

Benthic Megafauna from the North Pacific Abyss

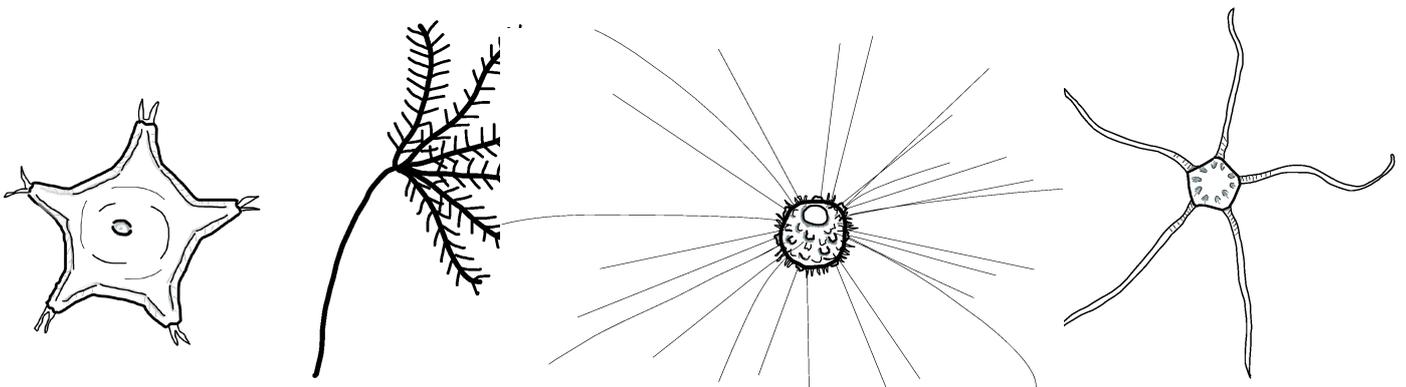
Phylum **Echinodermata**

Class **Asterozoa**

Class **Crinozoa**

Class **Echinozoa**

Class **Ophiurozoa**



Abyssal Pacific seafloor image-based megafauna morphotype catalogue v.1

Phylum **Echinodermata**:

Class **Asteroidea**; **Ophiuroidea**; **Crinoidea**; **Echinoidea**

Erik Simon-Lledó^{1*}, Diva J. Amon^{2,3}, Guadalupe Bribiesca-Contreras⁴, Daphne Cuvelier⁵, Jennifer M. Durden¹, Sofia P. Ramalho⁶, Katja Uhlenkott^{7,8}, Pedro Martinez Arbizu⁷, Noëlie Benoist¹, Jonathan Copley⁹, Thomas G. Dahlgren^{10,11}, Adrian G. Glover⁴, Bethany Fleming^{9,1}, Tammy Horton¹, Se-Jong Ju^{12,13}, Alejandra Mejia-Saenz¹, Kirsty McQuaid¹⁴, Ellen Pape¹⁵, Chailinn Park^{12,13}, Craig R. Smith¹⁶, and Daniel O. B. Jones¹

*corresponding author: erimon@noc.ac.uk

¹National Oceanography Centre, Southampton, UK

²SpeSeas, D'Abadie, TTO

³Marine Science Institute, University of California, Santa Barbara, USA

⁴Natural History Museum, London, UK

⁵Institute of Marine Sciences - Okeanos, University of the Azores, Horta, POR

⁶Centre for Environmental and Marine Studies & Department of Biology, University of Aveiro, Aveiro, POR

⁷German Centre for Marine Biodiversity Research, Senckenberg am Meer, Wilhelmshaven, GER

⁸Institute for Biology and Environmental Sciences, Carl von Ossietzky University, Oldenburg, GER

⁹Ocean & Earth Science, University of Southampton, Southampton, UK

¹⁰NORCE Climate and Environment, Bergen, NOR

¹¹Department of Marine Sciences, University of Gothenburg, Göteborg, SWE

¹²Korea Institute of Ocean Science and Technology, Busan, KOR

¹³Ocean Science Major, University of Science and Technology, Daejeon, KOR

¹⁴University of Plymouth, Plymouth, UK

¹⁵Marine Biology Research Group, Ghent University, Ghent, BEL

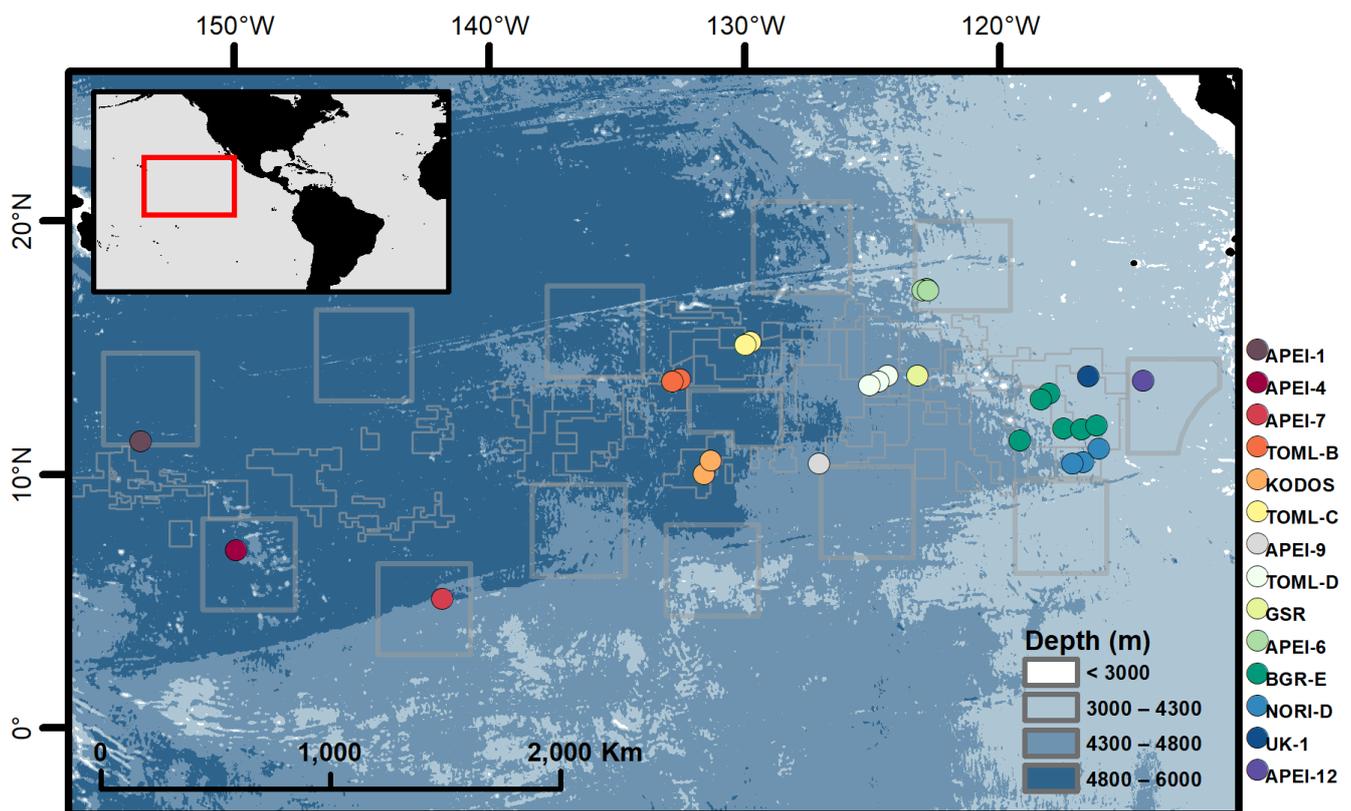
¹⁶Department of Oceanography, University of Hawai'i at Manoa, Honolulu, USA

