, group sizes of below 10 were often encountered. There is a distinct contrast between these modern encounter rates and the rates that persisted during the accumulation of the middens. In addition, the sheer abundance of these shells in the archaeological record suggests that the *C. fasciatus* population in the past was much larger. Harvesting smaller shells (a single specimen of *C. fasciatus* provides about 2.5 g of shell meat) is only a profitable activity when the mollusks can be collected in large numbers and in a short amount of time. It is unlikely that today's low encounter rates were the norm during the accumulation of the shell mounds.

From November 2012 to March 2014, a modern reference study was carried out to track seasonal changes of the $\delta^{18}O$ values in *C. fasciatus* shells (Hausmann et al. 2015a). It was found that on Farasan, *C. fasciatus* grow their shell in isotopic equilibrium with the surrounding water and that the seasonal changes in $\delta^{18}O$ values are effectively caused by changes in sea surface temperature. This is favored by the local marine environment that experiences little changes in salinity (38–39 psu), but moderate changes in temperature (26.5–34.9°C).

Here, we use this ability to track seasonal temperature change to determine the season of harvest. Temperature change throughout the year is roughly sinusoidal and allowed us to divide the year into all four seasons. In addition to that, it was often necessary to define the time of harvest as actually being between two seasons.

Sample selection. Six layers (1, 8, 13, 18, 20, 22) were chosen from the column for the seasonality study. This was done to cover the beginning and the end of occupation at JW1727 and also to pick up on trends happening throughout its exploitation. Additionally, the layers that were chosen from the center of the column contained well-preserved *C. fasciatus* shells. Complete shells and shell fragments that had a preserved adult lip were picked out of the exposed and cleaned section after the drawing of the section profile, and packed into bags according to their layers and sublayers

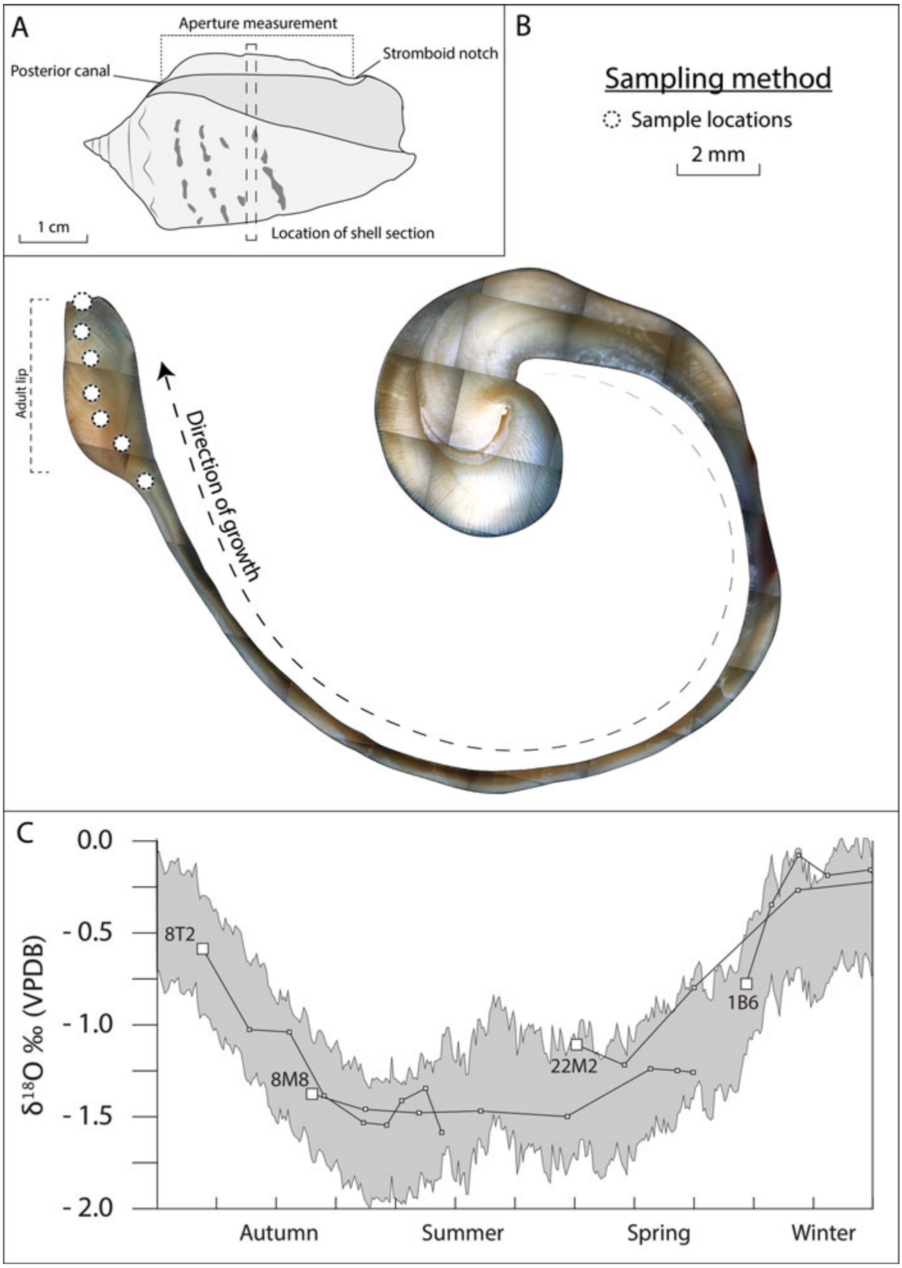

Figure 4. *A:* C. fasciatus *shell with indication of how specimens were measured for size and the position of the section. B: Indication of how shell sections were sampled in the adult lip. C: Examples of how sequential* ^{18}*O values of archaeological shells (shell ID: 8T2, 8M8, 22M2, 1B6) were visually fitted to the modern reference of estimated* ^{18}*O values based on Hausmann et al. (2015a). Large white rectangles indicate terminal* ^{18}*O value, smaller rectangles connected by black lines are preceding values.*

Table 2. **Numbers of shells collected from the section for seasonality study per layer. T, C, and B indicate "top," "center," and "base," respectively.**

Layer	MNI in bulk sample	Sublayers	Collected from section	Sampled for seasonality
1	177	T	16	2
		B	7	5
8	317	T	9	5
		C	16	8
		B	7	6
13	73	T	3	3
		C	13	7
		B	7	7
18	484	T	9	6
		C	13	8
		B	10	7
20	220	T	7	7
		B	8	8
22	263	A	28	7
Total				86

(top, center, base; Table 2). We chose to pick shells from the section to secure their individual location in the stratigraphy. It was visible from the exposed section that all sampled layers predominantly consisted of *C. fasciatus.*

Layer 8 is a distinct layer of well-preserved *C. fasciatus* shells with a thickness of between 11 and 8 cm. It is slightly sloped downwards towards the rim of the mound, overlies a layer of bivalves (layer 9), and is covered by a dense layer of charcoal (layer 7). Borders between these layers are distinct and no mixing seems to have occurred. Thirty-two shells were collected, with 19 sampled for stable isotope analysis. The shells were grouped into "top" ($n = 5$), "center" ($n = 8$), and "base" ($n = 6$) depending on their location within layer 8.

In layer 13 a similar sampling strategy was carried out. However, only 23 shells were collected because of a higher degree of fragmentation in the top part of the layer. It was covered by a *C. fasciatus* layer mixed with ash (layer 12) and overlaid another *C. fasciatus* layer with a distinct orange staining of unknown origin (layer 14). Layer 13 can be traced over 4 meters along the perpendicular section of the trench and was finally cut by a mixed layer of *C. fasciatus* and bivalves.

