Dear Referee #1

Thank you for the positive review of our work and we couldn't agree more on the im- portance of WoRMS to synchronise taxonomic data.

Comment: I have only one minor comment. In the recent years, the World Register of Marine Species (http://www.marinespecies.org/index.php) has gained increasing authority in providing valid scientific names of marine species. In order to facilitate international data sharing and ensure standardisation, I think that the authors should ensure scientific name checking.

Response: We updated the species-list (Table_1_species_list; Added here as ZIP-file) to the latest scientific names provided by WoRMS and added a column with current accepted Aphia-IDs to the species-list, allowing to track the taxonomy of our intertidal species.

Dear Referee #2,

Thank you for the positive and constructive review of our paper. Below we list how the minor comments were incorporated. Additionally, a word-file with track-changes is provided.

Specific comments:
Comment: Abstract (P.1 l.4) and introduction (P.2 l.5) "it is virtually unknown how the relationships between abundance patterns and different biotic and environ-mental processes change depending on spatial scales" Is that for any ecological com-munities or only referring to the seabed fauna?
Response: This is for any ecological community, making our efforts so special. Therefore, we also phrased the statement in such a general way.

Comment: Abstract (P.1 l.9) Are there only bivalves, polychaetes and crustaceans? Further down, I found out that it wasn't the case, I suggest a formulation like 'dominated by'
Response: Changed to "dominated by"

Comment: Abstract (P.1 l.13) I was a bit disappointed that the authors did not measure the taxa-level biomass. I do appreciate the substantial work that has already been put into the database and that it may not have been possible to do so but as for 'gaining insight in the role of biodiversity in maintaining ecosystem functioning', it would have been great to have some idea of the biomass of each taxa at each station considering that ecosystem processes (e.g. energy flow or productivity) are more tightly linked to the biomass.
Response: Indeed, measuring biomass of each taxa was not feasible. We agree that it would have been "nice to have".

Comment: Introduction (P.2 l.2) "...diversity and abundance is fundamental" and biomass as well, see above.
Response: We added "biomass" to the sentence.

5   Comment: Introduction (P.2 l.18) "i.e. bivalves, polychaetes and crustaceans...", same comment as before regarding the formulation. It feels like there are only those three taxa at the moment.
Response: Changed to "dominated by"

Comment: Introduction (P.2 l.22) Why is it time-effective?
10 Response: Changed to "efficient".

Comment: Introduction (P.2 l.27) "from the mangroves to the mid-tidal" the first time I read this bitI thought you meant 'halfway down the intertidal', I realised further down that it wasn'tthe case. I'd suggest the reformulation: "to the lower end of the middle intertidal zone"or something like that.
15 Response: Changed to "from the mangroves to the lower end of the intertidal zone in three…."

Comment: Introduction (P.3 l.4) "Shellhash", I did not know that word, thank you. It is however spelt in one or two words within the manuscript, be careful about consistency.
Response: Throughout the manuscript we now use "shellhash".
20
Comment:Mat & Met (P.4 l.13) (n= 1200), it took me awhile to work out where this number came from. Can you remind the reader that you have taken 400 cores in each of the three harbours here please?
Response: In part 2.1 we state "In each Harbour we took 400 cores". But, we added "on foot during low tide (n = 3*400 [1200 in total], thereby…….)"
25
Comment: Mat & Met (P.4 l.23) How was the seagrass coverage estimated? Was it in percentage, how was it done?
Response: Section 2.5 describes how seagrass coverage (%) was estimated, including references to software and my own publication with more details.
30
Comment: Mat & Met (P.4 l.24) How this number (n=960) relates to the previous one (n=1200), it wasn't 400 point per harbour this time then?
Response: P5, Section 2.5 states : " Note that at the smallest spatial scale, i.e. 30 cm, we took 3 adjoining benthic cores, but we limited ourselves to taking one photograph and one sediment sample to
35 represent the environmental features for these three locations. This was done to economically manage our time in the field and our financial budget for processing samples, leading to 320 photographs and 320 sediment samples per Harbour. See Kraan et al. (2015, 2019) or Greenfield et al. (2016) for details"

Comment: Mat & Met (P.5 l.11) Was the size-classes only done for bivalves?
40 Response: Yes. P5, Section 2.2. Here we state "For bivalves, the longest shell axis was also measured".

Comment: Mat & Met (P.5 l.21) Can you give reference(s) for the standard methods?

Response: Yes. We added here "(see Kraan et al., 2015)".

Comment: Mat & Met (P.5 l.21) Does the start and end dates of sample measurements matter? If so, why?
5   Response: We added ", avoiding degradation of samples over time".

Comment: Mat & Met (P.6 l.4) Can you give reference(s) for the standard methods?
Response: Yes. We added here "(see Kraan et al., 2015)".