Standardised taxonomic field guide used to develop (please cite as): Simon-Lledó, et al. (2023). Carbonate compensation depth drives abyssal biogeography in the northeast Pacific. *Nature Ecology & Evolution*; doi:10.1038/s41559-023-02122-9

Image copyright: the authors

The APSMA image-based taxonomical catalogue

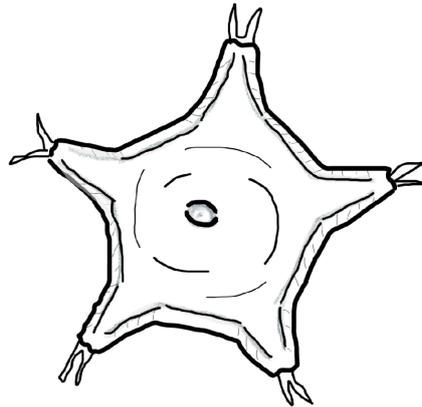
This code-based abyssal megafauna (invertebrates > 1 cm) catalogue was developed by morphological and taxonomical alignment of specimens encountered in seabed imagery collected across multiple seabed locations across the Clarion Clipperton Fracture Zone, in the NE Pacific basin (see map below and main study, Simon-Lledó et al. 2023, for further details). This work was conducted during a range of scientific workshops held between 2016 and 2021, in collaboration with taxonomic experts (see acknowledgements section) and by reference to existing literature (e.g. where available, links to studies describing physically collected specimens are provided in taxon descriptions). The catalogue follows the Horton et al. 2021 open nomenclature (e.g. 10.3389/fmars.2021.620702) to report the taxonomic resolution reached in the identification of each classified metazoan morphotype. Each morphotype was assigned a unique 7 character identification code (i.e. “XXX_nnn”). All taxa identified were deemed as sufficiently different morphologically by taxonomic experts to be confidently considered separate species. Note the catalogue is periodically revised, as new photographed and collected specimens get described, and hence some taxonomic identifications may vary in subsequent versions of this guide. The latest version of the APSMA catalogue is available as label tree for image/video annotation on BIIGLE (biigle.de; please contact authors for more detail).



Map of the Clarion Clipperton Zone in the North Pacific basin with detail on locations surveyed with photographic and video cameras mounted on autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), and towed cameras; between 2010 and 2021. Areas managed by the International Seabed Authority: Thick polygons, Areas of Particular Environmental Interest, and; Thin polygons, polymetallic nodule exploration licensed sites.

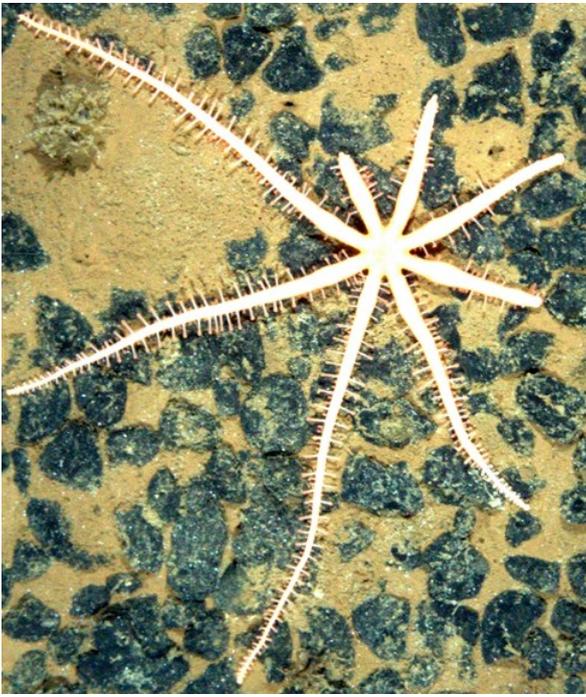
Phylum **Echinodermata**

Class **Asterozoidea**



AST_001

Brisingida fam. indet



Morphology: large orange disc and 8+ white, long, tapered arms with short thin lateral spines.

Notes: typically found with arms extended facing upwards on the seabed



AST_028

Brisingida fam. indet

Morphology: very large orange central disc and 10+ white, long, tapered arms with very long thin lateral spines.

Notes: typically found with arms extended facing upwards on the seabed.

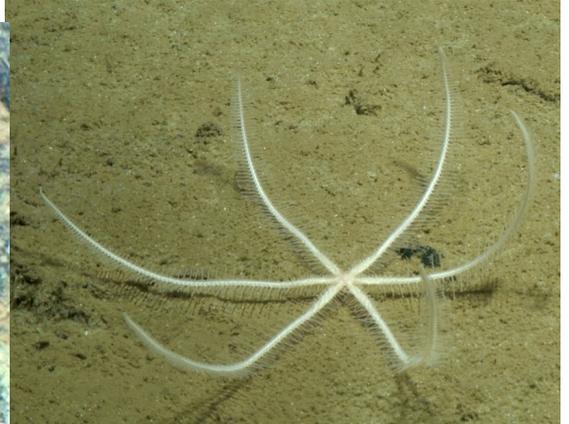
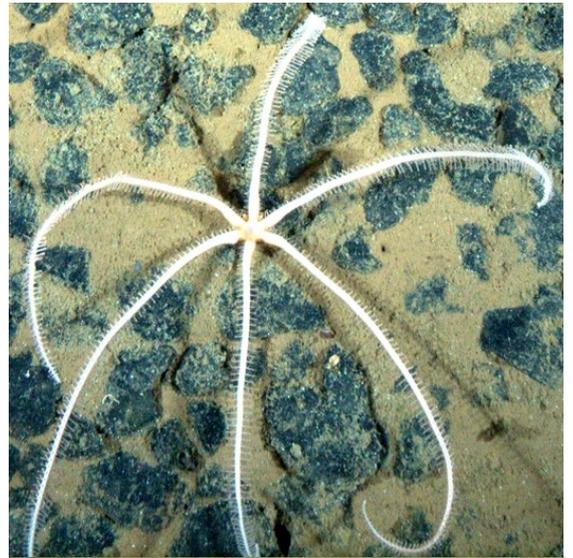
Although the number of arms has been traditionally used for taxonomical classification in deep-sea Brisingida, note that, provided that arms can break/regrow (or even exhibit additional numbers), a reorganisation of the Order, e.g. particularly *Freyella* spp, is currently undergoing based on other body features (e.g. spine typology or tube feet and pedicellariae morphology)

AST_002

Freyastera spp.

Morphology: small slightly orange central disc and six white, long, tapered arms with short/large* very thin lateral spines.

Notes: typically found with arms extended facing upwards on the seabed. *It is often difficult to see the length of spines in seabed images, when: i) short spines: *Freyastera* sp. indet (top specimen) or ii) long spines: *F. tuberculata* sp. inc. (bottom specimens). More detail: 10.3897/zookeys.1113.82172



AST_053

Freyastera benthophyla sp. inc.



Morphology: orange body, small central disc and six long, tapered arms with short thin lateral spines.

