Historical data on shallow-water invertebrates in Palu Bay, Indonesia to address the “Shifting Baselines” syndrome

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Abstract. As global change accelerates in the Anthropocene, the “shifting baselines” paradigm is also exacerbated. In this context, it is important to make historical data available in order to assist in evaluating and mitigating the changes occurring. Even though data from the first two decades of the 21st Century do not represent a pristine or true baseline condition, it is important to collate and curate data from this period. Unfortunately, many data are unpublished or stored in temporary repositories for a short time horizon (e.g. 3-10 years) or in printed format only, greatly limiting detection and access. We present data from four studies on shallow water invertebrates in Palu Bay collected over the period from 2008 to 2010. The taxonomic groups covered are Molluscs (Gastropods), Echinoderms and Cnidaria (corals), with some data on other taxa. These data will be of especial interest as a reference in evaluating the condition and recovery of the coastal ecosystems of Palu Bay after the 2018 tsunami.

1. Introduction
As global change accelerates in the Anthropocene, bringing global and local change in all aspects of human life and in our biosphere [1], the “shifting baselines” paradigm [2] is also accelerated. As each “generation” accepts what they see as “normal”, gradual change or shifts go unrecognised and even sharp changes can quickly fade as people become accustomed to the new “normal” they are experiencing. There is increasing awareness of the “shifting baselines” syndrome, which has been documented in a wide range of stakeholder groups [3,4] including fishing communities and coral reef scientists [5,6]. A number of initiatives are helping to address the problem through collecting and exposing historical data and demonstrating the trends, for example the Sea Around Us Project reconstructions of fisheries at global and regional scales [7,8]. In order to mitigate and adapt to the Anthropocene we need to detect change, which means that we need to know how things were before. In this context, it is important to make historical data available in order to assist in evaluating the changes occurring and responding to them in appropriate ways.

Sulawesi Island lies at the heart of Wallacea and the Coral Triangle; high marine biodiversity is coupled with a high dependency of (often fast-growing) human populations on marine living resources, including invertebrates (e.g. echinoderms, molluscs) [9,10]. Coastal ecosystems (coral reefs, seagrass meadows, mangrove forests, estuaries and others) are all under growing levels of threat.
Even though data from the first two decades of the 21st Century do not represent a pristine or true baseline condition in many regions, it is important to collate and curate data from this period. Unfortunately, many data are unpublished or stored in temporary repositories with a short time horizon (e.g. government agencies typically store documents and files for 3-10 years) or in printed format only (e.g. collections of student theses and research reports in academic institutions), greatly limiting detection and access. Many data have undoubtedly been lost, underlining the urgency of a drive to collate data and make them available in more accessible and durable formats and thereby prevent or limit further losses.

Palu Bay in Central Sulawesi is one region which was originally blessed with productive and biodiverse coastal ecosystems, but has been subjected to growing anthropogenic pressures in recent decades. Bisected by the Palu-Koro Fault in the Indonesian Triple Junction zone [11], Palu Bay and the surrounding area are intrinsically at high risk from phenomena related to tectonic activity. The “triple disaster” (earthquake, liquefaction and tsunami) on 28 September 2018 [12,13] caused devastation and loss of life on land [14,15], mirrored by extensive damage to shallow-water coastal ecosystems. In some areas the coastal shelf underwent subsidence [16] or even disappeared into Palu Bay in tsunamigenic landslides [12,15,17,18], at least some of which may have been related to liquefaction phenomena [13,19]. In others, the coastal shelf remains but natural seagrass beds and coral reefs were reduced to featureless bare substrate at Mamboro with extremely few fish or invertebrates [20,21]. The tsunamis and/or subsidence resulted in the disappearance of large, well-covered coral reef restoration modules (direct observations by the authors in 2019 and 2020), as well as many other man-made structures along the coast [12,14–16,22]. Furthermore, considerable changes to the bathymetry of the Bay will require extensive revision to navigational charts [23].