10   Comment: Mat & Met (P.6 l.7) I think it should be mention earlier that you've also measured thecarbon content (i.e. in the abstract along with the other environmental variables)
Response: We added "organic content" in the Abstract.

Comment: Mat & Met (P.6 l.16) I wouldn't list the failed samples here, this is a bit tedious for
15   something in the main text, I suggest putting it somewhere else together with the other lost sample from the macrobenthic data (table, footnote, supplementary).
Response: We added this information to Table 1.

Comment: Technical corrections: Mat & Met (P.4 l.23) Shell hash in two words here, consistency
20   Response: Changed into "shellhash"

Comment: Mat & Met (P.5 l.19) "0.1gr." The convention for grams is "g"
Response: Changed to "01.g"

25   Comment: Mat & Met (P.5 l.20) "Chlorophyll a", the "a" is not in italic
Response: Changed to 'a'.

30

35

Multi-scale data on intertidal macrobenthic biodiversity and environmental features in three New Zealand harbours

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Abstract. Understanding how the plants and animals that live in the seafloor vary in their spatial patterns of diversity and abundance is fundamental to gaining insight in the role of biodiversity in maintaining ecosystem functioning in coastal ecosystems, as well as advancing the modelling of species distributions under realistic assumptions. Yet, it is virtually unknown how the relationships between abundance patterns and different biotic and environmental processes change depending on spatial scales, which is mainly due to a lack of data. Within the project Spatial Organization of Species Distributions: Hierarchical and Scale-Dependent Patterns and Processes in Coastal Seascapes at the National Institute for Water and Atmospheric Research (NIWA) in New Zealand we collected multi-scale and high-resolution data on macrobenthic biodiversity. We found 146 species, dominated by bivalves, polychaetes and crustaceans (> 500µm) that live hidden in marine sandflats, and collected point measurements of important environmental variables (sediment grain-size distributions, chlorophyll *a* concentration, organic content, and visible sandflat parameters) in three large intertidal Harbours (Kaipara, Tauranga and Manukau). In each Harbour we sampled 400 points for macrobenthic community composition and abundances, as well as the full set of environmental variables. Using an elaborate sampling design, we were able to cover scales from 30 centimetres to a maximal extent of 1 km. All data and extensive metadata are available from the data publisher PANGAEA via the persistent identifier https://doi.org/10.1594/PANGAEA.903448 (Kraan et al., 2019).

1 Introduction

Understanding how the plants and animals that live in the seafloor vary in their spatial patterns of diversity, biomass, and abundance is fundamental to gaining insight in the role of biodiversity in maintaining ecosystem functioning in coastal ecosystems, as well as advancing the modelling of species distributions under realistic assumptions. Yet, it is virtually unknown how the relationships between abundance patterns and different biotic and environmental processes change depending on spatial scales (e.g. Lohrer et al., 2015; Kraan et al., 2015).

Most broad-scale research on mapping species distributions ignores spatial patterns (Kraan et al., 2010), scale-dependent variability (Kraan et al., 2015), and biotic interactions (Dormann et al., 2018), rendering these topics a main frontier in ecology (Araújo and Luoto, 2007). Moreover, twisting these often-separate lines of research together requires the availability of data to support such research. At present, data that allow bridging the gap between small-scale and landscape-scale ecological research, enabling full inference of pattern and process from the individual to the landscape scale across environmental gradients are scarce.

The research project Spatial Organization of Species Distributions: Hierarchical and Scale-Dependent Patterns and Processes in Coastal Seascapes at the National Institute for Water and Atmospheric Research (NIWA) in New Zealand aimed to asses scale-dependent variation in species distributions across environmental gradients in estuarine communities, dominated by bivalves, polychaetes and crustaceans that live hidden in marine sandflats. By employing an elaborate sampling scheme, we covered a large number of different spatial scales with enough replicate samples within each scale to allow explicit spatial analysis and warrant statistical power during analysis (see Kraan et al., 2015; Greenfield et al., 2016). This efficient sampling design allowed us to map intertidal macrobenthic fauna from the scale of a few centimetres to a maximal extent of 1 km. We focussed on macrobenthos (organisms > 500μm), due to their role in ecosystem functioning (e.g. Thrush et al., 2017), their ability to serve as sentinels for change (e.g. Hewitt and Thrush, 2009; Kraan et al. 2009), and the relative ease of collecting samples (Fig. 1). To increase the generality of our field study, we performed this sampling along an environmental gradient from the mangroves to the lower end of the

intertidal zone in three large intertidal harbours (Manukau, Kaipara and Tauranga Harbours in the North Island, New Zealand).

