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HOLOCENE CRAB CONSUMPTION AT WATINGLO, PAPUA NEW GUINEA

Konsumsi Kepiting Masa Holosen di Watinglo, Papua Nugini

Hendri A. F. Kaharudin[1, 2]

[1] *Archaeology and Natural History, College of Asia and the Pacific, Australian National University, Australia*

[2] *ARC Centre of Excellence for Australian Biodiversity and Heritage, The Australian National University, Australia*

hendri.kaharudin@anu.edu.au

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Abstract. *Malacostraca are commonly found in coastal archaeological sites in the Indo-Pacific; both swimming and terrestrial crabs. This archaeological evidence as well as ethnographic studies indicate that they formed an important component of the human diet in the past as they still do in many regions today. However, they often go unidentified and largely unanalysed in archaeological research due to the highly fragmentary state of the remains and the associated difficulties posed for identification and quantification. Here I discuss these issues and provide an example of crab remains recovered from a coastal archaeological site in Papua New Guinea, Watinglo shelter, with an occupation record spanning from the Terminal Pleistocene to historic times. These findings are discussed in the context of crab remains from archaeological sites of similar antiquity in Indonesia and the Philippines.*

Keywords*: Coastal, Mangrove, Quantification, Coral Triangle, Rockshelter*

Abstrak. Malacostraca seringkali ditemukan di situs arkeologi pesisir di Indo-Pasifik; baik kepiting perenang, maupun kepiting darat. Bukti arkeologi ini, serta dukungan studi etnografi, menunjukkan bahwa kepiting merupakan komponen penting dalam pilihan makanan manusia di masa lalu seperti yang terjadi di banyak tempat saat ini. Meskipun, temuan kepiting sering tidak teridentifikasi dan seringkali tidak dianalisis di banyak penelitian arkeologi karena keadaannya yang sangat terfragmentasi yang menyebabkan sulitnya untuk proses identifikasi dan kuantifikasi. Dalam tulisan ini, kami membahas permasalahan ini dan memberikan contoh sisa kepiting yang ditemukan dari situs arkeologi pesisir di Papua Nugini, Watinglo, dengan rekam hunian sejak dari Pleistosen Akhir hingga masa sejarah. Kami juga secara singkat membandingkan temuan ini dengan sisa-sisa kepiting dari situs arkeologi prasejarah lainnya dengan temuan serupa di Indonesia dan Filipina.

Kata Kunci: Pesisir, Mangrove, Penghitungan, Segitiga Koral, Ceruk

1. Introduction

1.1 Malacostraca in the context of human consumption

Malacostraca is the largest class within the Subphylum Crustacea, which consists of segmented, invertebrate animals such as crabs, lobsters, prawns, crayfish, and krill. This class has a wide ecological range, with species found in marine, freshwater, and terrestrial habitats (Richter and Scholtz 2001). Malacostraca typically have three tagmata (body subdivisions): the head, thorax, and abdomen. Adults generally have five segments within the head tagma, eight thorax segments, and six or seven abdomen segments (Dahl 1983). As natural predators and scavengers, these crustaceans play a major role in their respective environments (Hessler and Wilson 1983; Schweitzer and Feldmann 2010). The decapods (Order: Decapoda) and krill (Order: Euphausiacea) however, comprise the grouping of Malacostraca that provides the most direct benefit to the human economy (Kruse 2020).

Decapoda (*deca*: ten – *pod*: leg) is an order within Malacostraca distinguished by species which have five pairs of legs such as crabs, hermit crabs, crayfish, lobster, shrimp, and prawns (Fig. 1). They also have a fully formed carapace that covers the gills, a distinctive change from the more common Malacostraca morphology where the gills are mostly exposed (e.g. krill and isopods). Various decapod taxa are common dietary options for coastal communities due to their rich and delicious meat, and relative ease of exploitation (Wickins and Lee 2008). Some species of decapods are usually individually hunted, while others can be harvested in bulk. Despite these factors, not all decapod species are commonly edible. Some species are less likely to be consumed due to low meat content and some others is avoided because of their high toxin level (Alcala and Halstead 1970; Llewellyn et al. 2002). Identification of edible decapods species has been widely studied, especially throughout the Indo-Pacific region. Some species have been developed for farming in captivity specifically for human consumption (Motoh 1980; Williams and Primavera 2001; Wickins and Lee 2008; Subang Jr et al. 2020).

Land crabs (*Cardisoma sp.*) and the coconut crab (*Birgus latro*) are an important protein source among coastal and island communities with limited terrestrial resources (Ambrose et al. 1997). Coconut crabs are now considered to be an endangered delicacy in many Indo-Pacific communities due to overexploitation (Amesbury 1980; Drew et al. 2010; Yorisue et al. 2020; Serosero et al. 2021). Many species of marine crabs are exploited throughout Indo-Pacific, including the mud crab (*Scylla serrata*), sand crab (*Portunus pelagicus*), red crab (*Etisus splendidus*), and spotted reef crab (*Carpilius maculatus*). Similarly, many species

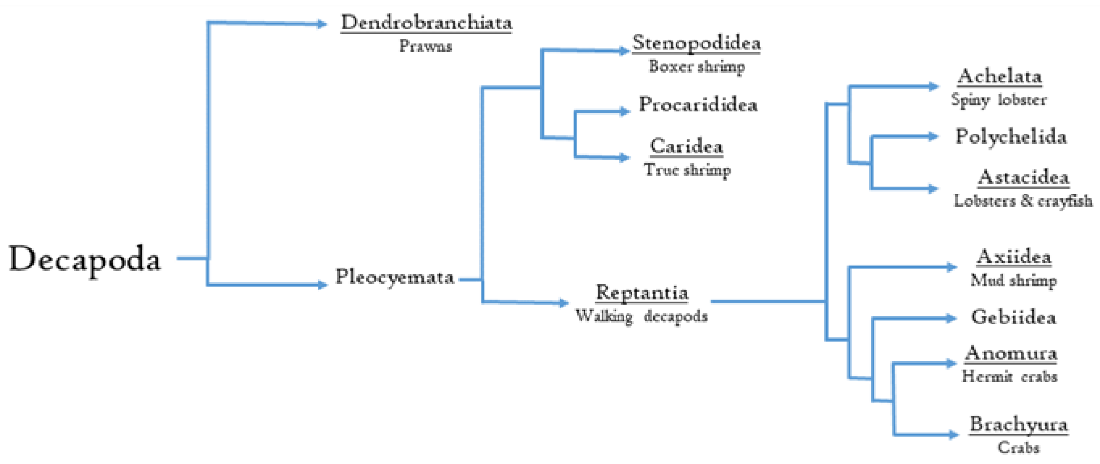

Figure 1. Cladogram of Decapoda based on Wolfe et al. (2019)