Layer 18 was also a *C. fasciatus* layer with little to no sedimentary matrix and in pristine preservation. Shells were again chosen for analysis from the top ($n = 3$), middle ($n = 8$), and bottom ($n = 7$). For layer 20 we defined two groups of shells, from the top of the layer ($n = 7$) and from the base of the layer ($n = 8$). All shells were sampled. Apart from *C. fasciatus*, layer 20 contained a small amount of *Arca avellana* and *Pinctada* species. Additionally, two smaller layers were analyzed at the top and the base of the midden (layer 1, layer 22).

Analysis of shell carbonate. After collection, all shells ($n = 86$) were processed in the laboratory at the University of York, and isotope analysis was performed at the Stable Isotope Facility of the British Geological Survey as previously described in Hausmann et al. (2015a). Since all shells were adult, they were drilled for aragonitic carbonate on the flared lip, which develops when *C. fasciatus* matures and which contains the most recent growth increments. The shell lip was sectioned along the axis of growth (Figure 4A) and following the sectioning, samples of carbonate were obtained by drilling sequentially along this section using a 0.4 mm drill bit attached to a Dremel drill (Figure 4B). Sequences of carbonate samples started at the very edge of the shell on the most recent growth increment. Considering the estimated growth rate for adult specimens (~13 mm/year; Hausmann et al. 2015a), the 0.4 mm sample area probably represents about two weeks of growth. However, this is only a tentative estimation as no comprehensive growth study has previously been carried out on *C. fasciatus.* Sequential samples were separated by gaps of 0–0.2 mm, although larger gaps (3–4 mm) were taken for samples on the main body of the shells. Generally, sequences of 10–15 samples were taken (shortest sequence: 7; longest sequence: 28).

Approximately 50–100 micrograms of carbonate powder samples were used for isotope analysis using an IsoPrime dual inlet mass spectrometer plus Multiprep device. Carbonate samples were loaded into glass vials and sealed with septa. The automated system evacuates vials and delivers anhydrous phosphoric acid to the carbonate at 90°C. CO_2 was collected for 15 minutes, cryogenically cleaned, and passed to the mass spectrometer. Isotope values ($\delta^{18}O$) are reported as per mill (‰) deviations of the isotopic ratio ($\delta^{18}O/^{16}O$) calculated to the VPDB scale using a within-run laboratory standard calibrated against NBS-19. The $CaCO_3$ - acid fractionation factor applied to the gas values is 1.00798. Due to the long run time of 21 hours a drift correction was applied across the run, calculated using the standards that bracketed the samples. The average analytical reproducibility of the standard calcite (KCM) is 0.05‰ for $\delta^{18}O$.

Subsequently, the sequential $\delta^{18}O$ values were compared and fitted to the estimated $\delta^{18}O$ values based on the modern reference (Hausmann et al. 2015a) (Figure 4C). Where it was not possible to sensibly fit the data to the expected seasonal changes in $\delta^{18}O$, shells were excluded from the study.

RESULTS

Species Composition and Shell Size

Generally, analysis of the bulk samples showed a clear dominance of *C. fasciatus* shells (72% of weight). Small percentages of *Arca avellana* (6%), *Modiolus auriculatus* (4%), *Beguina gubernaculum* (5%), *and Pinctada* species (5%) were also found (Figure 5, Table 3). Considering these proportions, the description of "mixed" layers in the section drawing can be defined as layers with a *C. fasciatus* component of below 70%. When previously viewed in the section, layer 15 was described as a bivalve layer. However, the analysis of the bulk samples showed a high amount of *C. fasciatus* shells (>80%). It is likely that while this layer was visible in the section, it was not captured in the bulk sample and instead amalgamated with layers 14 and 16 (72% and 94% *C. fasciatus*, respectively). Apart from the main species above, 42 additional species of gastropod and 26 species of bivalves were found in the assemblage (supplementary material 2).

In general, no major trends in species composition were visible throughout the column. Only the initial layers (23–26) at the base of the midden, which contained a relatively more mixed composition, potentially indicate an exploitation period prior to the focus on *C. fasciatus*. Layers with large amounts of charcoal were more often associated with more mixed layers of shell, possibly indicating a change in processing technique.

Size Distribution of *C. fasciatus*

We measured the aperture size of 2,816 shell specimens (Figure 6) and found no major trends indicating a shift in exploitation strategy happening over the course of the accumulation of the midden. Additionally, no signs of overexploitation of the resource were found. The mean aperture size in JW1727 was 21.1 mm with a minimum of 20.0 mm (Layer 23) and a maximum of 22.3 mm (Layer 24). However, both minimum and maximum mean size were likely to be the result of the small sample number in layers 23 and 24.