In contrast to the plethora of publications on many other aspects of this natural disaster in and around Palu Bay, including the mechanisms involved [12–14,16–19] and socio-economic impacts [14,22,24], attention to the impacts on life and ecosystems below the water appears to have been limited [20,21], despite it’s importance [25]. To remedy this, baseline or at least pre-disaster data are vital. This makes initiatives to gather unpublished data from recent decades on the coastal ecosystems of Palu Bay (especially data which are inaccessible and/or likely to be lost) all the more important, in particular to monitor natural recovery as well as to guide rehabilitation efforts and to evaluate their success. As a small contribution, we present data from three previously unpublished studies on shallow water invertebrates in Palu Bay collected over the period 2008–2010, representing three taxonomic groups. These data will be of especial interest as a reference in evaluating the condition and recovery of the coastal ecosystems of Palu Bay after the 2018 tsunami.

2. Materials and Methods

2.1. Study site and time-frame
This manuscript presents a synopsis of and commentary on the results of three studies carried out at sites in Palu Bay, Palu City, Central Sulawesi Province, Indonesia (Figure 1). The studies were conducted over the period 2008 to 2010. All authors took part in one or more of the studies, with the first and corresponding authors involved in all three studies.

According to local elders, Palu Bay was once largely surrounded by mangrove belts, most of which were destroyed during the Japanese occupation in World War II, due to a combination of a desire to destroy refuges for dissidents/freedom fighters and a taste for food cooked using mangrove charcoal. The Panau site (Figure 1) is in Palu Utara Sub-District, on the border with Tawaeli Sub-District, just north of the Palu City coal-fired electricity generating power station which began operations in 2006. At the time of the studies, this area had one of the last remaining stands of mangroves on the east side of Palu Bay, as well as productive and biodiverse seagrass meadows and coral reefs, making it an ideal site for marine ecology and survey practical sessions by local universities and tertiary colleges, a practice which began in 2004.
The Mamboro site (Figure 1) is also in Palu Utara Sub-District, in a relatively sheltered embayment in front of the Central Sulawesi Marine and Fisheries Service hatchery. The hatchery facilities were largely destroyed by the 2018 tsunami but were operational at the time of these studies. Mamboro was also one of the sites where coral reef restoration “fish home” modules were installed in 2007 and 2008 [26]; the good results, especially in terms of natural recruitment, were thought to be influenced by the healthy and diverse reefs at the Panau site, with over 50% hard coral cover in 2001-2003 [27].

**Figure 1.** Map of Palu Bay (Central Sulawesi, Indonesia) showing the study sites.

2.2. Data collection

2.2.1. Coral condition in Tawaeli and Panau. The manta tow method [28] was used to evaluate the condition of the fringing coral reefs along the coast of Palu Bay from just north of the Tawaeli-Panau border to south of the coal-fired electricity generating power station in Panau (operational from 2006). The survey took place on 18th December 2008. The use of a double manta tow board enabled two observers (the fourth and fifth authors) to be towed slowly along the reef crest by a wooden canoe powered by a longshaft outboard motor. One observer looked landward (reef crest/reef flat) and one looked seaward (reef crest/slope). Each tow lasted 2 minutes with 13 tows covering a total distance of approximately 2.5 km (Figure 1). Latitude and longitude coordinates were recorded using a GPS unit (Garmin eTrex, WGS 84 datum). The substrate composition was recorded using six substrate categories (Hard Coral = HC; Soft Coral = SC; Other = OT; Dead Coral = DC; Rubble = RB and Sand/Silt = SS) and five percentage cover categories (1 = 0-10%, mean 5%; 2 = 10-30%, mean 20%; 3 = 30-50%, mean 40%; 4 = 50-75%, mean 62.5%; and 5 = 75-100%, mean 86.5%). Coral condition was based on percentage hard coral cover (% HC) using these five categories, with the respective descriptive categories being Very Poor, Poor, Average, Good, and Excellent. The presence of the corallivorous crown of thorns starfish (*Acanthaster planci*) and general conditions were also noted.