of spiny lobster (*Panulirus sp.*), slipper lobster (*Scylla*ridae), and mud lobsters (*Thalassina anomala*) are captured for human consumption (Fig. 2). Other Malacostraca that are harvested for dietary purpose are mantis shrimp (*Squilla sp.*) and various species of penaeid shrimp/ prawn (Penaeidae) (Dalzell et al. 1996).

Here, I use Malacostraca (Class) to refer to crabs, lobsters, prawns, crayfish, and krill. I don't use Crustacea (Subphylum) because this classification includes barnacles (Cirripedia) which are also often recovered in archaeological contexts. The collection, processing technique, and consumption practice of barnacles is probably closer to shell rather than other Crustacea. Decapoda (Order) is also an appropriate term as archaeological contexts are unlikely to recover remains from the entirety of Malacostraca due to taxonomic and taphonomic characteristics (e.g. krill, mantis shrimp, fiddler crab). Lastly, some types such as young/newly moulted crabs due to their small size and/or softer carapace are eaten whole and thus have no remains left for preservation in archaeological sediments.

1.2 Malacostraca in archaeological context

Human consumption of Malacostraca can be dated back to prehistoric times in the Late Pleistocene. The majority of coastal archaeological sites in the Indo-Pacific have recovered various amounts of Malacostraca remains, mostly swimming crabs (O'Connor et al. 2019; Boulanger et al. 2019; Kealy et al. 2020), frequently from shell midden deposits along with other marine invertebrates such as shellfish and sea urchin (e.g. Kealy et al. 2020). While often recovered from throughout assemblages, the abundance ratios among the different coastal invertebrates are often uneven between the different periods of occupation. Generally, mollusca are the most abundant

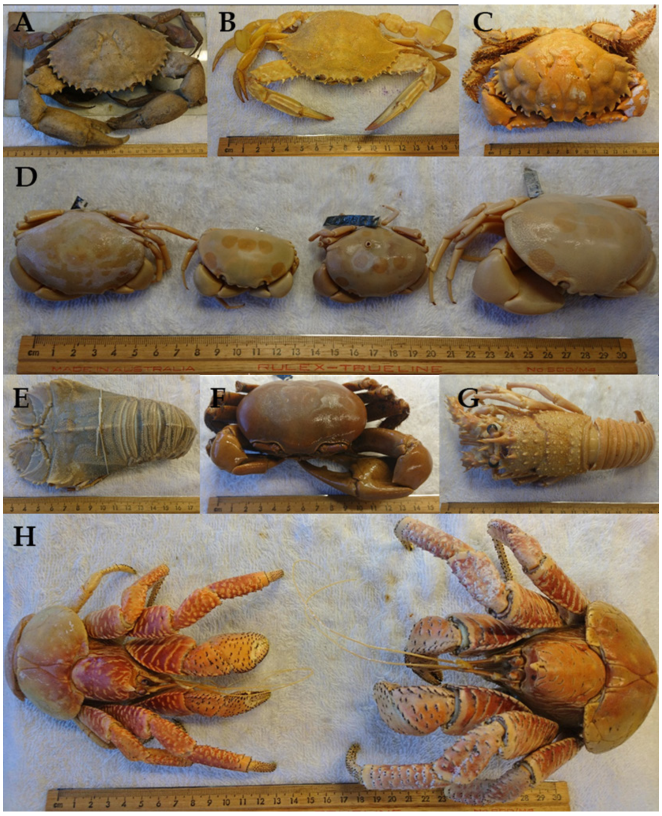

Figure 2 Some selected species of Malacostraca commonly consumed across Indo-Pacific. A: *Scylla serrata*, B: *Portunus pelagicus*, C: *Etisus splendidus*, D: *Carpilius maculatus*, E: *Scylla*ridae, F: *Cardisoma sp.*, G: *Panulirus sp.*, H: *Birgus latro*. Invertebrate collection of the Australian Museum, Sydney.

invertebrate, although there are examples where sea urchin are recovered in greater abundance from a particular occupation phase (Kaharudin 2020). The reasons behind high and low ratios recorded among coastal invertebrates in archaeological assemblages are complex. Fluctuations in abundance may result from differences in availability due to environmental factors, human preferences/collection strategies, preservation, archaeological recovery techniques, or a combination of these factors (Kaharudin et al. 2019). Determining which of these factors are the most influential requires site-specific analysis.

Terrestrial crabs are also often recovered in archaeological sites. The complete remains of a coconut crab (*Birgus latro*) were found at Golo Cave (Gebe Island, northern Maluku, Indonesia). This site recovered evidence of shell and crab exploitation to a depth of 245 cm, with an associated date of 30,299–28,381 cal. BP (Bellwood et al. 2019: 34). Gecarcinidae is another family of terrestrial crab with a significant meat yield, often consumed by prehistoric peoples. Gecarcinidae is the most abundant type of crab recovered from Laili (Timor-Leste) at nearly 46% of the total crab abundance (Hawkins et al. 2017). However, some smaller types of hermit crab (e.g. Paguroidea) have been identified as incidental inclusions in archaeological deposits rather than human food remains (Specht 1985; Walker 1989; Szabó 2012). Hermit crabs scavenge on the refuse discarded at occupation sites, may occupy abandoned shells found on midden deposits, and can burrow into the archaeological deposit. They can thus become incorporated in the deposit alongside human food remains. Crabs of the Paguroidea family were reported to be part of the assemblages recovered from Bubog I (Ilin Island, Philippines) and Jareng Bori (Pantar Island, Indonesia) among other types of Malacostraca (Boulanger et al. 2019; Hawkins et al. 2020).