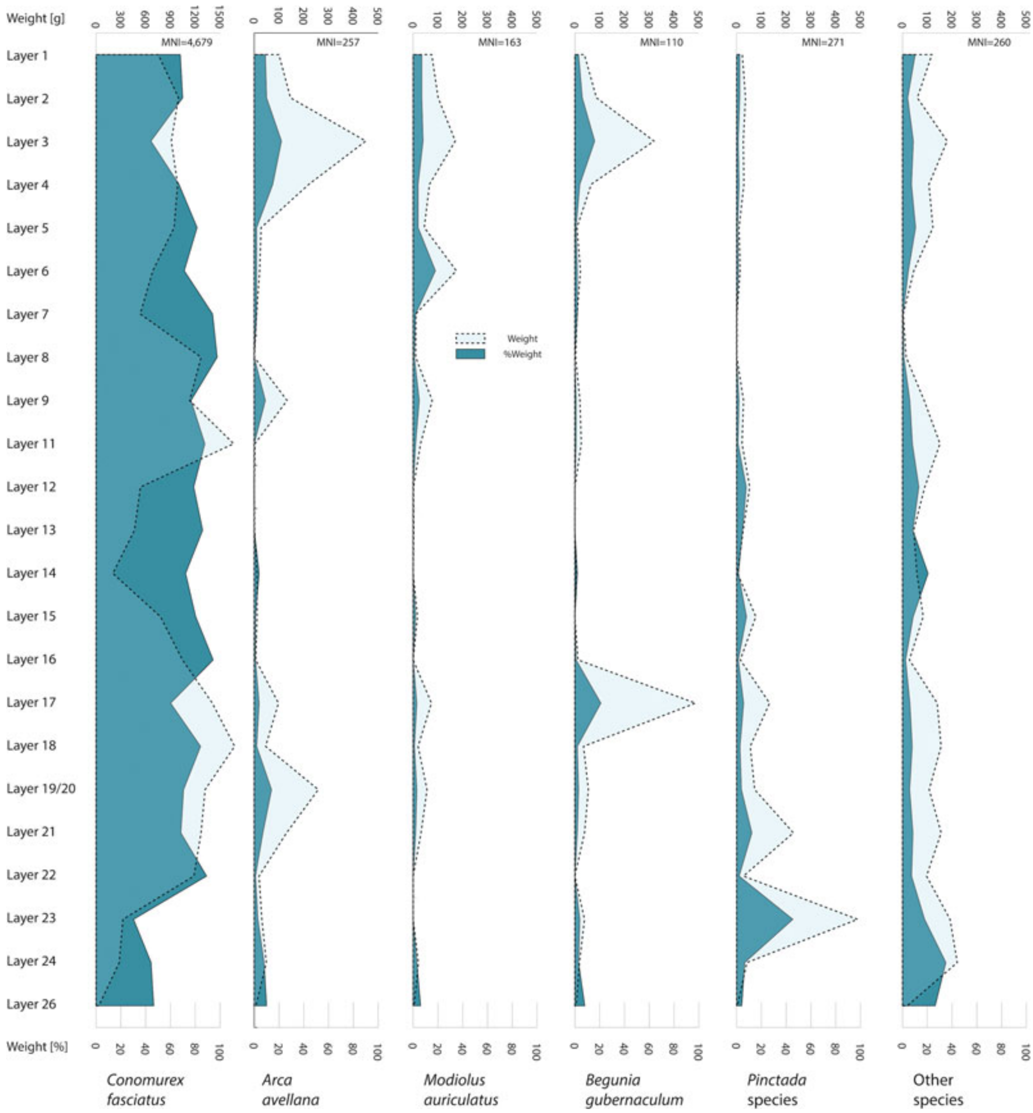

Figure 5. *Species composition with the five dominant species.*

Aperture sizes in almost every layer are normally distributed. Whilst the size distribution in some layers was skewed positively (4, 7, 11, 16, 17), this was only marginally so and were not distinct enough to be indicative for overexploitation. Layer 8 stands out with a platykurtic distribution. In this layer, few specimens have an extreme aperture size below 20 mm or above 24 mm. The reason for this concentration of medium-sized shells was not apparent and not discernibly linked to any other measurement of this layer.

Between layers short-term changes of the mean size were visible and most prevalent in the lower layers (22–26). However, this is likely to be the result of small sample sizes.

Table 3. **Weight (g) of dominant species found in the bulk samples.**

Layer	***Conomurex fasciatus***	***Arca avellana***	***Modiolus auriculatus***	***Beguina guberna***	**Pinctada species**	**Other species**	**Total**
1	752	100	75	39	23	119	1,108
2	998	147	101	87	36	60	1,429
3	911	450	170	319	27	180	2,057
4	987	221	66	66	30	107	1,477
5	944	28	45	9	10	123	1,159
6	687	22	174	23	14	46	966
7	534	10	11	9	2	3	569
8	1,271	1	11	3	1	15	1,302
9	1,132	133	77	21	28	88	1,479
11	1,665	3	30	26	22	151	1,897
12	538	0	2	0	53	90	683
13	465	2	3	0	27	45	542
14	203	11	0	5	4	58	281
15	779	12	18	0	78	84	971
16	1,046	6	0	13	15	28	1,108
17	1,407	98	74	487	133	140	2,339
18	1,677	46	20	35	55	156	1,989
19/20	1,320	259	56	55	73	108	1,871
21	1,271	131	32	39	229	156	1,858
22	1,184	20	0	0	28	97	1,329
23	325	31	0	39	488	192	1,075
24	280	49	21	19	42	221	632
26	34	7	4	6	3	19	73
Total	20,403	1,782	988	1,296	1,418	2,284	28,171
%	72	6	4	5	5	8	

Additionally, pairwise Mann-Whitney tests were used to examine whether there were statistically significant changes in frequency distribution between neighboring layers. The only significant change in mean aperture size was between layers 7 and 8 (with a mean size of 21.1 and 22.0, respectively, p-value with a Bonferroni correction of 0.03).

A more gradual change in mean size was found from layer 22 to 16 with values changing from 21.3 to 20.4 mm. In JW1727, Layer 22 was the first layer that was almost completely composed of *C. fasciatus*, and was likely to be the first instance of large-scale exploitation that took place at JW1727. This exploitation strategy possibly continued through to layer 16, as layers which contained the gradual change in aperture size (20, 19, 18, 16), were also purely composed of *C. fasciatus.* Only layers 17 and 21 also contained *Begunia gubernaculum* and *Arca avellana* shells to a small degree.

In total, the small changes in mean size and the generally normally distributed frequency distributions both indicate that the population of *C. fasciatus* was not overexploited and the general structure was not being influenced by a disproportionate exploitation of larger specimens. It has been

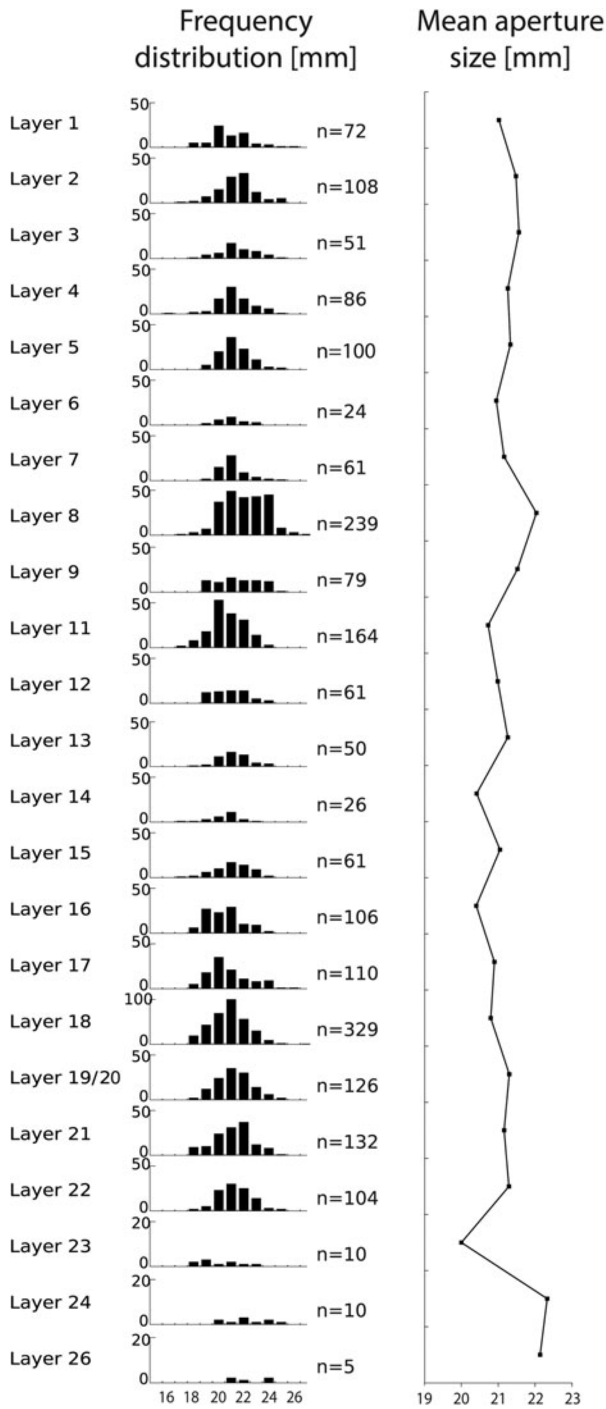

Figure 6. *Frequency distribution of the size of* C. fasciatus *shells throughout the column. Note the changing scale on the y-axis in layers 18, and 23–26. Aperture values are also available in the supplementary material (available online).*

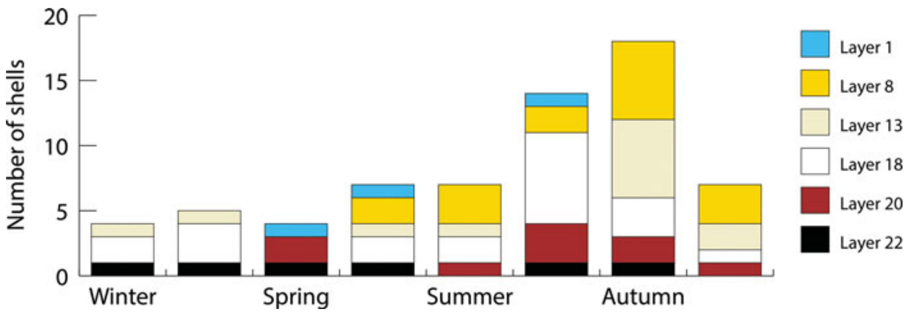

Figure 7. *Distribution of seasonality values in the analyzed layers.*

shown that environmental or pathological factors can also influence the mean size of shells, but do not usually have an effect on the mean age of the population. Hence measures of both the age and size are preferred to conclude whether natural factors or human predation affected the shellfish population (Campbell 2008; Claassen 1998; Giovas et al. 2010; Mannino and Thomas 2002; Milner et al. 2007; Roy et al. 2003). Here, we were not able to measure the individual age of the specimens, because the shell of *C. fasciatus* does not show clear indicators of age beyond a basic grouping of specimens into juveniles or adults based on the development of the thickened lip. However, because there are no major trends in size distribution to be found in our dataset, this lack of information should not be too significant.