2.2.2. Echinoderms at Panau. The benthic echinoderm fauna of Panau was observed on 19th August 2009 by a buddy pair diving using SCUBA equipment. Two surveys were conducted, one in the daytime and one at night. Echinoderms were recorded on a slate and, where possible, photographed using a digital underwater camera. Other invertebrates recognised were also recorded. Each survey comprised three belt transects 20 m long and 5 m wide (2.5 m each side of the transect line) laid at around 3 m depth. References used in species identification included [29,30].
2.2.3. Molluscs (Gastropods) at Mamboro. This study focused on the gastropod fauna in the seagrass beds at the Mamboro site. Data were collected during the 2nd and 3rd weeks of April 2010 from 5 quadrats (50 cm x 50 cm) at 5m intervals along 5 transects laid perpendicular to the shoreline at a distance of 50 m apart. Gastropods visible on the substrate or on the seagrass (predominantly Enhalus acoroides) were collected. The sediment was then excavated to a depth of approximately 20 cm and sieved to retrieve the gastropod infauna. The specimens were identified to Family level and where possible to genus or species level based on [29,31–33] and other references.

2.3. Data analysis
Data were analysed descriptively and presented as tables and/or graphs. The data were discussed in the context of coastal ecosystem management, with particular reference to the Tsunami of 28 September 2018 and post-tsunami conditions in Palu Bay.

3. Results and Discussion

3.1. Coral condition at Panau
The manta tow data (Table 1) shows that the most common coral condition category was 2 (10-30% HC cover, Poor). GPS reception was poor, but the coordinates ranged from approximately: 0º 43'42"S to 0º 45'00"S and 119º 51'12"E to 119º 51'24"E, following the outer edge of the reef crest.

| Tow No. | HC CR/F | SC CR/F | OT CR/F | DC CR/F | RB CR/F | SS CR/F | Remarks |
|---------|---------|---------|---------|---------|---------|---------|---------|
| 1       | 2       | 1       | 1       | 1       | 2       | 2       | 3       | 3       | 1       | 1       | COTS |
| 2       | 2       | 3       | 1       | 1       | 1       | 3       | 2       | 2       | 2       | 1       | 1       | COTS |
| 3       | 4       | 3       | 1       | 1       | 1       | 2       | 1       | 2       | 1       | 1       | 1       | COTS |
| 4       | 2       | 2       | 1       | 2       | 1       | 3       | 1       | 2       | 3       | 1       | 1       | COTS |
| 5       | 2       | 2       | 1       | 1       | 1       | 2       | 1       | 2       | 2       | 2       | 2       | COTS |
| 6       | 2       | 2       | 2       | 1       | 1       | 3       | 2       | 2       | 2       | 2       | 1       | COTS |
| 7       | 2       | 1       | 2       | 1       | 1       | 2       | 3       | 2       | 2       | 3       | 2       | COTS |
| 8       | 2       | 2       | 2       | 1       | 1       | 3       | 1       | 3       | 2       | 1       | 1       | COTS |
| 9       | 2       | 1       | 2       | 1       | 1       | 2       | 1       | 2       | 1       | 3       | 2       | COTS |
| 10      | 2       | 1       | 2       | 1       | 1       | 2       | 1       | 2       | 1       | 3       | 2       | HP   |
| 11      | 2       | 2       | 2       | 1       | 1       | 1       | 1       | 2       | 1       | 2       | 2       | HP   |
| 12      | 1       | 2       | 2       | 1       | 1       | 1       | 1       | 2       | 2       | 2       | 2       | HP   |
| 13      | 1       | 1       | 1       | 1       | 1       | 1       | 1       | 1       | 1       | 5       | 4       | HP   |

Table 1. Manta tow substrate cover categories* from a tow in the Panau area on 18 December 2008.