Ethnographic studies demonstrate that coastal communities commonly collect crabs, lobsters, and prawns, along with other marine resources, from the intertidal zone (Chapman 1987; McNiven 2010). These reef/near-shore gleaning activities tend to be pursued predominantly by women and make a significant and regular contribution to the diet of coastal communities; one which is often overlooked in studies of food security (Chapman 1987; Matthews and Oiterong 1991; Tilley et al. 2020). Such gender roles and division of labour in the family has been observed in some communities to the level of children, with girls carrying out reef gleaning and invertebrate collection, while the boys are more engaged with helping their fathers spear fishing or gillnetting (Kronen 2004). However, this is not a universal rule and in many parts of the Indo Pacific women also engage in fishing for scale fish. For example, Attenbrow (2010) has compiled a wealth of ethnographic records from eastern Australia that detail how shell fishhooks were constructed and used entirely by women.

Seasonality is a strong influence on hunting strategies employed by coastal communities. Most of the Indo-Pacific region is in the equatorial zone which has only two main seasons: wet and dry. People in Papua New Guinea (PNG) tend to conduct pelagic fishing more regularly during the wet season when the sea is calmer. During the dry season, they tend to rely more heavily on terrestrial fauna including freshwater resources. Fish, crabs, lobsters, prawn, and crayfish tend to retreat upstream at this time and are more easily collected (Kooijman 1960; McNiven 2010: 97-98). Malacostraca life cycles, behaviour, and local tidal ranges are all heavily correlated with phases of the moon (Reaka 1976; Amesbury 1980; Skov et al. 2005). Traditionally, a combination of seasonal and lunar calendars was used to maximize Malacostraca hunting efficiencies (Kooijman 1960).

In depth analyses on Malacostraca taxonomical identification and quantification in archaeological contexts are sparse. Excavation techniques may play a significant role in the scarcity of Malacostraca remains recovered from sites. This is particularly pertinent to the early years of archaeological research, where archaeologists used less than ideal equipment such as wider-gauged mesh for sieves, resulting in the loss of small sized materials. In addition, a lack of familiarity with specific taxa or different focuses in research questions may have resulted in a failure to identify Malacostraca remains leading to their subsequent discard (Leach and Boocock 1993; Spanier et al. 2015). Moreover, Malacostraca remains in certain contexts (i.e. shell midden) are not always a waste product of human consumption. As mentioned above, they can also be the product of animal predation or post-deposition taphonomic processes due to the fact that crabs are known to scavenge human domestic waste (Gilchrist 2003; Szabó 2012).

Decapods such as crabs (Infraorder: Brachyura) and lobsters (Family: Nephropidae) are the most commonly found in archaeological deposits. This may correlate with their higher preservation potential among other Malacostraca taxa (Plotnick et al. 1988; Klompmaker et al. 2017). In particular, the carapace and pincer are the most common decapod body parts found in archaeological assemblages. While it is highly probable that prehistoric people also exploited other types of Malacostraca such as shrimp, prawns, and krill, these species tend to have a thinner exoskeleton and relatively smaller body size, making it more difficult for their remains to be preserved. Rick et al.'s (2015) taphonomic experiment on modern blue crabs (*Callinectes sapidus*) remains demonstrated that the preservation of crabs relies on factors such as the season of harvesting, the length of time surface exposure, the degree of animal scavenging, soil acidity, as well as excavation techniques. An optimal preservation scenario of decapod remains in an archaeological context is likely to occur when hunting occurs during the season in which the particular species develops its thicker carapace, after which the remains are discarded in an area inaccessible by scavengers and deposited rapidly in an environment with relatively neutral to alkaline pH soils (Rick et al. 2015). Following their preservation, the remains are then best recovered using careful excavation and recovery techniques including small mesh size and detailed sorting of materials.

1.3 Various techniques and methods

Malacostraca taxonomical identification in palaeontology relies heavily on carapace morphology due to their relatively intact preservation (Scholtz and Richter 1995; Collins et al. 2003; Karasawa et al. 2008; Schweitzer et al. 2009). While carapace morphology has featured strongly in phylogenetics and taxonomy of Malacostraca, recently molecular analyses have influenced phylogenetic studies (Schram 2001). Conversely, in archaeological contexts, the remains are often fragmented due to butchery practices, so taxa identification based on pincer morphology and colour are more common, however this tends to make identification to species level more difficult (Losey et al. 2004; Rodrigues et al. 2016).

A number of quantification methods including 'number of identifiable specimens' (NISP) and 'minimum number of individuals' (MNI) have been applied to the analysis of crabs (or Malacostraca in general) (Gruet 2002; Losey et al. 2004; Gutierrez Zugasti 2011). For NISP, all fragments recovered from an excavation are taken into account. On the other hand, for MNI, the quantification is usually based on the number of recovered *dactylus* or *propodus* remains. All crabs have two pinchers (chelae) each, and each pincher consists of a *dactylus* as the movable part and *propodus* as the immovable part (Menzies 1951). Crab MNI is thus based on whichever is greater between the number of those parts and their identification to either the left or right side.

Allometric analysis is used to determine size distribution in a Malacostraca assemblage. Each taxon under certain environmental condition will have different sex ratios and growth patterns. This method has been used regularly in modern specimens to estimate population, growth, and mortality characteristics (Serosero et al. 2019; Indarjo et al. 2020a; 2020b). In archaeological contexts where the remains are heavily fragmented, allometric analysis is used to estimate the real size of the exploited fauna. The analysis utilises the size of selected body parts that are most abundant in the assemblage to estimate the whole-body size (Losey et al. 2004; Rick et al. 2015). Similarly, weight-meat ratio analysis is used to estimate the nutritional value of the Malacostraca among other dietary options (Losey et al. 2004). Both approaches require standard ratios derived from modern comparative samples.