Stable Isotope Values

Of the 86 shells that were analyzed through a total of 862 individual stable isotope measurements, 66 shells produced sequential $\delta^{18}O$ values that could be interpreted. Some sequences were incomplete because carbonate samples did not produce good-quality mass spectrometric values and hence were excluded from further analyses. The data can be found in the supplementary material 4.

Isotopic analysis of sequential shell carbonate samples indicate that *C. fasciatus* was exploited throughout the course of the year (Figure 7; Table 4), with an increase in exploitation in the second half of the year. Almost half of all analyzed shells indicate an exploitation during summer–autumn ($n = 14$, 21%) and autumn ($n = 18$, 27%), whilst winter and winter–spring had the lowest amount of harvested shells.

This range of seasons was also reflected in the distribution of seasons within single layers. This suggests that there were no major changes in the site seasonality. Layers where a large number of shells were able to be analyzed demonstrated this trend very clearly. In contrast, layers with fewer indicators for seasons of harvest did not reflect the general trend. This is likely due to the small sample. Still, their distributions do not dramatically differ from the overall result.

Layer 8 showed a succession of seasons from its base to the top. Shells from the base indicate a summer exploitation ($n = 4$), shells from the center a summer–autumn exploitation ($n = 7$), and shells from the top an exploitation in autumn–winter ($n = 5$). Since no shells from other seasons were found in this layer, it is likely that layer 8 represents a period of relatively continuous exploitation over the course of about half a year.

DISCUSSION

Site Composition and Changes in *C. fasciatus* Size

In general, the analysis of the species composition and the changes in size of *C. fasciatus* showed little variation throughout

Table 4. **Seasonal distribution of shells by layer and sublayer.**

Layer	Spit	Winter	Winter–Spring	Spring	Spring–Summer	Summer	Summer–Autumn	Autumn	Autumn–Winter	Total
1	All			1	1		1			3
8	Top							3	2	5
	Center					1	2	3	1	7
	Base				2	2				4
13	Top		1		1				1	3
	Center	1						4	1	6
	Base					1		2		3
18	Top	1			1	1	2	1		6
	Center		2			1	2	1	1	7
	Base	1	1		1		3	1		7
20	Top			2		1	1	1		5
	Base						2	1	1	4
22	All	1	1	1	1		1	1		6
Total		4	5	4	7	7	14	18	7	66

the column. Considering the short period of occupation of JW1727 (<100 years) it is less likely that major changes in either species composition or size would be observed. Large-scale changes in site composition or morphometric characteristics of mollusks in archaeological contexts often occur over long-term intervals associated with cultural or environmental changes (Faulkner 2009; Giovas et al. 2010). Neither of these scenarios seems to have taken place at JW1727. To fully understand the connection between species size distribution of the *C. fasciatus* population and human exploitation, the temporal range of samples needs to be widened. Shell assemblages that cover a longer time period need to be explored to compare the change of shell size over longer periods.

Changes in mean aperture size throughout the short period of occupation at JW1727, most importantly the gradual change happening throughout the first half of the stratigraphic sequence (Layers 22–16), are minor. Nevertheless, they could well be an indicator for a subsistence strategy that allowed the sustainable exploitation of *C. fasciatus*. While this strategy would not have caused an overexploitation of the species, it could have been invasive enough to be detectable by a subtle decrease in mean shell size.

The species composition of JW1727 showed a dominance of *C. fasciatus*, but also a wide range of other mollusk species, typical for Red Sea shallow water environments (supplementary material 2). At the time of occupation JW1727 would have been much closer to the shoreline and the now exposed areas (Figure 2) indicate extensive shallow water bays, which would likely have been a rich marine environment and easily accessible to human exploitation.

Considering the variety in species and the lack of overexploitation of *C. fasciatus* in the shell assemblage, the shallow water areas of Janaba Bay, and likely the Farasan Islands in general, were a rich source of marine resources.

Seasonality Study

Analysis of seasonality indicates a general exploitation of *C. fasciatus* throughout the year, with an increase in exploitation during the arid seasons (summer). A year-round distribution of exploitation allows us to rule out some presumptions about human subsistence strategies on Farasan. These presumptions are linked to both the availability of food sources and the mobility of the human population that makes use of these sources.

In some environments, shellfish can be seasonally unavailable to humans because their exploitation is connected to the seasonally changing estuarine environment (Meehan 1982). Also, fishing communities can make a conscious effort to refrain from collecting shellfish during the summer to avoid being poisoned by toxic blooms, which was shown to be the case on Kodiak Island, Alaska (Fitzhugh 1995). Evidently, the results from this study show that *C. fasciatus* was available for exploitation, and was indeed exploited, throughout the year; no general seasonal impact on the environment caused the mollusk to migrate to a different or inaccessible location or to be otherwise unavailable or unfavored.

The year-round seasonal distribution suggests that there were no incentives for the human population to move elsewhere or avoid harvesting shellfish at a particular time of year. More importantly, this is strong evidence that no seasonal movement was necessary to avoid hot summer conditions or to guarantee food supply in an arid landscape. The possibility of exploiting shellfish at every time of the year could have been enough incentive to stay put despite the seasonal variations in the availability of terrestrial resources.

The lack of precipitation in summer is likely to have had some impact on the availability and exploitation of vegetation. Plants as a food source can be highly dependent on their water supply and their availability can suffer with higher aridity. The seasonality results presented here suggest that instead of moving away from the coastal lowlands to counteract the lack of plant food during the dry season, people stayed at the coast and instead increased the shellfish consumption by double the amount (winter + spring: 20 of 66 shells; summer + autumn: 46 of 66 shells). A similar increase in seasonal exploitation was found at Franchthi Cave, Greece (Deith 1988), where the use of wild plants (*Horta*) was only available during the winter. Additionally, Deith and Shackleton (1988) argued that the greater attraction of shellfishing in warm waters could have increased the amount of gathered shellfish in the summer. In contrast, the ethnoarchaeological and archaeological record from fishing communities in higher latitudes showed no restraint when it comes to fishing in cold temperatures (Yesner et al. 2003). However, this may not be a significant factor on Farasan as the water temperature does not go below 25°C. Despite this, personal communications with local fishers and rangers from the wildlife commission on Farasan showed a definite reluctance to go diving in winter as it was perceived to be too cold. Whether the Middle Holocene population shared this perception is unclear.