Notes: typically found on sponge stalks

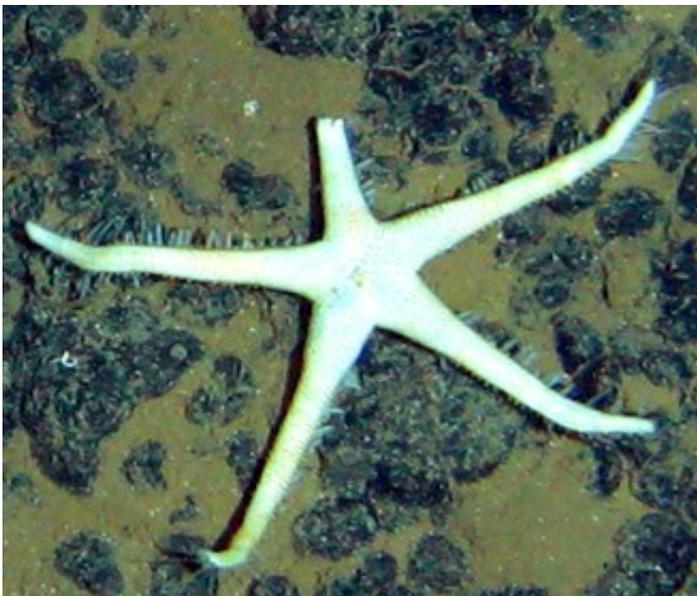


AST_032

Dytaster sp. indet.

Morphology: orange, very large; five long (> 5 times larger than disc) slender arms tapering distally with ventrally-facing short spines. Abactinal disc surface can be swollen.

Notes: Often found semi-buried on sediment mounts,



AST_005

Astropectinidae gen. indet.

Morphology: white, very large; five long slender arms tapering distally with ventrally-facing long spines

AST_040

Forcipulatida fam. indet.

Morphology: orange, very large; small disc with 5-6 long slender arms, gradually tapering distally



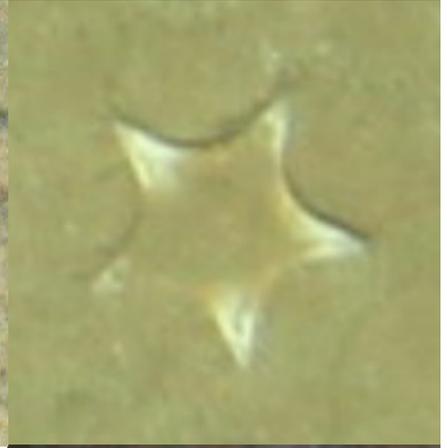
AST_004

Paxillosida fam. indet.

Morphology: white, very small; five slender arms tapering distally

AST_020

Porcellanasteridae
gen. indet.



Morphology: white, relatively small; five semi-fused arms with few short terminal spines

Notes: can be found semi-buried or with sediment covering abactinal surface



AST_003

Porcellanasteridae
gen. indet.

Morphology: white, relatively small; five moderately fused arms with rounded terminal edge

Notes: can be found semi-buried or with sediment covering abactinal surface

AST_009

Hyphalaster sp. indet.

Morphology: white, relatively small; five slightly-fused arms (sharp-edge) and swollen abactinal disc surface

Notes: can be found semi-buried or with sediment covering abactinal surface



AST_051

Porcellanasteridae
gen. indet

Morphology: white; five slightly-fused slender arms with rounded terminal edge

Notes: can be found semi-buried or with sediment covering abactinal surface

AST_029

Pterasteridae gen. indet

Morphology: light orange/pink slime star, very large; wide disc with five semi-fused arms. With very short spines covering the abactinal surface of the arms and disc



AST_019

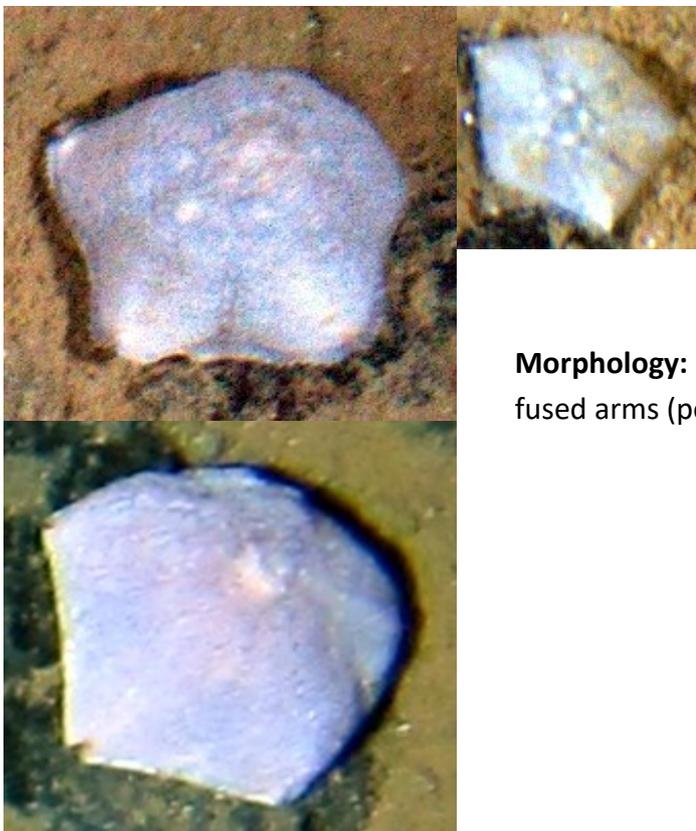
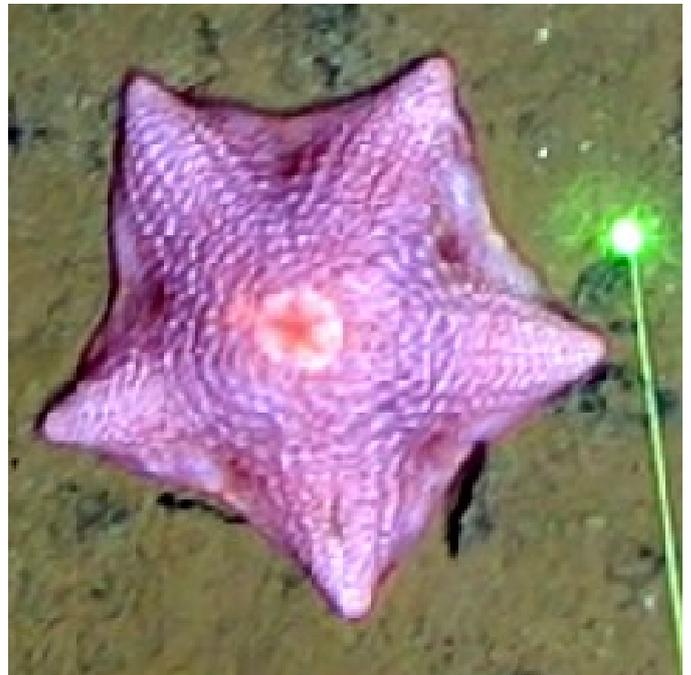
Hymenaster sp. indet.

Morphology: blue slime star, large; wide disc with five fused arms. Exposed edge (i.e. protruding and white coloured) of each arm with few lateral spines

AST_013

Hymenaster sp. indet.

Morphology: bright purple slime star, large; wide disc with five fused arms. With very short spines covering the abactinal surface of the arms and disc (absent in the interdigitations that fuse the arms)



AST_054

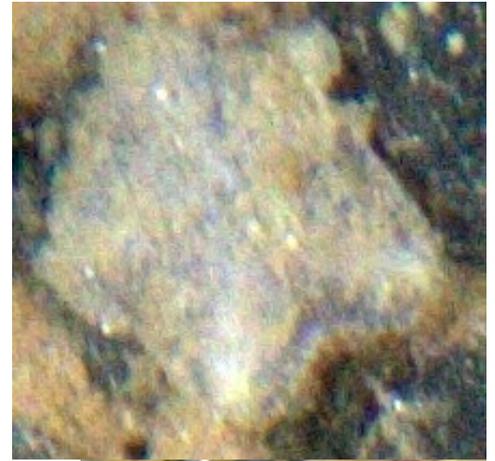
Hymenaster sp. indet.

Morphology: light violet slime star, large; wide disc with five fully fused arms (pentagonal shape). Smooth abactinal surface

AST_012

Hymenaster sp. indet.