*HC = Hard Coral; SC = Soft Coral; OT = Other; DC = Dead Coral; RB = Rubble; SS = Sand/Silt; 1 = 0-10%; 2 = 10-30%; 3 = 30-50%; 4 = 50-75%; 5 = 75-100%; CR = reef crest; F = reef flat; S = reef slope

1 = Very Poor; 2 = Poor; 3 = Average; 4 = Good; 5 = Excellent

COTS = crown of thorns starfish (Acanthaster planci); HP = heat pollution

The data show considerable variation between observers as well as between tows. While the latter was due to changes in overall coral cover and reef condition, the former was largely due to the difference in substrate composition between the areas being observed by each of the two recorders, i.e. the reef flat/crest and crest/slope area. Overall, the data revealed a sharp reduction in coral cover compared to the 2001-2003 data. Two readily visible reasons for this were a severe outbreak of the coral predator Acanthaster planci in the northern part of the surveyed area, with recently killed corals still bright white or only slightly green or grey discolouration due to algal overgrowth; and thermal pollution from the Panau power station in the four southernmost tows. There were hot currents with water...
temperature high enough to make it extremely uncomfortable and at times only just bearable for the observers.

The overall average live hard coral (HC) cover was around 21%, in the Poor category, as was the mean rubble (RB) cover, with sand/silt cover around 20%. Soft coral cover ($\approx$ 15%) was less than dead hard coral ($\approx$17%), while cover of other (OT) substrates (e.g. sponges, macroalgae or debris) was less than 6%. The difference in estimated mean substrate composition (combined data from both observers using mean values for each category normalised to 100% per tow) in two segments: the least damaged area to the north (tows 1-6) and the area close to the Panau power station in the south (tows 9-13) can be seen in Fig 2. The transition zone (tows 7-8) is not included in these graphs. A substantial proportion of the dead coral and rubble in Figure 2A was recently killed coral due to the COTS outbreak, and most of the sand/silt component was sand. In contrast, the dead coral and rubble in Figure 2B was mostly covered with slimy overgrowth and most of the live corals were pale, covered with sediment, competing with algal or other overgrowth, exhibiting signs of disease, or a combination of these, and the sand/silt component was dominated by silt. These graphs demonstrate the impact of the power station, with a combination of thermal pollution and sedimentation.

![Figure 2. Average substrate composition at Panau: A. northern segment; B. southern segment.](image)

### 3.2. Daytime and night time Echinoderms at Panau

Echinoderms observed belonged to five broad groups. Some echinoderms were seen during both time period; however, the majority were only seen during the daytime or the night time survey (Table 2).

**Table 2.** Echinoderms observed during daytime and night time on Panau reef on 19th August 2009.

| No. | Group                  | Taxon (Family or lower)               | Time period | Density (ind/100m$^2$) |
|-----|------------------------|---------------------------------------|-------------|------------------------|
| 1   | Sea cucumbers          | Stichopodidae: *Stichopus horrens*    | night       | 0.33                   |
| 2   | Synaptidae: genera *Synapta* and *Euapta* | night      | 2.67                   |
| 3   | Unidentified species   |                                       | night       | 0.33                   |
| 4   | Starfish               | Acanthasteridae: *Acanthaster planci* | day         | 0.67                   |
| 5   | Ophidiasteridae: *Linckia laevigata* | day         | 6.33                   |
|     | Ophidiasteridae: genus *Gomphia* | day/night | 1.33                   |
| 6   | Sea urchins            | Toxopneustidae: *Toxopneustes pileolus* | night       | 0.33                   |
| 7   | Cidaridae              |                                       | night       | 6.33                   |
| 8   | Echinometridae: genus *Echinometra* | night      | 1.33                   |
| 9   | Diadematidae: *Echinothrix diadema* | night     | 0.67                   |
| 10  | Diadematidae: *Echinothrix calamaris* | night     | 21.33                  |
| 11  | Diadematidae: genus *Diadema* | day/night | 6.67                   |
| 12  | Brittle stars          | Ophiocomidae                           | night       | 27.00                  |
| 13  | Ophiotrichidae         |                                       | night       | 9.67                   |
The species was not recorded during this survey but most likely included *D. setosum* and *D. savignyi*.

Some of the species seen as well as an overview of the conditions at the site are shown in Figure 3 (daytime) and Figure 4 (night time). The coral cover and reef structure was dominated by massive life-forms, although some branching corals still remained after the COTS outbreak in 2008, mostly of the genus *Porites* (Figure 3h).