Malacostraca fossils and their biogenic sedimentary structure (i.e. *Ophiomorpha*, *Thalassinoides*, *Spongeliomorpha* and *Psilonichnus*) have been used as an indicator for palaeoenvironmental reconstruction in ichnology and sedimentary geology studies. This approach is used to identify coastal stratigraphic sequence, shoreline, and sea level in the past (Frey 1973; Freay et al. 1984; Nesbitt and Campbell 2006). In archaeological contexts, palaeoenvironmental indicators can be obtained from the stable isotopic composition of chitin of Malacostraca specimens. Schimmelmann et al. (1986) compared the isotope ratio between archaeological and modern remains from similar environments. They also used scanning electron microscopy (SEM) and transmission electron microscopy (TEM) to conduct micro-morphological comparative studies and ensure there is no contamination. The study suggests that both measurements are in good agreement and it is possible to use Malacostraca chitin for palaeoenvironmental reconstruction (Schimmelmann et al. 1986). However, this approach is currently underutilised in any archaeological research.

This study aimed to test the taxonomical identification based on morphological analyses and quantification methods on Malacostraca remains in archaeological context. Analyses on Malacostraca remains can be useful for broader interpretations of modern human subsistence strategies, movement, and regional environmental changes.

2. Materials & Methods

2.1 Site Description

This research project focused on analysing Malacostraca specimens recovered from a 1 x 1 metre test pit, Square A, at

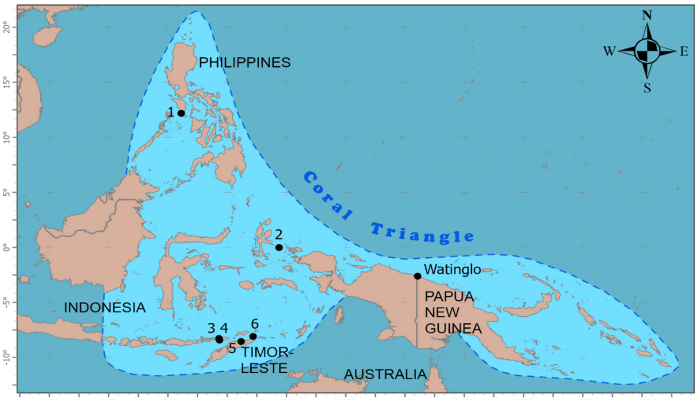

Figure 3. Watinglo and other select prehistoric sites within the Coral Triangle (pale blue; Veron et al., 2009) reported with Malacostraca remains. Numbered sites are: 1) Bubog I; 2) Golo; 3) Jareng Bori; 4) Makpan; 5) Laili; 6) Here Sorot Entapa

Watinglo rockshelter located near the north coast of Papua New Guinea (Fig. 3). Watinglo is also located inside the Coral Triangle which known for its rich marine biodiversity (Veron et al. 2009). This site preserved evidence of prehistoric human occupation from the Terminal Pleistocene through to the historic period. The dating records from Watinglo indicate occupation began at least 12,000 years ago (Table 1), and continued until into the historic period ca. 200 years before present (O'Connor et al. 2011).

The site was excavated in 2005 with the excavation consisting of two 1x1 m test pits: square A (270 cm deep) and square C (205 cm deep), dug in approximate 5 cm spits with a total of 91 spits removed from square A (Fig. 4). Today, Watinglo is located at an elevation of approximately 100 m above sea mean level and less than 1 km from the north coast of PNG (O'Connor et al. 2011). Based on the evidence for human occupation (Bulbeck and O'Connor 2011) and the sites distance from the shore, the majority of the Malacostraca remains recovered are presumed to be the result of human food waste.

Watinglo recover high abundance of marine shells and other coastal resources since their initial occupation, but fish is relatively scarce. Terrestrial fauna remains are abundant including pig dated around ~400 years ago in the top spits (3 – 10), correspond with pottery layers (O'Connor et al. 2011). There are 264 pottery fragments from Watinglo A spit 3 to 12 consisting of body and rim components. Some of them are decorated with red slip or impressed, brushed, and incised wavy line (Beaumont et al. 2019). The nearby sites, Lachitu and Taora are also located in the north coast of Papua. Lachitu has an occupation record older than 30

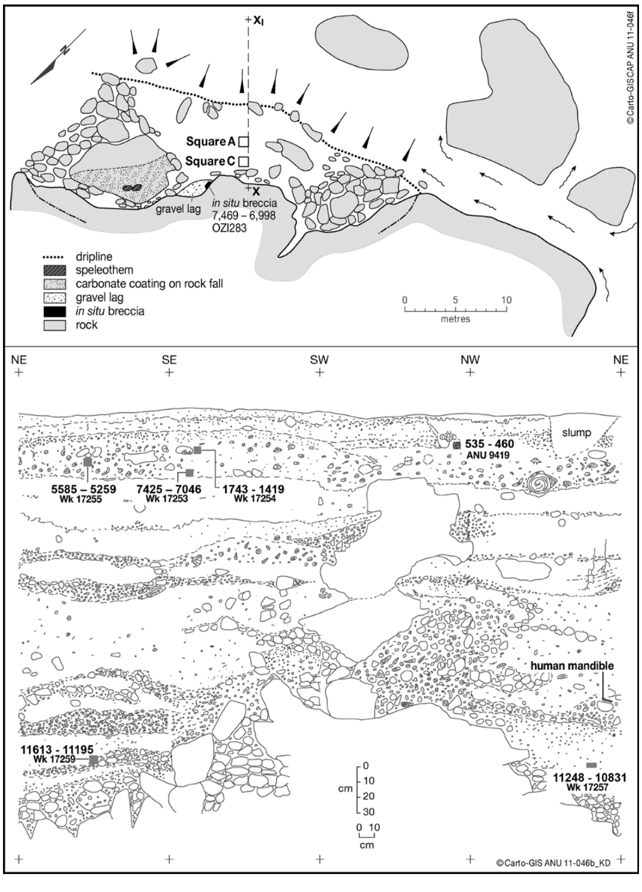

Figure 4. Top: Site plan of Watinglo rockshelter showing location of the 2005 excavation squares. Bottom: Section drawing of Watinglo square A. Figure modified from O'Connor et al., 2011: Fig. 9 & 10.