Morphology: grey to blueish slime star; wide disc with five semi-fused arms. Edges of the arms covered in very small spines fused into a thin membrane (i.e. extending for the whole perimeter of the star). Slightly exposed edge (i.e. white coloured) of each arm



AST_031

Hymenaster echinulatus

sp. inc.

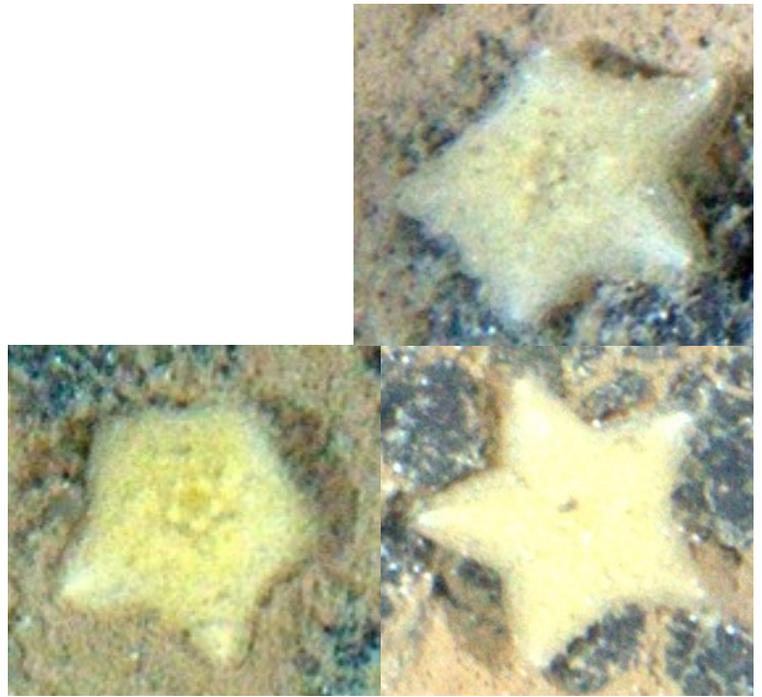
Morphology: bright white slime star; wide disc with five fused arms. Edges of the arms covered in very small spines fused into a thin membrane (i.e. extending for the whole perimeter of the star). Slightly darker opercular spines usually visible in the abactinal plate.



AST_049

Hymenaster sp. indet.

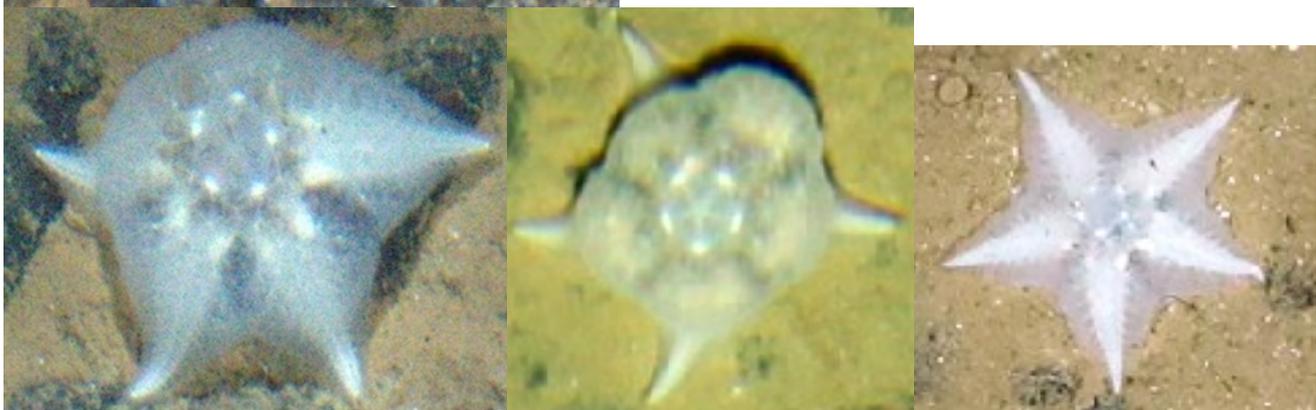
Morphology: yellow slime star; wide disc with five semi-fused arms. Slightly exposed distal termination (i.e. unfused, white coloured) of each arm. 'Spongy' appearance



AST_012

Hymenaster pellucidus sp. inc.

Morphology: slime star, 5 semi-fused arms; with transparent membrane covering disc and arms—i.e. white ambulacral system clearly visible. Abactinal disc surface can be (sometimes largely) swollen.



AST_016

Pterasteridae gen. indet.

Morphology: dark orange slime star; wide disc with five fused arms. Short spines covering the whole abactinal surface and slightly exposed arm edge



AST_017

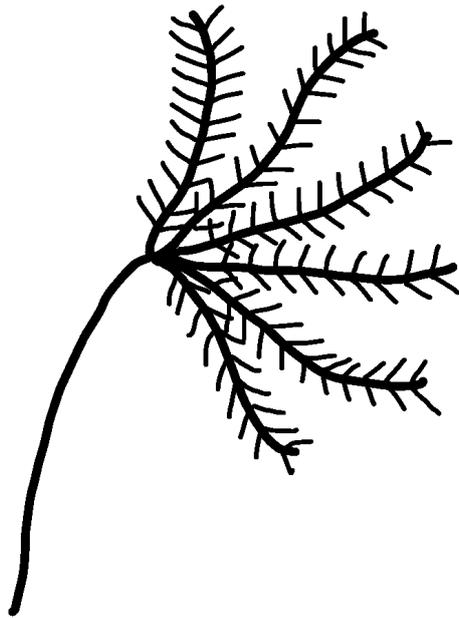
Hymenaster sp. indet.

Morphology: white slime star, small; wide disc with five fully fused arms (pentagonal shape). Abactinal surface depicting a 'flower' shape pattern. Long spine in each arm termination

Notes: usually found attached to outcropping bedrock patches or rock fragments

Phylum Echinodermata

Class Crinoidea

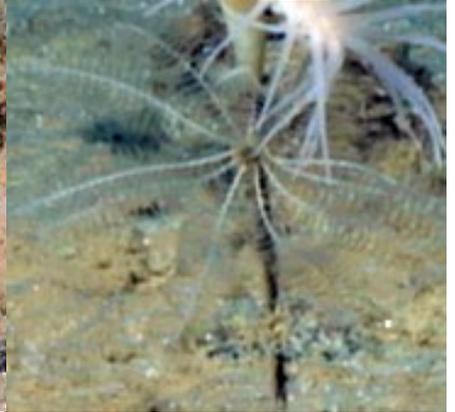


CRI_001

Antedonidae fam. inc.

Morphology: non-stalked, white; 10 arms with ~20 short pinnules each

Notes: typically found attached to sponge stalks



CRI_019

Comatulida fam. indet.

Morphology: non-stalked, white; 10 arms with >20 long thin pinnules each

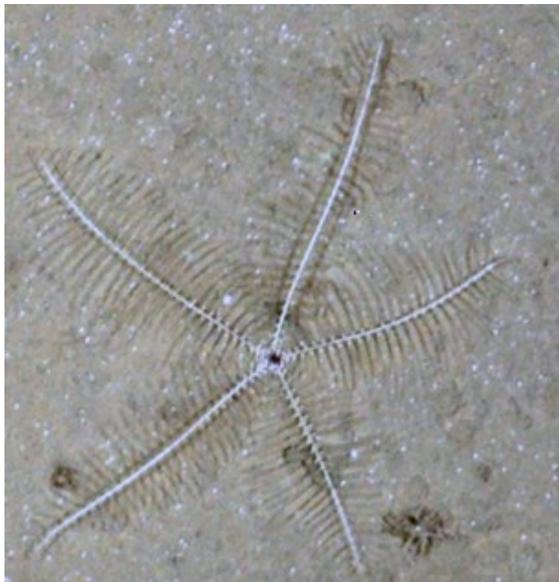
Notes: typically found attached to sponge stalks

CRI_027

Pentametrocrinus sp. indet.