Despite the results indicating an exploitation of shellfish at JW1727 in all seasons, they do not confirm JW1727 as a habitational site. It is more likely that JW1727 was a simple processing site. The distribution of shell midden sites around Janaba Bay is very water-centric as almost every site is located on a palaeoshoreline (Bailey et al. 2013). They appear to have been positioned at the most convenient place to process shellfish immediately after collection. Other parts of the Farasan Islands, especially around Khur Maadi Bay and the island Saqid, have sites that are clustered around features other than palaeo-shorelines, albeit not far from them. This distribution of sites possibly indicates central places that are more closely related to habitational sites than the middens found along Janaba Bay. It is conceivable that people moved along the shallow coastlines to collect shells and then processed them immediately afterwards at sites like JW1727. After that the meat was taken somewhere else. Locating signs of habitational sites in the future will be key to understand the movement between shell midden sites.

Despite the lack of habitational sites in connection with JW1727, the exploitation of shellfish in consecutive seasons observed in layer 8 suggests that at some point the site was used as a processing site continuously for several months (Table 4).

CONCLUSION

Seasonality data, obtained through stable $\delta^{18}O$ isotope analysis of *C. fasciatus* from shellmound JW1727, indicates that shellfish were gathered on the Farasan Islands in every season of the year. This stands in contrast to the assumptions of studies on coastal exploitation in arid landscapes (Cavulli and Scaruffi 2013; Williams 2011). The data suggest that shellfish were gathered throughout the year, with greater exploitation during the summer and autumn, when the landscape was the driest and other food sources were less abundant. The increased exploitation implies a seasonal subsistence change, but it also shows that there were other food sources available in other seasons that worked supplementary to the staple food fish. Additionally, it shows that people most probably stayed on the islands for longer periods than previously thought and constant exchange with the mainland must not have been a necessity. However, the lack of habitational sites on Farasan and the Arabian mainland prevents any complete analysis of subsistence or mobility patterns.

Based on these results, we argue that coastal exploitation on the Farasan Islands has been sustainable throughout the year and possibly serves as an example for maritime landscapes on both sides of the Red Sea.

Globally, the Farasan Island shell middens appear to represent relatively unusual patterns of coastal subsistence. Typically, when vegetation becomes scarce, population mobility increases. In Farasan, despite the increasing aridity in the summer months, these sites continue to be exploited. If people chose to live on the coast and gather shellfish instead of adapting herding and planting food in the nearby temperate mountains, then this can tell us a lot about shellfish gathering as an alternative food source in other Neolithic societies (or any other time period) around the world.

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SUPPLEMENTAL

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18O values

Layer	Subla	Shell ID	Dist. to Edge	d18O [‰VPDB]	Season			
1	T	1	0.42424	0.26	-			
			1.86916	-1.15				
			3.56613	-0.54				
			5.86332	-0.61				
			7.81668	-0.73				
			10.59739	-0.89				
			13.48413	-1.28				
			17.72543	-1.37				
			20.78073	-1.44				
			26.4078	-1.12				
			30.69837	-1.21				
			33.9176	-1.22				
			38.99147	-1.29				
			42.09195	-1.2				
			47.2766	-1.5				
			51.51126	-1.06				
			55.92443	-1.15				
			60.53792	-1.34				
			64.94704	-1.28				
			70.57775	-1.05				
1	T	2	0.7415	-0.98	summer-autumn			
			3.72231	-1.01				
			6.85072	-1.22				
			9.242	-1.18				
			12.35632	-1.44				
			16.42024	-1.63				
			18.54174	-1.33				
			22.962	-1.19				
			25.7281	-1.35				
			28.58708	-1.63				
			31.58708	-1.11				
	T		34.58708	-1.1				
			37.58708	-1.36				
			40.58708	-1.01				
			43.58708	-1.19				
			46.58708	-1.22				
			49.58708	-1.24				
			52.58708	-1.05				
			55.58708	-1.18				
			58.58708	-1.12				
1	B	1	1.11984	-0.5	-			

			4.69727	-1.1				
			8.77596	-1.17				
			11.55458	-1.28				
			14.38059	-1.15				
			18.52413	-1.53				
			20.44398	-1.12				
			21.46932	-1.33				
			24.84653	-1.39				
			29.03756	-1.5				
			32.13756	-1.04				
			35.23756	-1.17				
			38.33756	-1.3				
			41.43756	-1.32				
			44.53756	-1.23				
			47.63756	-1.09				
			50.73756	-1.08				
			53.83756	-1.29				
			56.93756	-1.41				
			60.03756	-1.21				
1	B	3	0.193439	-0.5	-			
			0.327496	-0.75				
			0.636286	-0.55				
			0.900932	-0.8				
			1.388241	-0.49				
			1.80177	-0.15				
			2.284751	-0.1				
			2.632929	-0.3				
			2.993033	-0.45				
			3.404296	-0.36				
			3.542333					
1	B	5	0.189404	-0.98	Spring-Summer			
			0.33	-0.98				
			0.488987	-1.14				
			0.843801	-1.23				
			1.271195	-1.02				
			1.775639	-0.89				
			2.107539	-0.86				
			2.416763	-0.54				
			2.605536	-0.72				
1	B	6	0.201965	-0.78	Spring			
			0.468799	-0.35				
			0.762929	-0.08				
			1.071788	-0.19				
			1.531559	-0.16				
			1.780982	-0.41				
			2.087689	-0.34				

			2.291813	-0.59				
1	B	8	0.111984	-0.74	-			
			0.469727	-0.76				
			0.877596	-0.95				
			1.155458	-0.89				
			1.438059	-1.01				
			1.852413	-1.03				
			2.044398	-0.75				
			2.146932	-0.87				
			2.484653	-1.11				
			2.903756	-1.03				
8	T	2	0.208304	-0.94	autumn			
			0.579636	-1.27				
			0.894825	-1.28				
			1.170375	-1.54				
			1.483178	-1.65				
			1.665784	-1.66				
			1.784032	-1.56				
			1.975801	-1.51				
			2.102959	-1.69				
			2.233703	-1.49				
8	T	3	0.291792	-1.19	autumn			
			0.6853	-1.09				
			1.009118	-1.12				
			1.265192	-1.12				
			1.517518	-1.17				
			1.780483	-1.24				
			2.082738	-1.29				
			2.436357	-1.58				
			2.775668	-1.52				
			3.148027	-1.53				
8	T	4	0.447702	-1.09	autumn			
			0.788084	-1.08				
			1.214854	-1.23				
			1.669275	-1.21				
			1.94788	-1.29				
			2.422088	-1.33				
			3.539721	-1.45				
			4.654005	-1.47				
			6.709839	-1.35				
			7	-1.35				
8	T	5	0.063503	-0.44	autumn-winter			
			0.317313	-0.75				
			0.642239	-0.88				
			1.088777	-1.11				
			1.387533	-0.93				
			1.63773	-1.07				