Table 1. Radiocarbon dates from Watinglo square A (O'Connor et al., 2011). Calibrated in OxCal v.4.4 (Bronk Ramsey, 2009) using IntCal20 (Reimer et al., 2020) calibration curves for charcoal and seed and Marine20 (Heaton et al., 2020) for marine shell samples. Calibrated dates are shown at 95.4% probability.

ID	Spit	Sample type	14C Date ± error	Calibrated date BP (cal BP)
ANU-9418	6	Marine shell	865 ± 25	470 - 183
ANU-9419	West wall	Charcoal	445 ± 30	535 - 460
Wk-17254	9	Marine shell	2,178 ± 38	1743 - 1419
Wk-17255	10	Marine shell	5,248 ± 51	5585 – 5259
Wk-17253	14	Marine shell	6,932 ± 65	7425 – 7046
Wk-17259	East wall	Seed	9,892 ± 65	11613 - 11195
Wk-17260	71	Seed	9,990 ± 51	11,707 – 11,262
Wk-17257	North wall	Marine shell	10,143 ± 53	11248 - 10831
ANU-9420	86	Marine shell	10,445 ± 45	11,713 – 11,252

ka and continues until the Holocene. Lachitu has similar fauna remains to Watinglo. On the other hand, Taora is only occupied around 6.5 ka and has high abundance of fish, shell, crab, and sea urchins (O'Connor et al. 2011).

2.2 Malacostraca analyses

Quantification methods used were Number of Identified Specimens (NISP) and Minimum Number of Individuals (MNI). NISP was performed by counting each identified fragment recovered per spit (unit of excavation removal), while MNI was performed by counting the chelae (crab and lobster pincers) to distinguish each individual present (Fig. 5). Taxonomic identification was conducted by comparison with the invertebrate reference collections at the Australian Museum, Sydney.

NISP and weight values per spit were also adjusted to account for variability in excavated spit volume (see Kaharudin et al. 2019; 2023; Kealy et al. 2020). The following formula was used: (50,000 g ÷ total excavated sediment (g)) × raw quantification data (i.e. NISP or weight g). The 50,000 number is derived from a hypothetical volume of a 1x1 m test pit dug to a depth of 5 cm per spit (100 cm × 100 cm × 5 cm). Total excavated sediment is the total weight per spit including soil and archaeological remains after heavy rocks or any disturbance is discarded. This method is necessary to standardise the NISP and weight values and minimise the proportion differences between spits due to excavator limitations, soil compaction, or any disturbance/inclusions in the sediment such as large rocks or roots. For instance, despite the 5 cm spit protocol, excavated sediment recovered from each spit in Watinglo is highly diverse ranging from just 8000 to 73,000 g (Appendix Table 1; O'Connor et al. 2011). The adjustment formula helps to reduce this bias and improve our ability to meaningfully compare abundance of Malacostraca remains between spits.

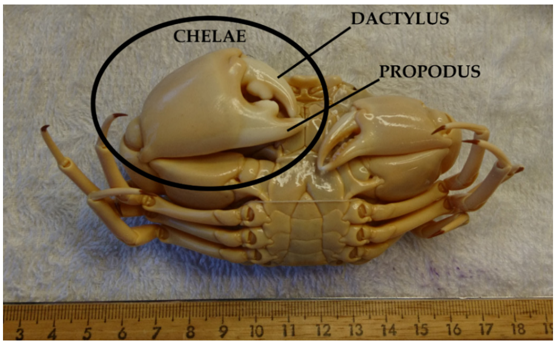

Figure 5. Chelae on Carpilus maculatus consist of *dactylus* and *propodus* (left and right) as an example of the indicator of MNI on crabs. Invertebrate collection of the Australian Museum, Sydney.

3. Result and Discussion

Quantification analyses of the Watinglo assemblage showed relatively low density of Malacostraca remains, but consistently present across most spits (Fig. 6). There is a total of 5197 Malacostraca fragments equating to 337.09 g. The majority of spits however, failed to recover any chelae for MNI, or only recovered 1-7 quantifiable elements, with the exception of spit 25. Spit 25 recovered an exceptionally higher proportion of Malacostraca remains, compared to other spits, with a total of 1498 Malacostraca fragments (NISP), 22 MNI, and 123.35 g. Spit 25 recovered nearly 30% of the total Malacostraca assemblage from Watinglo (Appendix Table 1). The next highest was from spits 30 and 33, with 449 and 206 fragments, respectively. However, despite having a lower NISP count, the heaviest weight after spit 25 was from spit 70 with 87 fragments equating to 14.46 g of Malacostraca remains. Unfortunately, weight measurements for some spits are effected by calcium carbonate accretions adhering to the crab remains, in particular spits 18, 19, 81, and some remains from spit 25, thus meaningful comparisons of weights between these and other spits cannot be easily made. In particular, the chelae from spit 18 is even cemented to fragments of shellfish, the separation of which would very likely damage the specimen.