Given the scarcity of large-scale high-resolution biodiversity data, identified to the lowest taxonomic level possible, and associated point-measurements of environmental features, such as sediment grain-size parameters, chlorophyll *a* concentration, organic content, and visible sandflats parameters, such as the coverage of seagrass or shellhash (broken shell fragments), we here publish these one-of-a-kind data (see Kraan et al., 2019) so that they can serve as key-data to advance and support future multi-scale biodiversity studies.

2 Material and methods

2.1 Fieldwork

Sampling macrobenthic fauna and environmental variables was conducted during the austral summer 2012 in Kaipara, Manukau, and Tauranga harbours, North Island, New Zealand (Table 1). Physical descriptions of each of these areas can be sourced from a large number of publications by Simon F. Thrush and co-workers (e.g. Thrush et al., 2003). In each Harbour we took 400 cores (13 cm diam., 20 cm deep) on a pre-determined grid (four 1000m transects, spaced at 100m) on foot during low tide (n = 3*400 [1200 in total]), thereby covering the area from the high- to low-water mark (Fig. 1 for an illustration). Sampling points along transects were spaced at distances of 30 cm, 1 m, 5 m, 10 m, 30 m, 50 m, 100 m, 500 m and 1000 m (see Fig. 1 in Kraan et al., 2015), located by using measuring tape and handheld GPS. Given the close proximity of sampling locations we provide sampling coordinates in NZTM (New Zealand Transverse Mercator; Geodetic CRS: NZGD2000; Unit = m) at the data publisher PANGAEA (Kraan et al., 2019). Cores were sieved in the field (500μm mesh) and the residue preserved with 70% isopropyl alcohol.

Prior to destructive sampling, we took a photograph of 50cm x 50cm at each sampling point (n = 960) to assess coverage of seagrass (*Zostera mulleri*), bare sand, and shellhash. In addition, at each point (n = 960), we pooled three surface sediment cores (2 cm diam., 2 cm deep) to do sediment grain-

size analyses (median grain-size and sediment fractions), chlorophyll *a* measurements, and determine the organic content of the sediment (Table 1). These samples were stored in the dark on ice immediately after collecting. Note that at the smallest spatial scale, i.e. 30 cm, we took 3 adjoining benthic cores, but we limited ourselves to taking one photograph and one sediment sample to represent the environmental features for these three locations. This was done to economically manage our time in the field and our financial budget for processing samples, leading to 320 photographs and 320 sediment samples per Harbour. See Kraan et al. (2015, 2019) or Greenfield et al. (2016) for details.

2.2 Macrobenthic data

In the laboratory, Rose Bengal (2%) stained taxa were identified to the lowest practical taxonomic resolution and their abundance assessed. In total we identified 146 species, mostly bivalves, polychaetes and crustaceans, encompassing 73813 individuals (Table 1; Kraan et al., 2019). For bivalves, the longest shell axis was also measured, allowing adults and juveniles to be distinguished, because habitat preferences can differ between adults and juveniles (Kraan et al., 2010, 2013). Size-classes were categorized as: < 1mm, 1-5mm, 5-10mm, 10-15mm, 15-20mm, 20-25mm, 25-30mm, 30-35mm, 35-40mm and > 40mm. Each sample was sorted and its taxa identified by Casper Kraan, after which Barry L. Greenfield verified species identifications on each sample(Kraan et al., 2019).

2.3. Chlorophyll a measurements

Sediment samples were freeze-dried upon arrival in the laboratory. Prior to freeze-drying, seagrass and bivalves were removed. For measuring, 0.1g sediment was weighed and topped-up with 90% acetone buffer and centrifuged for 10 min. at 3300rpm. Chlorophyll a and pheophytin concentrations (n = 960) were determined using a fluorometer, using standard methods (see Kraan et al., 2015). First sample was measured May 10th 2012 and the last sample was measures June 28th 2012, avoiding degradation of samples over time (see Kraan et al., 2019).

2.4 Sediment grain-size distributions

To determine sediment median grain-size and sediment fractions (silt < 63μm, very fine 63–125μm, fine 125–250μm, medium 250–500μm, and coarse > 500μm), sediment grain-sizes were measured ($n = 960$), following standard methods for using a Malvern Mastersizer 2000 with a particle range of 0.02-2000 μm (see Kraan et al., 2015). This involved digesting about a teaspoon of sediment by adding 10% hydrogen-peroxide to remove organic content from the sediment, leave to digest for 7 days, stirring every couple of days.

2.5 Organic content of the sediment

Organic content ($n = 960$) was determined after burning a tea-spoon of freeze-dried sediment for 5.5 hrs in a furnace at 560 ^{0}C, i.e. the loss-on-ignition approach.