			1.854212	-1.37				
			2.05202	-1.24				
			2.146419	-1.32				
			2.270572	-1.18				
8	T	6	0.290004	-0.89	autumn			
			0.77761	-0.91				
			1.370531	-1.02				
			1.770997	-1.2				
			2.059724	-1.31				
			2.25837	-1.51				
			2.481858	-1.16				
			2.669217	-1.4				
			2.894917	-1.36				
8	C	2	0.078266894	-0.75	autumn-winter			
			0.412125918	-0.68				
			1.608766528	-1.63				
			2.578689468	-1.6				
			3.265542687	-1.54				
			4.117623445	-1.58				
			6.528706125	-1.54				
			7.143074897	-0.67				
			10.94840114	-0.81				
			14.86777574	-0.24				
			18.59913625	-0.37				
			22.43578799	-0.52				
			26.3349835	-0.41				
			30.06060161	-0.78				
			33.92782062	-0.9				
			37.77814903	-0.9				
			41.57313679	-1.25				
			45.41551751	-1.22				
			49.22775752	-1.37				
			53.04621253	-1.6				
			56.9115855	-1.49				
			60.70500133	-1.23				
			64.49284147	-1.37				
			68.37746072	-1.35				
			72.15099966	-1.24				
			76.00934339	-1.33				
			79.8643114	-0.75				
			83.6578793	-1.03				
8	C	4	0.320787	-0.91	autumn			
			1.003423	-1.75				
			1.570166	-1.65				
			2.073553	-1.49				
			2.510619	-1.55				
			2.834593	-1.78				
			3.157814	-1.47				
8	C	5	0.220069	-1.25	summer			
			0.560875	-1.38				
			0.831898	-1.4				

			1.099144	-1.38				
			1.25766	-1.4				
			1.338384	-1.42				
			1.380485	-1.2				
			1.939994	-1.37				
			2.520851	-1.35				
			3.302404	-1.25				
8	C	8	0.332395	-1.37	summer-autumn			
			0.768427	-1.46				
			1.205247	-1.48				
			1.707418	-1.47				
			2.413332	-1.5				
			3.090223	-1.24				
			3.309092	-1.25				
			3.437158	-1.26				
			3.528041	-1.14				
8	C	12	0.044205	-0.87	autumn			
			0.333499	-1.21				
			0.57845	-1.26				
			0.878983	-1.24				
			1.087366	-1.37				
			1.615391	-1.14				
			1.667922	-1.01				
			2.134007	-1.05				
			2.498953	-0.98				
			2.528497	-0.9				
			2.887883	-1.08				
			3.094337	-1.21				
			3.267434	-1.07				
			3.659169	-1.17				
			4.070489	-1.14				
8	C	13	0.023056	-0.98	summer-autumn			
			0.175507	-0.98				
			0.447854	-1.1				
			0.577778	-1.23				
			0.815367	-1.18				
			0.999892	-1.04				
			1.212375	-1.2				
			1.42552	-1.21				
			1.665961	-1.01				
			1.874059	-0.99				
			2.241633	-0.9				
			2.533372	-0.81				
			2.754935	-0.81				
			2.852592	-0.73				
			3.65592	-0.62				
8	C	14	0.058054	-1.07	autumn			
			0.299455	-1.01				
			0.479466	-1.21				
			0.773274	-1.05				

18O values

			1.308412	-1.49				
			1.724402	-1.47				
			1.95626	-1.28				
			2.417106	-1.44				
			2.91991	-1.18				
			3.193604	-0.98				
			3.779307	-1.37				
			4.248382	-0.98				
			4.573655	-0.88				
			4.751786	-0.58				
			4.929917	-0.82				
8	B	3	0.16	-1.29	summer			
			0.61	-1.41				
			1.12	-1.32				
			2.05	-1.51				
			2.51	-1.32				
			2.83	-1.43				
			3.18	-1.43				
			4.16	-1.31				
8	B	4	0.61	-2.03	summer			
			1.49	-1.73				
			1.93	-1.81				
			2.45	-1.68				
			2.99	-1.68				
			3.38	-1.74				
			3.86	-1.03				
			4.18	-1.18				
			4.38	-0.89				
8	B	5	0.25	-1.38	spring-summer			
			0.76	-0.79				
			1.31	-0.8				
			2.08	-1.38				
			2.42	-1.5				
			2.72	-1.44				
			3.78	-1.41				
8	B	7	0.31	-1.41	spring-summer			
			0.85	-1.49				
			1.22	-1.23				
			1.63	-1.32				
			2.01	-0.97				
			2.43	-1.25				
			2.84	-1.24				
			3.48	-1.25				
			4.01	-0.64				
13	T	1	0.003	-0.69	winter-spring			
			0.327004	-0.49				
			0.667051	-0.49				
			0.995312	-0.83				
			1.389813	-0.87				
			1.739147	-0.99				

18O values

			2.053381	-1.08				
			2.443436	-1.05				
			2.831812	-1.02				
			3.164807	-1.22				
			3.47395	-1.08				
			3.694058	-1.09				
			3.922868	-1.05				
			3.992267	-1.1				
			4.027775	-0.67				
13	T	2	0.067265	-0.12	autumn-winter			
			0.287174	-0.54				
			0.476261	-0.78				
			0.595246	-1.24				
			0.898547	-1.25				
			0.971154	-1.27				
			1.41013	-1.24				
			1.812373	-1.17				
			2.093761	-1.17				
			2.333965	-1.14				
			2.405663	-1				
			2.62586	-1.06				
			2.685568	-0.99				
13	T	3	0.299042	-2.06	spring-summer			
			0.475911	-1.17				
			0.718072	-0.35				
			1.035769	-0.49				
			1.359312	-1				
			1.71157	-1.11				
			2.021908	-1.16				
			2.346604	-0.95				
			2.585808	-1.29				
			2.872589	-0.85				
			3.192521	-0.54				
			3.640585	-0.54				
			3.998111	-0.98				
			4.365868	-1.16				
			4.760391	-1.35				
			5.027438	-1				
			5.276386	-1				
			5.493059	-1.43				
			5.538527	-1.25				
			5.813862	-1.17				
			6.005299	-1.79				
13	C	1	0.057134	-0.72	autumn			
			0.566443	-0.5				
			0.956157	-0.78				
			1.284603	-0.94				
			1.719745	-1.26				
			2.34793	-1.27				
			2.969639	-1.2				
			3.442409	-1.27				
			3.856921	-1.19				

			4.018519	-1.26				
13	C	3	0.102476	-0.83	autumn-winter			
			0.403794	-1.19				
			0.908033	-1.27				
			1.3564	-1.19				
			1.868618	-1.44				
			2.291937	-0.52				
			2.82961	-0.68				
			3.356232	-1.08				
			3.953432	-1.29				
			4.525089	-1.21				
13	C	4	0.34701	-1.77	autumn			
			0.620349	-2.17				
			0.966368	-1.5				
			1.320507	-1.79				
			1.708529	-1.48				
			2.126325	-1.43				
			2.470451	-1.31				
			2.79994	-1.14				
			3.100142	-1.25				
13	C	5	0.57524	-1.14	autumn			
			0.978233	-1.3				
			1.464579	-1.46				
			2.066114	-1.63				
			2.560129	-1.49				
			3.096987	-1.66				
			3.937224	-1.43				
			4.560313	-1.4				
			5.156212	-1.21				
13	C	7	0.133572638	-0.84	autumn			
			0.410320215	-0.82				
			0.899967531	-0.72				
			1.177283826	-1.16				
			1.547307074	-1.37				
			1.867471721	-1.36				
			2.277454644	-1.38				
			2.712281131	-1.28				
			3.257525682	-1.34				
			3.624753623	-1.55				
13	C	8	0.585591	-1.14	winter			
			1.072282	-0.91				
			1.490647	-1.2				
			1.909012	-1.05				
			2.271359	-0.8				
			2.582172	-1.25				
			2.820823	-1.55				
			2.999597	-1.61				
			3.15	-1.98				
13	B	2	0.044244	-1.33	summer			