Morphology: non-stalked, dark yellow; 5 arms with >50 long thin pinnules each

Notes: can be found attached to nodules or sponge stalks

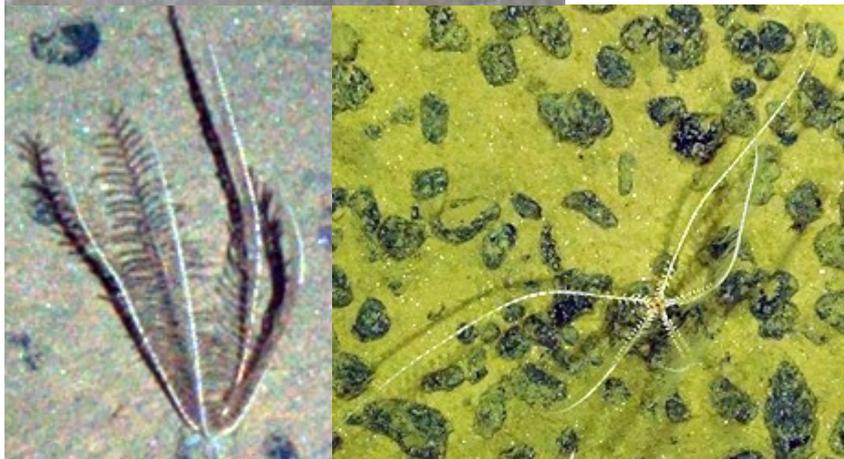


CRI_002

Pentametrocrinus sp. indet.

Morphology: non-stalked, white; 5 arms with >50 long thin pinnules each

Notes: can be found attached to nodules or sponge stalks



CRI_003

Bathycrinidae gen. indet.

Morphology: stalked; 10 arms with >40 short pinnules each. White crown (i.e. arms, pinnules and calyx) and yellow stalk

Notes: typically found attached to nodules or rocks



CRI_004

Bathycrinidae gen. indet.

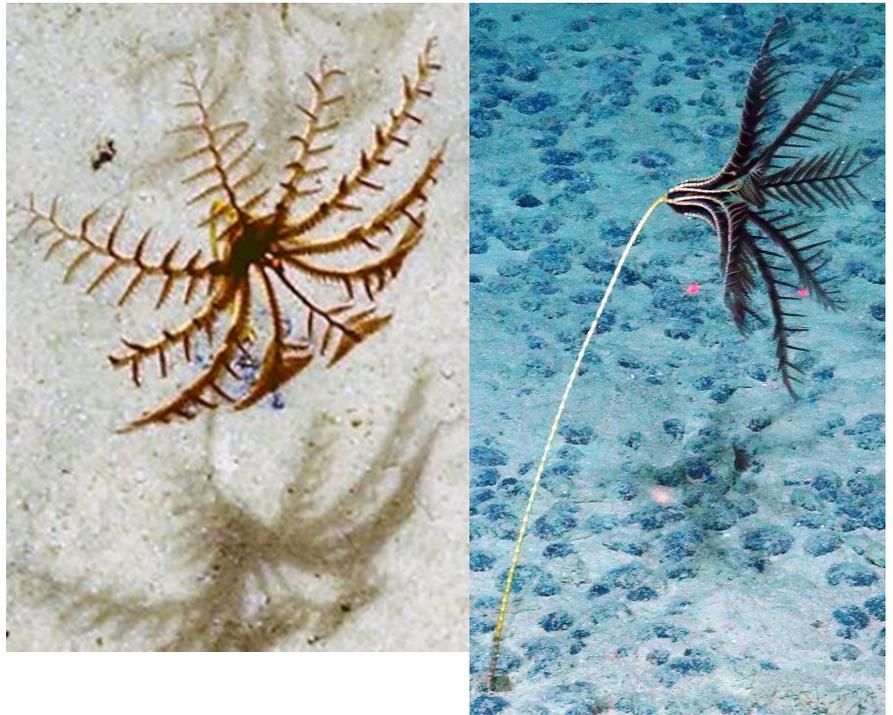
Morphology: stalked; 10 arms with >40 short pinnules each. White crown (i.e. arms, pinnules and calyx) and stalk

Notes: typically found attached to nodules or rocks

CRI_005

Hyocrinidae

fam. inc.



Morphology: stalked; 10 arms with ~16 long, thick pinnules each. Purple arms and yellow pinnules, calyx and stalk

Notes: typically found attached to nodules or rocks



CRI_030

Hyocrinidae fam. inc.

Morphology: stalked, large; 5 arms with >30 thin pinnules each. Yellow crown and stalk

Notes: typically found attached to nodules or rocks

CRI_009

Hyocrinidae fam. inc.

Morphology: stalked; 10 arms with >30 short pinnules each.
Yellow crown and stalk

Notes: typically found attached to nodules or rocks



CRI_007

Hyocrinidae gen. indet.

Morphology: stalked; 5 arms with >10 long pinnules each. Yellow crown and stalk

Notes: typically found attached to nodules or rocks

CRI_022

Hyocrinidae gen. indet.

Morphology: stalked; 5 arms with ~5 (dichotomous) pinnules each.
Yellow crown and stalk

Notes: typically found attached to nodules or rocks



CRI_023

Hyocrinida order. inc.

Morphology: stalked, small; 5 arms with very short pinnules.
Yellow crown and stalk

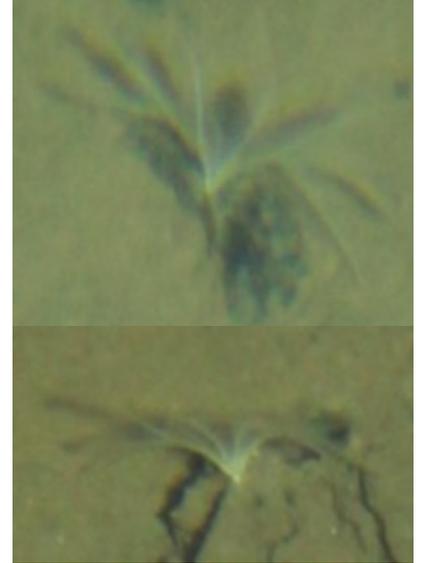
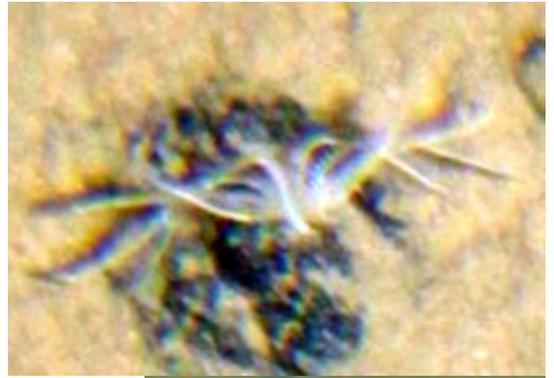
Notes: typically found attached to nodules or rocks

CRI_028

Comatulida order inc.

Morphology: non-stalked, white; 5 bifurcated arms (at the base) with very thin pinnules.

Notes: typically found attached to nodules or rocks



CRI_014

Comatulida order inc.

Morphology: stalked, white; 5 bifurcated arms (at the base of the arms) with very thin pinnules.

Notes: typically found attached to nodules or rocks

CRI_010

Comatulida order inc.

Morphology: non-stalked, white; ~10 arms with very thin pinnules.