2.5 Visible sandflat parameters

Coverage of seagrass, shellhash and bare sand within each photograph ($n = 960$) was estimated based on 75 random points within a photograph using the software CPCe (Kohler and Gill, 2006) (see Kraan et al., 2019).

3 Data availability

All data collected during this project, including extensive meta-data, are available from the data publisher PANGAEA (Kraan et al., 2019). For convenience, all data are grouped into a parent dataset (https://doi.org/10.1594/PANGAEA.903448, Kraan et al., 2019).

A number of scientific studies have used these data. For example, Kraan et al. (2015) described the cross-scale variation in biodiversity-environment links using Moran's Eigenvector mapping (MEM). Greenfield et al. (2016) focussed on the spatial distribution of functional groups to gain insight in the

scale-dependency of resilience. Thrush et al. (2017) and Douglas et al. (2017) based their experimental set-up on the spatial distribution of functional hot- and cold-spots to experimentally study the impact of nutrient-loading on ecosystem functioning and resilience.

Competing interests. The authors declare no conflict of interest.

Author contribution. CK and SFT designed the study, and CK and BLG carried them out. CK prepared this manuscript with contributions and final approval of all authors.

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Table 1. Regional summary of collected data and their mean values to give an impression of their physical appearance and the macrobenthic benthic biodiversity they harbour.

	Region		
Fieldwork 2012	**Manukau**	**Tauranga**	**Kaipara**
Sampling	4-5 May	23-25 April	18-19 April
Sediment samples (*n*)	320	320	320
Organic content samples (*n*)	320	320	320
Chlorophyll a samples (*n*)	320	320	320
Visible sandflat parameters (*n* photos)	318	319	297
Lost photos due to water coverage	m.1.10.9, m.4.39.7	k1.4.2, k2.19.4, k2.19.5, k2.19.6, k2.19.7, k2.19.8, k2.19.9, k2.19.10, k2.20.1, k2.20.2, k2.20.3, k2.20.4, k2.20.5, k2.20.6, k2.20.7, k2.20.8, k2.20.9, k2.20.10, k4.31.1, k4.31.2, k4.31.3, k4.37.3, k4.38.10	t1.8.5
Macrobenthos samples (*n*)	400	399	398
Lost macrobenthos samples		T4.35.5	K3.24.3, k4.35.5
Results of laboratory work 2012-2014			
Species identified (*n*)	109	81	114
Individuals (*n*)	26573	25394	21846
Median grain-size (μm)	166	197	213
Silt (% <63μm)	14	5	1
Very fine sediments (% 63–125μm)	17	17	6
Fine sediments (% 125–250μm)	48	44	6
Medium sediments (% 250–500μm)	18	28	32
Coarse sediments (% > 500μm)	3	6	0.4
Organic content (%)	2	2	0.8

Chlorophyll a (mg/g)	23	11	5
Bare sand cover (%)	79	73	84
Shellhash cover (%)	16	3	2
Seagrass cover (%)	5	23	13
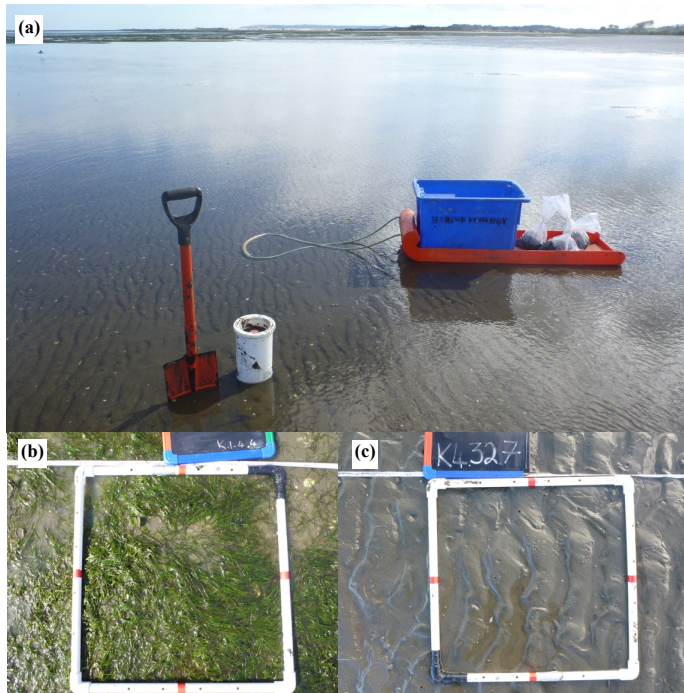
Figure 1. (a) Example of a sampling area during low-tide and the low-tech gear used for sampling.
Examples of **(b)** a high-density seagrass sampling point and **(c)** of a sandy sampling point (photos:
Casper Kraan).

Page 12: [1] Deleted   **Casper Kraan**   **1/10/20 10:40:00 AM**