			0.331149	-1.22				
			0.387869	-1.28				
			0.682275	-1.4				
			1.130373	-1.12				
			1.355714	-1.24				
			1.631024	-1.17				
			1.87577	-0.92				
			2.188873	-0.87				
			2.54558	-0.69				
			2.74775	-0.47				
			2.9499	-0.45				
13	B	7	0.110654	-0.75	autumn			
			0.780928	-0.56				
			1.301438	-1.02				
			1.793589	-1.19				
			2.214239	-1.26				
			2.723634	-1.27				
			3.106031	-1.29				
			3.523429	-1.19				
			3.920607	-0.91				
			4.023451	-0.81				
13	B	8	0.041451	-0.79	autumn			
			0.550912	-1.42				
			1.017348	-1.95				
			1.535586	-1.53				
			2.054653	-1.54				
			2.521089	-1.5				
			2.821607	-1.37				
			3.093615	-1.43				
			3.344255	-1.35				
			3.703528	-1.39				
18	T	2	0.164279	-0.79	autumn			
			0.463254	-0.93				
			0.739043	-1.15				
			1.082174	-1.23				
			1.388291	-1.36				
			1.758016	-1.19				
			1.922663	-1.36				
			2.254342	-1.29				
			2.464998	-1.17				
			2.849096	-1.3				
			2.991714	-0.9				
			3.321801	-1.09				
			3.535203	-1.09				
			3.726789	-1.25				
			3.938148	-0.86				
18	T	3	0.097435	-1.01	summer			
			0.338693	-1.02				
			0.667722	-0.89				
			0.935159	-0.88				
			1.260629	-0.2				

			1.42848	-0.52				
			1.833993	-0.96				
			2.24778	-1.25				
			2.49618	-1.17				
			2.895187	-1.03				
			3.208638	-1.04				
			3.005469	-1.23				
			3.730526	-0.95				
			0.626572	-1.18				
18	T	4	0.181353	-1.37	spring-summer			
			0.710557	-0.69				
			0.857189	-0.67				
			1.301816	-0.55				
			1.35992	-0.71				
			1.68651	-1.02				
			2.172689	-1.37				
			2.574419	-1.36				
			2.994522	-1.35				
			3.106981	-1.37				
			3.557264	-1.23				
			3.850165	-0.95				
			4.074432	-0.45				
18	T	5	0.090804	-0.46	winter			
			0.233954	-0.24				
			0.665257	-0.5				
			1.028396	-0.78				
			1.272148	-0.76				
			1.631439	-0.58				
			1.9811	-1.18				
			2.273434	-1.22				
			2.774925	-1.56				
			3.235684	-1.38				
			3.648265	-1.63				
			3.925982	-1.23				
			4.326807	-1.22				
			4.668051	-1.15				
			4.959652	-0.71				
18	T	6	0.103932	-0.76	summer-autumn			
			0.369374	-1.02				
			0.586028	-1.12				
			0.916421	-1.16				
			1.652708	-1.16				
			1.224227	-1.13				
			2.149183	-1.29				
			2.539398	-1.15				
			2.905657	-1.47				
			3.345691	-1.22				
			3.75535	-1.26				
			4.2276	-1.13				
			4.459871	-1.21				
			4.679115	-0.9				
			4.93347	-0.7				

18O values

18	T	7	0.059635	-0.79	summer-autumn			
			0.484044	-0.56				
			0.760125	-0.65				
			1.318385	-0.88				
			1.024104	-0.78				
			1.628412	-0.92				
			1.786495	-1.13				
			2.312629	-1				
			2.625895	-0.79				
			3.079214	-0.81				
			3.473814	-0.61				
			3.852123	-0.53				
			4.165389	-0.32				
			4.228165	-0.7				
			2.528804	-1.2				
18	C	1	0.171527	-0.82	summer			
			0.383984	-0.84				
			0.446453	-0.99				
			0.888321	-1.01				
			1.06737	-0.99				
			1.683595	-0.94				
			1.915993	-0.53				
			2.922351	-0.55				
			3.097462	-0.49				
			3.299016	-0.63				
18	C	2	0.157406	-0.27	autumn-winter			
			0.309989	-0.07				
			0.730784	-0.37				
			0.995228	-0.54				
			1.458174	-0.68				
			1.652172	-0.84				
			2.206843	-0.86				
			2.373221	-0.97				
			2.64843	-0.94				
			2.893768	-1.04				
			3.281983	-1.14				
			3.476969	-0.97				
			3.930604	-0.92				
18	C	4	0.069324	-0.77	winter-spring			
			0.242749	-0.91				
			0.540432	-0.45				
			0.913088	-0.53				
			1.36502	-0.28				
			1.570902	-0.71				
			1.85317	-0.8				
			2.001529	-0.69				
			2.34014	-0.71				
			2.575836	-0.59				
			2.909745	-0.59				
			3.135448	-0.88				
			3.589083	-0.82				

18O values

			3.805658	-0.93				
			4.080867	-1.02				
18	C	5	0.058729	-0.71	summer-autumn			
			0.253785	-0.92				
			0.547594	-0.88				
			0.841403	-1.39				
			1.226057	-1				
			1.558855	-1.16				
			1.62807	-1.35				
			1.972893	-1.23				
			2.234095	-1.1				
			2.697086	-0.92				
			3.136851	-1.01				
			3.527732	-0.54				
			3.815791	-0.48				
			4.124874	-0.62				
			4.255475	-0.21				
18	C	6	0.142659	-0.72	winter-spring			
			0.33112	-0.27				
			0.4004	-0.41				
			0.807917	-0.36				
			0.945432	-0.27				
			1.156936	-0.35				
			1.532454	-1.04				
			1.690436	-1.03				
			1.976082	-0.24				
			2.318996	-0.41				
			2.723674	-0.69				
			3.12347	-0.8				
			3.437604	-1.01				
			3.815806	-1.1				
			4.236652	-1.15				
18	C	7	0.178759	-0.82	summer-autumn			
			0.380709	-1.01				
			0.682483	-0.91				
			0.932232	-1.14				
			1.234652	-0.96				
			1.373187	-1.04				
			1.667247	-1.07				
			1.853115	-0.93				
			2.078654	-1				
			2.372561	-1.63				
			3.003527	-0.78				
			3.449143	-0.68				
			4.158892	0.04				
			4.589049	-0.26				
			5.146654	-0.16				
18	C	8	0.111877	-0.39	autumn			
			0.426215	-0.64				
			0.648437	-1.03				
			1.032059	-2.23				

			1.324721	-1.06				
			1.620288	-1.16				
			2.210911	-1.19				
			2.629263	-1.12				
			3.067951	-1.13				
			3.459508	-1.12				
			3.847503	-1.04				
			4.105321	-0.98				
			4.605567	-1.15				
			4.796121	-1.01				
18	B	2	0.074979	-1.17	spring-summer			
			0.450633	-1.39				
			0.711723	-1.17				
			1.1004	-0.62				
			1.18909	-0.45				
			1.526769	-0.31				
			1.694753	-0.38				
			2.186778	-0.07				
			2.242478	-0.22				
			2.619183	-0.43				
			2.740112	-0.55				
			2.931216	-0.48				
			3.309391	-0.42				
			3.874057	-0.89				
18	B	3	0.16811	-0.65	summer-autumn			
			0.519881	-0.7				
			0.690569	-0.94				
			1.000558	-1.05				
			1.366745	-0.96				
			1.41233	-0.97				
			1.875247	-0.73				
			1.934684	-1.09				
			2.305115	-0.64				
			2.376321	-0.81				
			2.854466	-0.83				
			2.912486	-0.55				
			3.288392	-0.38				
			3.327606	-0.61				
			3.674121	-0.56				
18	B	4	0.104687	-0.89	summer-autumn			
			0.531928	-1.25				
			0.807055	-1.24				
			1.230355	-1.4				
			1.451269	-0.78				
			1.721172	-1.16				
			1.935646	-1.08				
			2.336308	-0.97				
			2.671739	-0.93				
			2.980925	-0.76				
			3.052641	-0.81				
			3.293401	-0.73				
			3.65217	-0.55				