The Watinglo remains are dominated by crab walking legs and carapace fragments. Most of the remains are unidentified taxonomically due to heavy fragmentation. However, based on the shape of the chelae and coloration of the carapace (recovered from spits 12, 14, 25, 41, and 70), at least two genus of swimming crabs were identified as regularly exploited at the Watinglo site: *Thranita cf. crenata* and

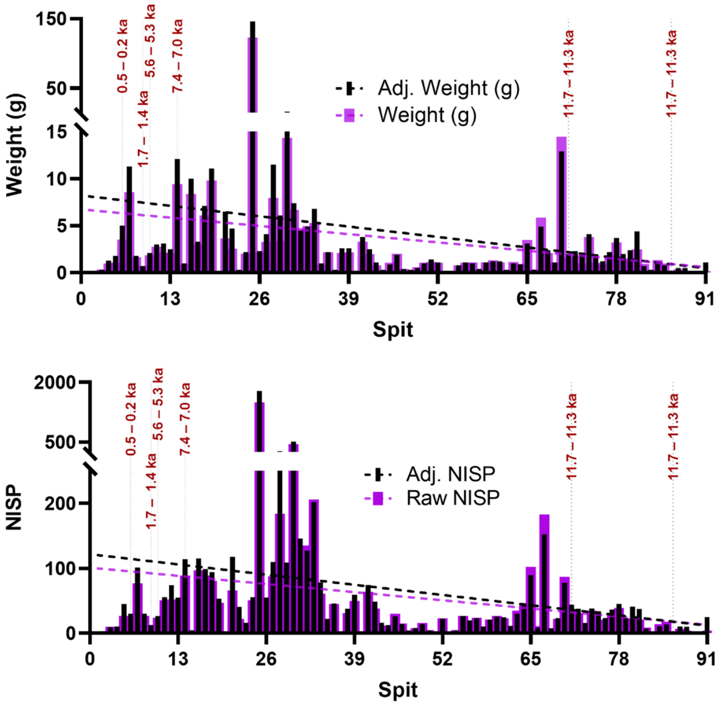

Figure 6. Quantification results on Watinglo Malacostraca. Top: raw (purple) and adjusted (black) weight (g); bottom: raw and adjusted NISP. Simple linear regression line (horizontal dotted black and purple) shows a general decrease in abundance from the top to bottom spits. Note that the x-axis (Weight and NISP) has been broken and the interval rate changed near the top. Radiocarbon dates from O’Connor et al. (2011: Table 3) recalibrated here in cal BP using OxCal v.4.4 with the IntCal20 calibration curve for terrestrial carbon samples and Marine20 curve for marine shells. Dates written in thousands of years (ka).

Scylla spp. Both genera are within the family Portunidae, characterised by their flat fifth leg that is used for swimming and paddling. Portunidae live in a wide range of habitats throughout the Indo-Pacific (Stephenson and Campbell, 1960). They would have been obtainable by the occupants of Watinglo from the marine environments immediately to the north of the site. Additionally, *Parasesarma* spp. (spit 14) and *Carpilius* spp. (spit 25) were also identified in smaller numbers.

3.1 Statistical Differences between Quantification Methods

A simple correlation coefficient analysis was used to determine the variation of the results between quantification methods (i.e. MNI vs NISP vs Weight). Values per spit for each quantification methods were used for the analysis (Table 2). The results suggest a strong positive correlation between all three methods (Table 2).

Table 2. Correlation analysis of the quantification methods on Malacostraca. Values shown are r values where the closer the value is to 1, the stronger the correlation. All correlations were recovered as statistically significant with $p < 0.05$.

	MNI	NISP	Weight
MNI	1		
NISP	0.89	1	
Weight	0.89	0.97	1

3.2 Discussion

Malacostraca remains are frequently recovered from archaeological contexts and have the potential to inform on a wide range of factors regarding early human-environment interactions. While a number of analytical techniques have been developed for archaeological Malacostraca remains, they have seen only a limited application thus far to real-world assemblages. Each method of quantification analysis has its own advantages and disadvantages. MNI can be a good indicator of the number of individual Malacostraca consumed at a site. However, in sites where the remains are poorly preserved or highly fragmented, such as Watinglo, this method is likely to underrepresent the true number of Malacostraca consumed. Although, in some spits at Watinglo (e.g. spit 39) a high abundance of Malacostraca remains were recovered, unfortunately none of the body parts were suitable for MNI quantification. In case such as this, NISP provides important information to assess relative abundance of Malacostraca. However, NISP may not provide a 'true' reflection of fluctuations in quantity of Malacostraca consumed because a high NISP can be the product of heavy fragmentation, e.g. low numbers of Malacostraca crushed into tiny pieces. Thus, the weight method is considered the best presentation of the relative amount of Malacostraca remains recovered at Watinglo across the assemblage. Unfortunately, the weight method overall can be less applicable when sediments are heavily calcified, making the archaeological materials heavier due to adhering carbonate.

Exploitation of Malacostraca at Watinglo was relatively minimal in the lower spits (spits 91 - 86), increasing in the following spits 86 – 65, although radiocarbon dates from spits 86 (ANU-9420) and 71 (Wk-17257) show that these spits all likely correspond to the same period of occupation ca. 11.7 ka (O'Connor et al., 2011). A high rate of sedimentation over a short period of time is often an indicator of an increase in occupation intensity at the site (Kealy et al., 2020). It is possible the increase in Malacostraca remains towards the end of this occupation period corresponds to a culmination in site use at the end of the Pleistocene. Exploitation of Malacostraca is low and irregular in spits 64 – 35 (presumably Early Holocene), followed by the peak in Malacostraca remains (spits 35 – 25), corresponding to the period when sea levels reached their present-day position during the Mid-Holocene. Following the peak of spit 25, consumption declines in the top spits (24 - 1) of the Late Holocene, although remains above the low levels of the Early Holocene period (Fig. 5). However, radiocarbon dates from spit 14 (Wk-17253), 10 (Wk-17255), 9 (Wk-17254), and 6 (ANU-9418) indicate that these spits cover a much longer timespan (about 7,000 years; O'Connor et al., 2011) than the lower levels of the deposit. Even accounting for a possible hiatus between ~5.5 ka to 2 ka (as suggested by O'Connor et al., 2011), this slower sedimentation rate implies a lower occupation intensity during the Mid- to Late Holocene.