Notes: typically found attached to nodules or rocks or stalks



CRI_015

Comatulida order inc.

Morphology: stalked, white; 5 double bifurcated arms (proximally, at the base and distally, close to the terminal side of the arms) with very thin pinnules.

Notes: typically found attached to nodules or rocks

CRI_008

Porphyrocrinus sp. indet.

Morphology: short stalk; crown with 5 undivided arms with 5-6 pinnules (more details: 10.3897/zookeys.1113.82172)

Notes: typically found attached to nodules or rocks



CRI_024

Hyocrinida order. inc.

Morphology: stalked, white; 5 arms with 2 short, thick pinnules each.

Notes: typically found attached to nodules or rocks

CRI_017

Hyocrinidae fam. inc.

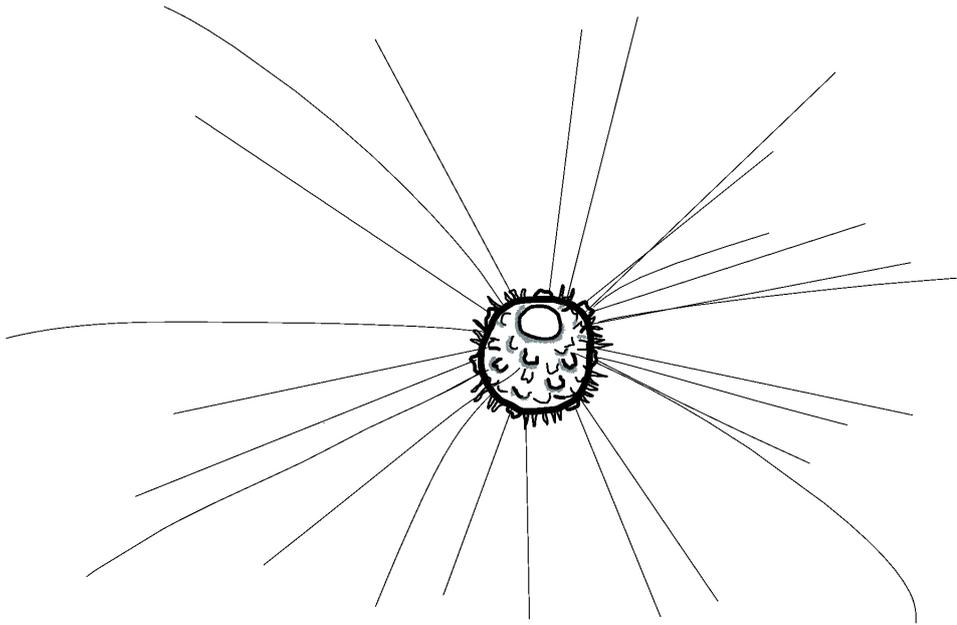
Morphology: stalked; 10 arms with 4-5 short, thick pinnules each. White crown and brown stalk

Notes: typically found attached to nodules or rocks



Phylum Echinodermata

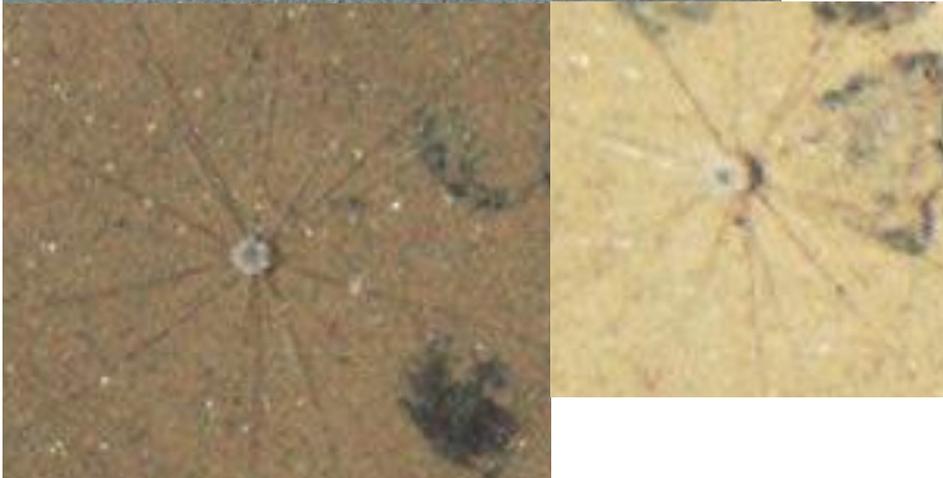
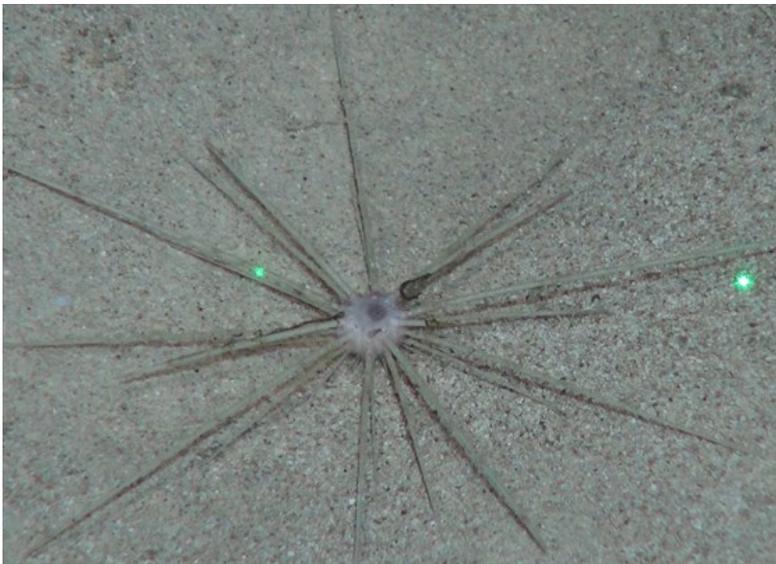
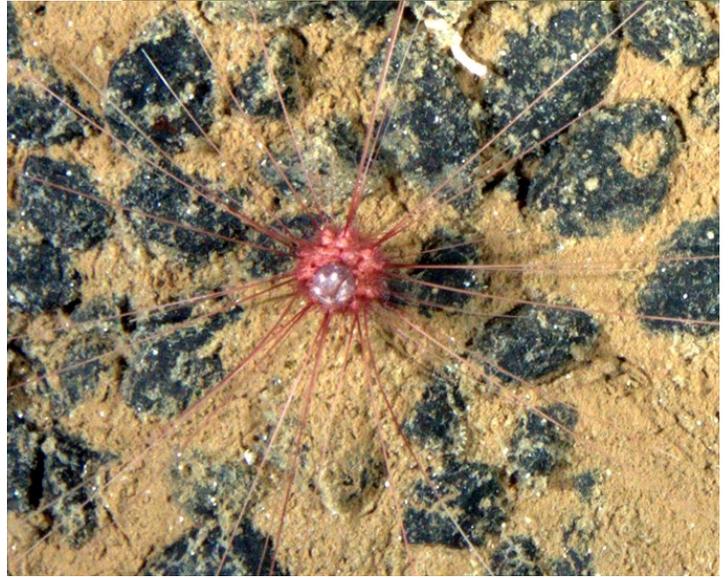
Class Echinoidea



URC_003

Plesiodiadema globulosum
sp. inc.

Morphology: spherical, slightly flattened purple test and very long thin spines. Greyish to blue inflated anal cone (more details: 10.3897/zookeys.1113.82172)



URC_004

Aspidodiadematoidea
gen. indet.

Morphology: spherical, slightly flattened grey test and very long spines

URC_005

Urechinus sp. indet.