			3.948437	-0.49				
			4.221028	-0.56				
18	B	5	0.104687	-1.17	summer-autumn			
			0.531928	-1.38				
			0.807055	-1.11				
			1.230355	-1.45				
			1.451269	-1.25				
			1.721172	-1.33				
			1.935646	-1.48				
			2.336308	-1.31				
			2.671739	-1.17				
			2.980925	-1.32				
			3.052641	-1.19				
			3.293401	-1.11				
18	B	6	0.07253	-0.35	winter			
			0.449751	-0.06				
			0.806193	0.02				
			0.981488	-0.67				
			2.198309	-0.47				
			2.621066	-1.03				
			2.901831	-1.19				
			3.243088	-1.19				
			3.606294	-1.34				
			4.028635	-1.23				
			4.423776	-1.23				
			5.319595	-1.12				
			5.53329	-1.03				
18	B	7	0.095639	-0.48	autumn			
			0.213738	-0.7				
			0.444588	-0.74				
			0.819788	-1.15				
			1.054009	-1.15				
			1.223109	-1.3				
			1.358032	-1.29				
			1.58692	-0.62				
			1.906964	-0.15				
			2.244615	-0.2				
			2.710744	-0.63				
			3.104486	-0.89				
			3.318181	-1.5				
18	B	8	0.149408	-1.04	winter-spring			
			0.343034	-0.84				
			0.771567	-0.4				
			1.05627	-0.74				
			1.387853	-0.78				
			1.651459	-0.79				
			2.00587	-0.73				
			2.350882	-0.46				
			2.821958	-0.89				
			3.135249	-0.97				
			3.529863	-0.96				

18O values

			3.836205	-1.04				
			4.194313	-1.09				
			4.593641	-1.16				
			4.837995	-1.13				
20	T	1	0.151776	-1.43	spring			
			0.545576	-1.4				
			0.860008	-1.42				
			1.140921	-1.22				
			1.524686	-1.27				
			1.971922	-1.1				
			2.271771	-1.18				
20	T	2	0.102136	-1.03	spring			
			0.386714	-0.57				
			0.632689	-0.22				
			0.838316	-0.5				
			1.075606	-0.79				
			1.303988	-1.14				
20	T	3	0.024746	-0.29	autumn			
			0.451689	-0.66				
			0.952219	-0.51				
			1.455786	-0.72				
			1.921614	-0.83				
			2.280629	-0.72				
			4.293269	-0.76				
			7.455972	-1.19				
			10.490109	-1.36				
			14.652594	-0.92				
20	T	4	0.120755	-1.26	summer-autumn			
			0.450353	-1.4				
			0.778643	-1.3				
			1.13201	-1.27				
			1.46796	-1.59				
			1.703271	-1.5				
			1.998051	-1.37				
			2.267621	-1.11				
			2.637783	-1.02				
			2.743563	-0.84				
20	T	7	0.085762	-1.29	summer			
			0.428809	-1.41				
			0.751158	-1.34				
			1.04252	-1.49				
			1.46583	-1.32				
			1.833884	-1.29				
			2.160107	-1.1				
			2.422493	-1.09				
			2.743462	-1.38				
			3.024885	-1.47				
20	B	2	0.59054	-0.51	autumn-winter			
			3.14489	-1.22				

			5.82654	-1.62				
			9.52791	-1.23				
			14.28509	-1.71				
			16.34879	-1.69				
			20.49327	-1.12				
			24.74337	-1.5				
			28.15879	-1.35				
			30.21991	-1.43				
			33.18146	-1.34				
			38.67958	-1.64				
			42.85843	-1.42				
			46.90694	-0.91				
			50.10829	-0.88				
			54.16406	-1.02				
			57.49239	-1.28				
			60.95209	-1.1				
			63.88268	-0.93				
			67.13821	-1.66				
			69.96037	-1.4				
			72.03261	-1.32				
			74.66056	-1.21				
			76.65996	-1.04				
			78.60286	-0.8				
20	B	3	0.049628	-1.38	summer-autumn			
			0.230837	-1.77				
			0.435277	-1.61				
			0.653555	-1.71				
			0.934654	-1.61				
			1.166076	-1.36				
			1.358171	-1.23				
			1.675621	-0.96				
			1.875145	-0.98				
			2.089152	-0.64				
20	B	4	0.021421	-1.35	summer-autumn			
			0.165041	-1.81				
			0.337742	-1.8				
			0.538701	-1.75				
			0.854763	-1.35				
			1.166413	-1.12				
			1.348012	-1				
			1.71574	-0.83				
			2.062088	-0.75				
			2.516958	-1.02				
20	B	7	0.125244	-0.74	autumn			
			0.505488	-0.96				
			0.581724	-1.11				
			0.934404	-1.16				
			1.334599	-1.25				
			1.731561	-1.31				
			2.085613	-1.18				
			2.565374	-1.01				
			3.577757	-0.57				

22	A	1	0.216846	-0.9	-			
			0.656608	-0.82				
			1.030256	-0.87				
			1.475962	-0.95				
			1.784088	-1.11				
			2.156065	-0.43				
			2.534582	-0.55				
			2.927917	-0.61				
			3.312082	-0.84				
			3.635187	-0.87				
22	A	2	0.08128	-1.11	Spring-Summer			
			0.273437	-1.22				
			0.546424	-0.8				
			0.962078	-0.27				
			1.37308	-0.21				
			1.77832	-0.59				
			2.2405	-0.97				
			2.696296	-1.02				
			3.271431	-1.06				
			3.729403	-0.92				
22	A	3	0.14578	-0.69	Autumn			
			0.607797	-0.78				
			1.049075	-1.1				
			1.519955	-0.91				
			1.84428	-0.92				
			2.195177	-0.48				
			2.514204	-0.3				
			2.91925	-0.16				
			3.308005	-0.22				
			3.857609	-0.4				
22	A	4	0.066667	-0.93	Winter-Spring			
			0.514064	-0.67				
			0.930405	-0.41				
			1.308799	-0.42				
			1.704378	-0.81				
			2.096945	-1.16				
			2.445484	-0.98				
			2.9127	-1.41				
			3.537652	-0.55				
			4.134185	-0.44				
22	A	5	0.074756	-0.87	Summer-Autumn			
			0.422615	-1.08				
			0.902616	-1.36				
			1.474825	-0.98				
			1.839658	-1.1				
			2.295845	-0.92				
			2.685901	-0.74				
			3.011895	-0.69				
			3.425193	-0.85				

			3.815653	-0.76				
22	A	6	0.051395	-1.18	Spring			
			0.314379	-0.9				
			0.536186	-1.01				
			0.994818	-0.82				
			1.319249	-0.61				
			1.706936	-0.46				
			2.172687	-0.37				
			2.423556	-0.41				
			2.817981	-1.2				
			3.309477					
22	A	7	0.103245	-0.92	Winter			
			0.47712	-0.58				
			0.884102	-1.1				
			1.317109	-0.89				
			1.7285	-0.94				
			2.121547	-0.99				
			2.411774	-0.91				
			2.728763					
			2.994752	-0.85				
			3.208615	-0.97				