One scenario to explain the differences in sedimentation rates but similarly high Malacostraca consumption during the initial Pleistocene-Holocene period and later Mid- to Late Holocene is that the sedimentation rate reflects the permanency of occupation at the site. Whereby, Watinglo was occupied more permanently during the Pleistocene-Holocene transition and more transiently in the Mid- to Late Holocene. These differences may also be the result of changing climatic and ecological conditions which drove shifts in subsistence strategies towards Malacostraca consumption (see below). The Malacostraca record from the upper Late Holocene spits may also be slightly inflated relative to the underlying deposit as a result of greater preservation and more minimal taphonomic effects. However, fragmentation of Malacostraca remains appear relatively consistent throughout the assemblage, with the exception of the rich spit 25, suggesting that preservation processes were also relatively consistent throughout the deposit.

A similar scenario was also found at other Indo-Pacific coastal sites with extensive marine exploitation including Bubog I (Ilin Island, Philippines), Here Sorot Entapa (Kisar Island, Indonesia), and Makpan (Alor Island, Indonesia) (respectively Boulanger et al. 2019; Kaharudin et al. 2019; Kealy et al. 2020). In all these assemblages, intensification of Malacostraca consumption begins during the Terminal Pleistocene and into the Holocene. Both Bubog I and Makpan show high levels of Malacostraca exploitation during the Holocene (Boulanger et al. 2019; Kealy et al. 2020), while Here Sorot Entapa peaked during the Terminal Pleistocene, decreasing again in the Holocene (Kaharudin et al. 2019). Moreover, Makpan also shows a similar occupation episode to Watinglo where there is a rapid increase in sedimentation dense with archaeological materials covering the span of only a thousand years (~11 ka ago) during the Pleistocene-Holocene transition (Kealy et al., 2020). More inland sites with limited access to coastal resources such as Laili (Timor-Leste) and Mandung (Java, Indonesia) also record the presence of Malacostraca remains but in too low abundance to show any meaningful consumption patterns (Hawkins et al. 2017; Kaharudin et al. 2023).

Increases in occupation intensity and intensive crab exploitation during the Terminal Pleistocene and Pleistocene-Holocene transition may correlate to the changing climate and sea level fluctuations of this period. Exploitation of Malacostraca at both Makpan and Here Sorot Entapa begins during the Terminal Pleistocene at ~15 ka and rapidly increased through to the early Holocene at ~14 - 11 ka (Kaharudin et al. 2019; Kealy et al. 2020). This corresponds with the deglaciation of the West Antarctica ice sheet and rapid rise of global sea levels from around 14 - 15 ka (Clark et al. 2009). Additionally, PNG, Philippines, and Indonesia are all located in the area known as the "Coral Triangle" (Fig. 3). The Coral Triangle is known for its extensive shallow water areas, long coastlines, and a wealth of marine biodiversity (Sanciangco et al. 2013). A significant change in sea level and ocean temperatures may have greatly affected the ecological equilibrium of this region.

Many Malacostraca species are temperature-sensitive, particularly for their larvae development (Hamasaki et al. 2009; Andrés et al. 2010; Steneck and Wahle 2013). Warming climate and ocean temperatures post-Last Glacial Maximum may have driven an increase in Malacostraca populations within the Coral Triangle. Furthermore, rising sea levels likely submerged pre-existing coastlines, driving the development of new inter-tidal zones. Malacostraca, many of whom have evolved to live in rocky ecosystems (Landschoff et al. 2013), may have been better suited to these newly eroding coastlines, and had the capacity to move into new zones more rapidly (Hull and Bourdeau 2017) than other more sessile marine invertebrates.

Currently, the mangrove ecosystem provides a significant economic resource of fish, crabs, shrimp, and shells in the area. A study conducted in Youtefa Bay, around 30 km west of Watinglo, found that fishery products retrieved from mangrove ecosystems were the highest when compared to coral reef and seagrass systems (Rumahorbo et al. 2020). Among the identified crab taxa exploited by Watinglo's early inhabitants, *Thranita cf. crenata* and *Scylla* spp. are both distributed across a wide ecological niche which encompasses estuarine and mangrove systems (Cannicci et al. 1996). Similarly, *Parasesarma* spp. is a burrowing crab that mostly inhabits mangrove forests (Setyadi et al., 2021), while *Carpilius* spp. is mostly found in coral and rocky reef environments (Dalzell et al. 1996). Other than crabs, Watinglo also recovered other marine invertebrates including shells and sea urchin. Despite this high abundance of marine invertebrates, most vertebrate remains were obtained from the terrestrial, rather than of marine environment (O'Connor et al. 2011). The distance of Watinglo from the coastline as well as its altitude, no doubt contributed to this pattern. It is likely that significant quantities of marine resources would have been consumed at the coast following procurement, rather than carried back to the cave up the steep slope. The low number of fish bones recovered from the excavation, in addition to the near-shore habitat of the invertebrate in the assemblage, suggests that the subsistence strategy at Watinglo was focused on expedient near-shore coastal resources, coupled with terrestrial exploitation, rather than offshore reef or pelagic fishing.

Taxonomical identification on Malacostraca tends to be less successful in archaeology due to low numbers of remains and/or their heavy fragmentation. The challenges that such heavy fragmentation pose for identification will likely be somewhat alleviated when these methods are applied to sites with a higher abundance of Malacostraca remains. Morphological analysis is probably the simplest and most affordable method for taxonomic identification. However, it also has a huge disadvantage due to the wide variety of morphological variation, even within the same species. To resolve this, various other methods have been developed including using molecular analysis, aDNA sequencing, nuclear and mitochondrial DNA markers (Vartak et al. 2015; Sarower et al. 2017). More detailed analyses of Malacostraca remains will greatly benefit the understanding of prehistoric subsistence strategies in coastal communities including targeted type, size, seasonal collection, and the fluctuations in quantity throughout the occupation period. Malacostraca remains also have potential to be used as a proxy to inform on the local palaeoenvironmental conditions around the site. This can be achieved by looking at the taxonomical distribution recovered in the site or using microscopic analyses (e.g. SEM and TEM) on their chitin.