Morphology: ovoid and laterally flattened; reddish-brown test and short thin grey spines. Periproct usually brighter coloured; distinguishable in vertically-facing imagery



URC_025

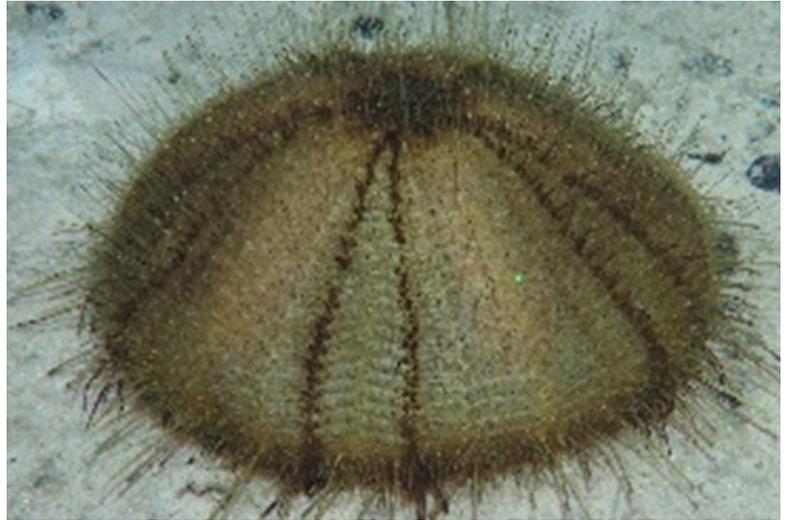
Urechinus sp. indet.

Morphology: ovoid and laterally flattened; grey test and short thin grey spines. Periproct usually brighter coloured; distinguishable in vertically-facing imagery

URC_022

Holasteroidea

fam. indet.



Morphology: discoidal and dorsoventrally flattened; light green body and very short thin brown spines. Evident ambulacra stripes. Periproct usually darker coloured; distinguishable in vertically-facing imagery



URC_009

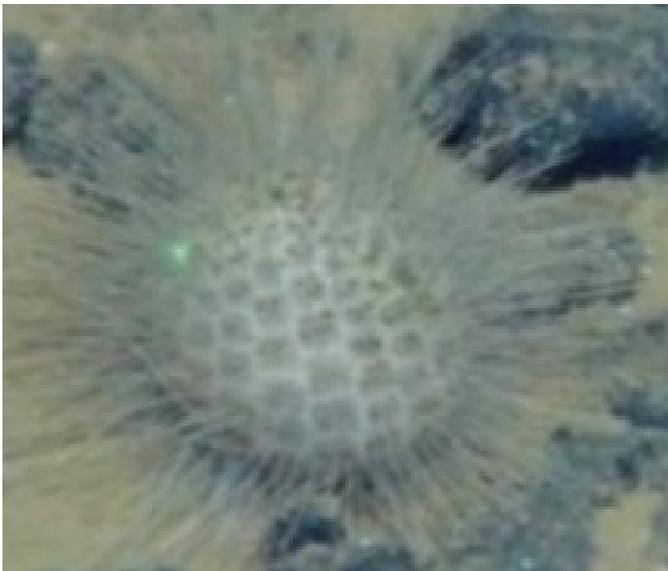
Holasteroidea fam. indet.

Morphology: discoidal and slightly dorsoventrally flattened; light green test and very short thin grey spines. Evident ambulacra stripes. Periproct usually brighter (i.e. green-yellow) coloured; distinguishable in vertically-facing imagery

URC_027

Holasteroidea fam. indet.

Morphology: ovoid and slightly dorsoventrally flattened; brown test and short thick grey spines. Periproct slightly brighter reddish, dorsally but slightly on the side of the test



URC_021

Holasteroidea order inc.

Morphology: ovoid and slightly dorsoventrally flattened; white test and short long grey spines. Evident ambulacra and interambulacral stripes

URC_010

Kamptosoma abyssale sp. inc.

Morphology: rounded and flattened, reddish-brown test and short thin spines. Oral spines swollen and brighter at the tip (often not visible from seabed imagery). Periproct slightly brighter coloured (more details: [10.3897/zookeys.1113.82172](https://doi.org/10.3897/zookeys.1113.82172)).



URC_014

Echinothurioida fam. indet

Morphology: rounded and dorsoventrally flattened, silver-red test and brown short thin spines. Oral spines, also brown, depict a brown "crown" around the test in vertical facing seabed imagery. Periproct darker coloured

URC_007

Cystocrepis sp. indet

Morphology: elongated, tapering in one side, and strongly dorsoventrally flattened; purple test and short spines. Seemingly triangular-shaped in vertical imagery

Notes: can be found half-buried in sediment



URC_008

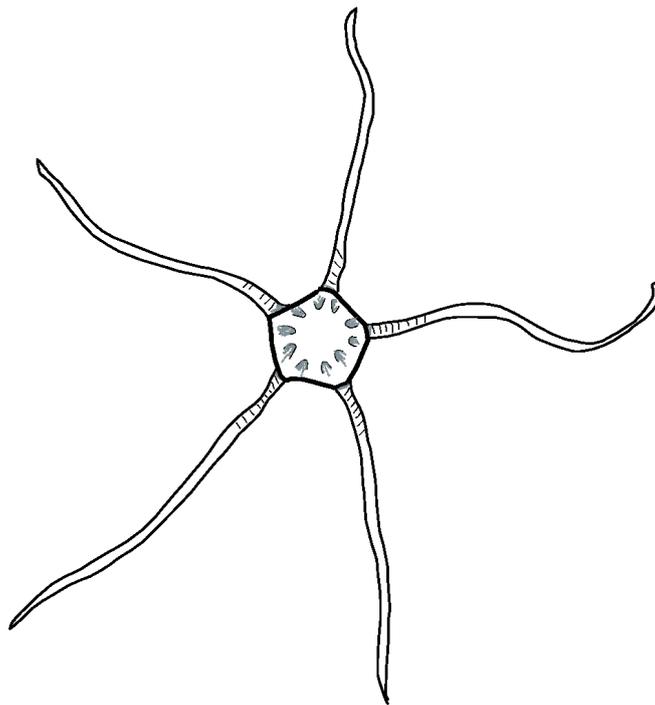
Echinocrepis sp. indet.

Morphology: elongated, tapering in one side, and strongly dorsoventrally flattened; white test and short spines, except for few long spines in one of the test sides. Triangular-shaped in vertical imagery

Notes: can be found half buried in sediment, usually exposing the side of the test with the longer spines

Phylum Echinodermata

Class Ophiuroidea



OPH_002

Ophiacanthidae gen. indet.

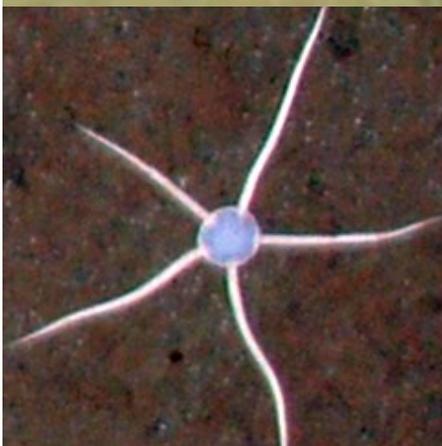
Morphology: round edged disc; slightly orange to bright pink disc and arms



OPH_014

Ophiurida fam. indet.

Morphology: round edged disc; white arms and edge of disc with slightly blue dorsal surface



OPH_017

Ophiurida fam. indet.

Morphology: round edged disc; white arms and blue dorsal surface of disc



OPH_003

Ophiopyrgidae gen. indet

Morphology: round edged disc; white arms and disc

Notes: usually found attached to outcropping rocks or exposed bedrock

OPH_016

Ophiurida fam. indet.