![Figure 3. Daytime echinoderms at Panau: Pearsonothuria graeffei (off-transect) (a); Acanthaster planci (b); Comasteridae (c); laying the transect (d); Linckia laevigata (e); Comasteridae (g); Tropiometridae (h).](image-url)
Figure 4. Night time echinoderms at Panau: Toxopneustes pileolus (a); Diadema setosum and an unidentified holothurian (b); Echinometra sp. (c); Euapta sp. (d); Culcita novaeguineae (off transect) (e); Echinothrix calamaris (f); brittle star, Ophiotrichidae (g); feather star, Mariametridae (h).

This survey took place approximately 6 months after the manta tow described in section 3.1. Despite the presence of some Acanthaster planci (Figure 3b), the outbreak appeared to be over. Coral cover and diversity had been reduced; in particular the proportion of acroporid corals was less than prior to the outbreak. However, the reef seemed to be recovering with considerable numbers of juvenile colonies of many species as well as recent coral recruits on dead coral substrate; for example near the Linckia laevis in Figure 3e there were both young colonies and coral recruits.

In addition to the echinoderms observed on-transit, several Pearsonothuria graeffei (Semper, 1868) were observed at this site, at depths of around 1-6 m. This species, formerly known as Bohadschia graeffei [29,30], is now considered to be the sole extant species in the monophyletic genus Pearsonothuria [34], considered a sister clade to the genus Bohadschia by [35]. During the day time survey, one individual was seen exhibiting behaviour associated with male sea cucumber spawning (Figure 3a). As described briefly by [36] in P. graeffei, and in more detail by [37] in several related species, in sea cucumbers male spawning behaviour typically involves raising up the anterior part of the body vertically in the water column with a waving or weaving motion prior to and during spawning. Similar behaviour to that witnessed at Panau was followed by active spawning (release of a stream of sperm from the genital papilla posterior to the tentacles) during observations of B. graeffei in the Wakatobi Islands (Southeast Sulawesi, Indonesia) in 1995 and 1997 (Abigail M. Moore,
unpublished data). However, during this survey spawning was not observed, possibly due to the limited amount of time for such serendipitous and unanticipated observations.

The *Diadema* urchins seen were recorded at the genus level. However, visual records from other surveys and activities at this and nearby sites e.g. Mamboro [20,21] show that two species were common in this area (at least up until the tsunami): *Diadema setosum* and *Diadema savignyi*. Both were identified using DNA barcoding from specimens collected in Palu Bay, at Mamboro and a site between the Panau survey site in this study and the Panau power station [20]. The five white spots visible in Figure 3b identify this specimen as *D. setosum*.

3.3. Molluscs (Gastropods) at Mamboro

The 462 gastropods collected comprised members of 33 Families (Table 3). One specimen was identified with a high degree of certainty to species level, *Haliotis asinina* (Haliotidae). Genera identified with a high level of confidence at the time included *Lambis* (Strombidae), tentatively identified as *Lambis lambis*; *Conus* (Conidae); *Cypraea* (Cypraeidae); and *Oliva* (Olividae).

**Table 3.** Gastropod families identified at Mamboro in April 2010.

| No | Family          | Density ind/m² | No | Family          | Density ind/m² | No | Family          | Density ind/m² |
|----|----------------|----------------|----|----------------|----------------|----|----------------|----------------|
| 1  | Angariidae     | 0.27           | 12 | Haminoeidae    | 0.53           | 12 | Potamididae    | 0.27           |
| 2  | Architectonicae| 0.27           | 13 | Hipponicidae   | 1.07           | 24 | Pyramidalidae  | 0.27           |
| 3  | Cerithidae     | 0.80           | 14 | Littorinidae   | 0.80           | 25 | Rissoidae      | 2.40           |
| 4  | Chepalaspidae  | 0.27           | 15 | Mitridae       | 3.20           | 26 | Stomatellidae  | 0.80           |
| 5  | Conidae        | 9.60           | 16 | Muricidae      | 5.60           | 27 | Strombidae     | 26.67          |
| 6  | Costillaridae  | 1.60           | 17 | Nasaridae      | 7.73           | 28 | Tonnidae       | 0.27           |
| 7  | Cymatiidae     | 0.27           | 18 | Naticidae      | 6.67           | 29 | Triviidae      | 2.13           |
| 8  | Cypraeida      | 3.20           | 19 | Neritidae      | 19.73          | 30 | Turidae        | 10.93          |
| 9  | Epitonidae     | 0.27           | 20 | Olividae       | 13.87          | 31 | Turritellidae  | 0.27           |
| 10 | Fasciolariida  | 0.27           | 21 | Patellidae     | 1.33           | 32 | Unbracuillida  | 1.07           |
| 11 | Haliotidae     | 0.27           | 22 | Planaxidae     | 0.27           | 33 | Volutidae      | 0.27           |