4. Conclusion

Malacostraca are one of the vital dietary components in human subsistence strategies from prehistoric through to modern times, especially in coastal and island communities. Malacostraca remains have been recovered in significant quantities from many prehistoric sites across the Indo-Pacific, however they have often been overlooked in analyses of marine zooarchaeological assemblages. Different archaeological sites in the region have varying abundance of Malacostraca remains with assorted degrees of fragmentation due to their butchery practice and taphonomical factors. Watinglo shelter in Papua New Guinea is one site that shows heavy fragmentation of Malacostraca remains. The best results can be achieved by using a variety of different quantification methods: weight, MNI, and NISP, as together, these complement each other. Archaeological data from various sites in PNG, Indonesia, and the Philippines suggests that there is limited evidence for Malacostraca exploitation in the region during the Late Pleistocene (prior ~15 ka). Intensive Malacostraca exploitation only begins at the Terminal Pleistocene/early Holocene boundary. Rising sea levels coupled with wetter-warmer climate conditions may have been the vital factors which increased Malacostraca availability to prehistoric coastal foragers.

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Appendix

Table 1. Minimum Number of Individuals (MNI), raw & adjusted Number of Identified Specimens (NISP), and raw & adjusted weight of Malacostraca remains from 91 spits of Watinglo.

Spit	Excavated sediment (g)	Raw Quantification			Adjusted Quantification	
		MNI	NISP	Weight (g)	Adj. NISP	Adj. Weight (g)
1	41500	0	0	0	0.00	0.00
2	43000	0	3	0.16	3.49	0.19
3	53000	0	13	0.49	12.26	0.46
4	38500	1	8	0.98	10.39	1.27
5	30000	1	28	2.14	46.67	3.57
6	35000	1	21	3.52	30.00	5.03
7	38000	3	77	8.58	101.32	11.29
8	45000	1	27	1.66	30.00	1.84
9	53000	0	14	0.94	13.21	0.89
10	45000	0	24	1.86	26.67	2.07
11	46000	2	51	2.75	55.43	2.99
12	35000	3	52	2.15	74.29	3.07
13	42000	1	46	2.06	54.76	2.45
14	39000	6	89	9.43	114.10	12.09
15	42000	0	4	0.88	4.76	1.05
16	42000	2	97	8.37	115.48	9.96
17	45000	6	90	3.41	100.00	3.79
18	43000	4	81	6.1	94.19	7.09
19	44000	4	48	11.14	54.55	12.66
20	59000	0	2	0.05	1.69	0.04
21	28000	3	66	3.66	117.86	6.54
22	27000	3	22	2.55	40.74	4.72
23	31000	0	10	0.17	16.13	0.27
24	46000	1	51	2.02	55.43	2.20
25	42000	22	1498	123.35	1783.33	146.85
26	48000	1	53	2.17	55.21	2.26
27	40000	1	90	3.49	112.50	4.36
28	34500	5	188	8.11	272.46	11.75
29	28000	2	63	3.52	112.50	6.29
30	44000	7	449	14.35	510.23	16.31
31	45000	3	131	6.68	145.56	7.42
32	53000	1	135	4.73	127.36	4.46
33	51000	3	206	4.97	201.96	4.87
34	39000	2	61	5.3	78.21	6.79
35	43000	0	19	0.87	22.09	1.01
36	49000	0	45	2.18	45.92	2.22
37	39000	0	1	0.23	1.28	0.29
38	41000	0	31	2.1	37.80	2.56
39	42000	0	52	2.43	61.90	2.89

40	47000	0	0	0	0.00	0.00
41	43000	2	66	4.09	76.74	4.76
42	39000	1	38	1.98	48.72	2.54
43	37000	0	12	0.78	16.22	1.05
44	43000	0	11	0.26	12.79	0.30
45	57000	0	30	1.07	26.32	0.94
46	53000	2	15	2.02	14.15	1.91
47	47000	0	4	0.39	4.26	0.41
48	49000	0	8	0.25	8.16	0.26
49	57000	0	17	0.62	14.91	0.54
50	55000	1	5	1.08	4.55	0.98
51	42000	1	3	1.16	3.57	1.38
52	51000	0	23	1.08	22.55	1.06
53	59000	0	0	0	0.00	0.00
54	56000	0	5	0.16	4.46	0.14
55	51000	0	27	0.78	26.47	0.76
56	47500	0	19	1.06	20.00	1.12
57	52000	0	24	1.09	23.08	1.05
58	48000	0	10	0.35	10.42	0.36
59	50000	0	21	1.09	21.00	1.09
60	53000	1	27	1.31	25.47	1.24
61	47000	0	23	1.09	24.47	1.16
62	39000	0	9	0.27	11.54	0.35
63	58000	0	35	1.13	30.17	0.97
64	50000	0	43	0.93	43.00	0.93
65	57000	2	103	3.55	90.35	3.11
66	63000	0	11	0.36	8.73	0.29
67	60000	2	186	6.13	155.00	5.11
68	44000	3	7	2.08	7.95	2.36
69	47000	0	22	1.08	23.40	1.15
70	56000	7	87	14.46	77.68	12.91
71	42000	0	37	1.65	44.05	1.96
72	41000	0	31	1.89	37.80	2.30
73	25000	0	28	1.87	56.00	3.74
74	46000	0	35	3.8	38.04	4.13
75	31000	0	21	1.04	33.87	1.68
76	36000	0	17	0.88	23.61	1.22
77	41000	0	30	1.84	36.59	2.24
78	43000	0	39	3.21	45.35	3.73
79	38000	0	18	1.52	23.68	2.00
80	28000	1	23	1.34	41.07	2.39
81	28000	0	21	2.49	37.50	4.45
82	63000	0	9	0.94	7.14	0.75
83	39000	0	2	0.23	2.56	0.29
84	64000	0	14	1.35	10.94	1.05

85	65000	0	18	0.98	13.85	0.75
86	73000	0	2	0.1	1.37	0.07
87	33000	0	7	0.35	10.61	0.53
88	20000	0	4	0.19	10.00	0.48
89	14000	0	0	0	0.00	0.00
90	11000	0	0	0	0.00	0.00
91	8000	0	4	0.17	25.00	1.06
TOTAL	3976000	112	5197	337.09	6096.89	400.95