Morphology: round edged disc; yellow disc and arms with very small short lateral spines. Spongy appearance in seabed images

Notes: commonly found attached to sponges or stalks



OPH_001

Ophiacantha sp. indet.

Morphology: round edged disc; red disc and red to white (distally) arms with very small short lateral spines

Notes: commonly found attached to sponge stalks

OPH_015

Ophiurida fam. indet.



Morphology: small size with round edged disc; white arms and disc (relatively short, smooth thick arms)



OPH_019

Ophiopyrgidae gen. indet.

Morphology: round edged disc; light purple disc and pink to white (distally) arms with very small short lateral spines

Notes: commonly found attached to sponge stalks

OPH_010

Ophiosphalma glabrum

sp. inc.

Morphology: pentagonal-shaped disc; slightly orange to white disc and arms. More detail:
doi:10.5194/bg-17-1845-2020.



OPH_013

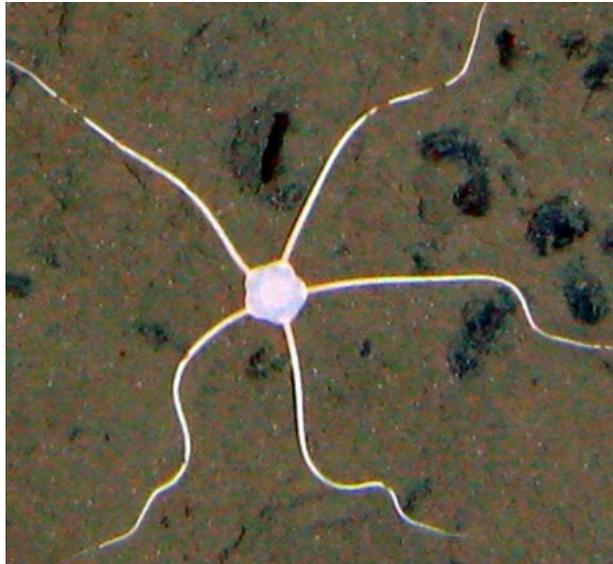
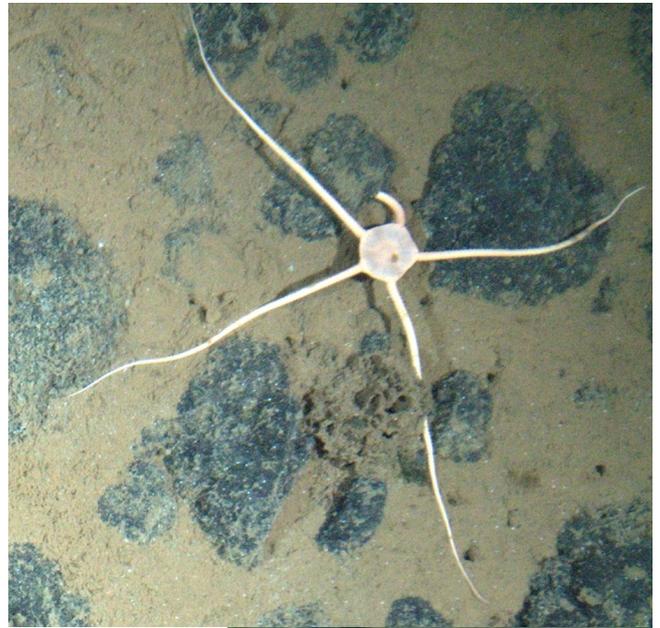
Ophiocymbium rarispinum sp. inc.

Morphology: pentagonal-shaped disc; greyish blue disc and white arms (more details: 10.3897/zookeys.1113.82172)

OPH_022

Ophiurida fam. indet.

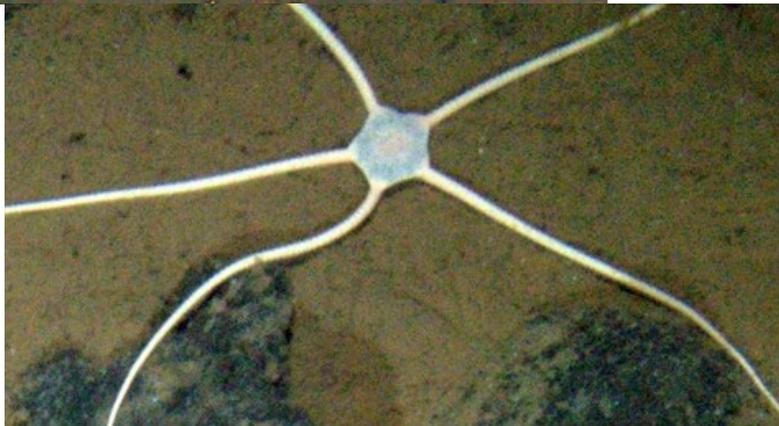
Morphology: pentagonal-shaped, small disc and long arms; orange to white arms and greyish blue disc



OPH_021

Ophiurida fam. indet.

Morphology: pentagonal-shaped, small disc with rounded edges and long arms; white arms and greyish blue disc



OPH_020

Ophiurida fam. indet.

Morphology: pentagonal-shaped disc; greyish blue disc and white arms



OPH_023

Ophiurida fam. indet.

Morphology: pentagonal-shaped disc with rounded edges (concave shape between disc vertex) and long arms; orange to white arms and disc

Acknowledgements

We would like to thank all the taxonomic experts who helped in the classification of taxa during the generation of the standardised megafauna catalogue: David Billet, Dhugal Lindsay, Saskia Brix, Sammy De Grave, Tina Molodtsova, Helena Wiklund, Amanda Serpell-Stevens, Daniel Kersken, Joana Xavier, Les Watling, Astrid Leitner, Jeff Drazen, Craig Young, Andrey Gebruk, David Pawson, Andrei Grischenko, Magdalini Christodoulou, Chris Mah, Sven Laming, Autun Purser, Brian Bett, and Andrew Gates. We would also like to thank Veerle Huvenne for her support, and Emma Knowles and Loïc Van Audenhaege for their assistance in the generation of this field guide.

Funding

This work was part of the UK Natural Environment Research Council funded Seabed Mining And Resilience To EXperimental impact (SMARTEx) project (Grant Reference NE/T003537/1). DOBJ, ESL, NB, AMS, GBC, and AG also received support from TMC Inc. (The Metals Company) through its subsidiary Nauru Ocean Resources Inc.(NORI); this is contribution TMC/NORI/D/007. SPR work was supported by funds from FCT/MCTES in the scope of the CEEC contract (CEECIND/00758/2017) and funds attributed to CESAM (UIDP/50017/2020, UIDB/50017/2020 and LA/P/0094/2020). Images from the BGR license area were made available by C. Rühlemann and A. Vink from the Federal Institute for Geosciences and Raw Materials (BGR) in Hannover. PMA and KU acknowledge EU JPIO-Oceans project Ecological Aspects of Deep-Sea Mining and MinigImpact-2 (German Ministry for Science and Education BMBF contract 03F0707E and 03F0812E.). The KODOS and APEI-9 datasets had been collected through environmental baseline studies for the polymetallic manganese nodules exploration contract of Republic of Korea (Ministry of Ocean and Fisheries' R&D #: 20160099). DC acknowledges funding from Mining2/0002/2017, Miniing2/0005/2017, granted by FCT/MCTES and DGPM and OP AZORES 2020 (01-0145-FEDER-000140 "MarAZ Researchers: Consolidate a body of researchers in Marine Sciences in the Azores" and funds attributed to Okeanos-UAç (UIDB/05634/2020, UIDP/05634/2020 and M1.1.A/REEQ.CIENTIFICOU I&D/2021/010).