The Strombidae were the most abundant Family. Most species of this Family are gleaned by local people for human consumption, as evidenced by (mostly broken) discarded shells as well as observations of gleaning activity at this site. Taxonomic revisions in the Strombidae cast doubt on the initial assignment of all but a few strombid specimens to the genus *Strombus* with the remainder assigned to *Lambis*. The species previously assigned to *Strombus* and *Lambis* in many reference works [29,31,33] are now considered to be polyphyletic, with at least nine Indo-Pacific genera in Strombidae according to [38] (*Euprotomus*, *Gibberulus*, *Conomurex*, *Lambis*, *Tricornis*, *Canarium*, *Laevistrombus*, *Doxander*, *Labiostrombus*) and three Eastern-Pacific/Atlantic genera (*Tricornis*, *Lentigo*, *Strombus*). Based on the recent evaluation of the genus *Laevistrombus*, it would seem that two specimens which differed quite clearly from the remaining strombids were almost certainly *L. turturrella* [39].

Other families known to be gleaned and consumed in Palu Bay are the Conidae (cone shells) and Cypraeidae (large cowries). Gastropods of the abalone family (Haliotidae) are a valuable commodity; however they were too scarce to be likely to represent an economic resource or contribute meaningfully to food security at the study site. One single individual *H. asinina* was found during this survey, and the authors have rarely seen this species at this or other sites in Palu Bay. It is not known whether this scarcity is a natural situation or the result of human impacts such as environmental degradation and/or past exploitation. Long neglected in comparison to finfish fisheries, overfishing in invertebrate fisheries is widespread and a threat to global food security and ecosystem integrity.
The high levels of gleaning in many areas around Sulawesi [9,42–45] mean that many species are at risk of undetected overfishing and even extirpation; species may be lost without ever having been recorded at sites where they were once abundant, especially those belonging to the infauna such as many of the taxa recorded in this study. One sign of this problem is the greatly reduced abundance and variety of shells seen along shorelines, including those of Palu Bay, even between the 1990’s and the first two decades of the 21st Century.

One lesson learned from this study is the need for expertise in taxonomy and the infrastructure to support taxonomic studies. This is especially true for species groups such as the Molluscs which have received relatively little attention with the exception of a few economically valuable and/or endangered species such as pearl oysters, tridacnid clams, abalone and a few other edible bivalves (e.g. cockles and mussels). For example, as new studies refine molluscan taxonomy [38,39] or improved guides become accessible [46], it would be advantageous to revise and refine past identifications. A network of repositories, well-run and accessible (physically and virtually) reference collections and a network of scientists (including “citizen scientists”) with taxonomic expertise would greatly enhance the value of studies such as this one through greater taxonomic resolution and long-term access to the specimens collected.

4. Conclusion
The data from Palu Bay presented in this paper represent a first step towards preserving and making widely available a considerable body of historical data from “grey literature” and unpublished sources on the coastal ecosystems of Central Sulawesi Province, Indonesia. The data show that, despite the many anthropogenic pressures, Palu Bay still supported biodiverse coastal ecosystems in the first decade of the 21st Century. These data should be of especial interest as a reference in evaluating the condition and recovery of the coastal ecosystems of Palu Bay after the 2018 tsunami. We recommend similar efforts to preserve data on other regions and ecosystems and make them accessible to researchers and all interested stakeholders through collating and publishing such data in digital scientific literature and/or data repositories. We also advocate for a national network of specimen repositories and reference collections for all marine and coastal taxa, in particular molluscs.

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