# Remotely operated vehicle surveys as a robust tool for assessing multi-scale habitat associations of rocky reef fish assemblages

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# Introduction

The restructuring of marine communities from overexploitation, climate change, and other anthropogenic disturbances in an urgent management priority (FAO, 2020)[1]

Require robust methods for quantifying species, the types of assemblages, and their spatial distributions throughout time

Providing comprehensive monitoring of marine reserves has proven difficult (Nichol et al., 2009)[1]

- Large-scale
- Remote / offshore
- Deep-water

[1] FAO. 2020. The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome.

# Marine Surveying Methods

Summary of underwater survey methods used to survey demersal fish (Sward et al. 2019)[1]

| | Fisheries-dependent | SCUBA diver | Towed video | BRUVS | AUVs | Manned submersibles | ROVs |
|---|---|---|---|---|---|---|---|
| Suitable in deep-water (>40 m) | | | | | | | |
| Non-destructive | | | | | | | |
| Habitat associations and behaviours observed | | | | | | | |
| Provides fine-scale assessments | | | | | | | |
| Suitable for surveys of complex/ high relief habitat | | | | | | | |
| High manoeuvrability | | | | | | | |
| Suitable in high turbidity | | | | | | | |
| Bait used | | | | | | | |

[1]Sward, D., Monk, J., & Barrett, N. (2019). A Systematic Review of Remotely Operated Vehicle Surveys for Visually Assessing Fish Assemblages. Frontiers in Marine Science, 6.

# Fisheries-dependent methods

Summary of underwater survey methods used to survey demersal fish (Sward et al. 2019)[1]

| | Fisheries-dependent |
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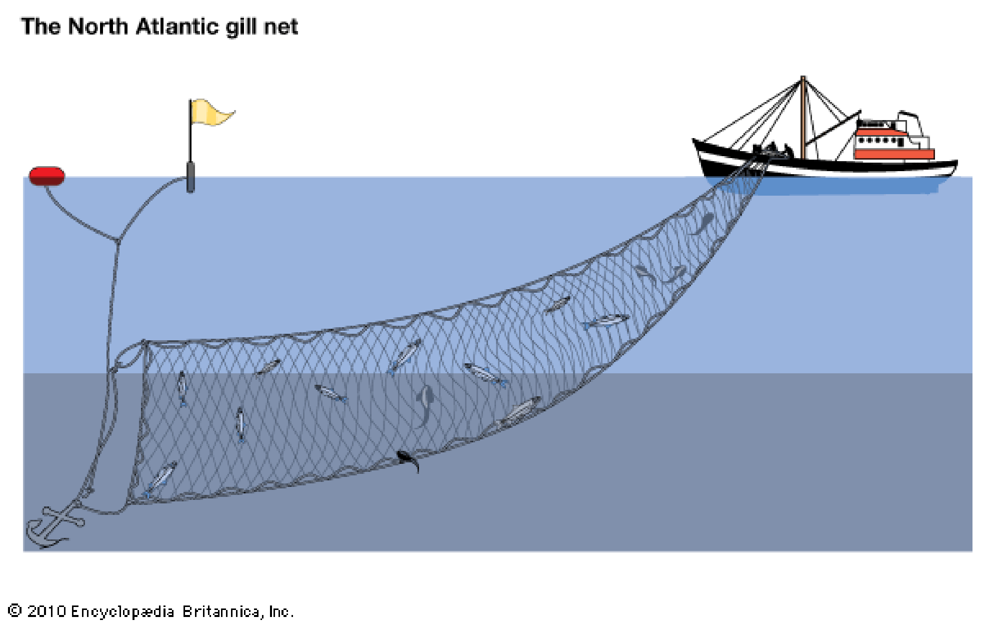
| Suitable in high turbidity | X |
| Bait used | Sometimes |




- E.g. gill-netting, long-line, trawls
- Pros: Deep-water / remote capabilities
- Cons: Extractive / imprecise

[1]Sward, D., Monk, J., & Barrett, N. (2019). A Systematic Review of Remotely Operated Vehicle Surveys for Visually Assessing Fish Assemblages. Frontiers in Marine Science, 6.

# SCUBA diver-based methods

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|---|---|---|---|---|---|---|---|
| Suitable in deep-water (>40 m) | X | | | | | | |
| Non-destructive | | **X** | | | | | |
| Habitat associations and behaviours observed | | **X** | | | | | |
| Provides fine-scale assessments | | **X** | | | | | |
| Suitable for surveys of complex/ high relief habitat | | **X** | | | | | |
| High manoeuvrability | | **X** | | | | | |
| Suitable in high turbidity | X | | | | | | |
| Bait used | Sometimes | | | | | | |

- E.g. underwater visual census, diver-operated video, etc…
- Pros: Fine-scale assessments, extensively used
- Cons: Limited by depth & unsafe in certain weather conditions / currents

[1]Sward, D., Monk, J., & Barrett, N. (2019). A Systematic Review of Remotely Operated Vehicle Surveys for Visually Assessing Fish Assemblages. Frontiers in Marine Science, 6.

# Underwater towed video

Summary of underwater survey methods used to survey demersal fish (Sward et al. 2019)[1]

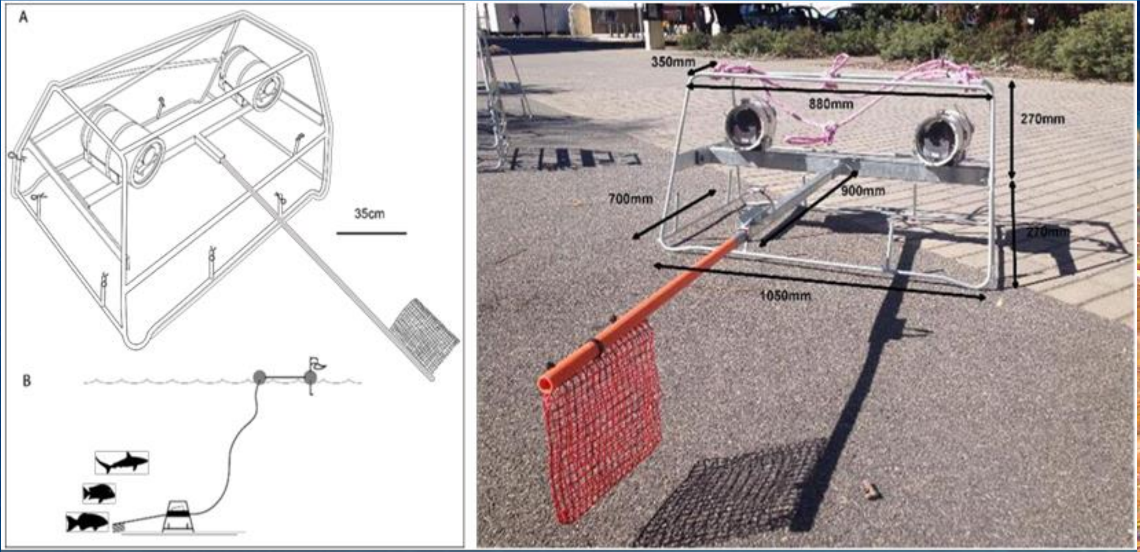
| | Fisheries-dependent | SCUBA diver | Towed video |
|---|---|---|---|
| Suitable in deep-water (>40 m) | X | | **X** |
| Non-destructive | | X | **X** |
| Habitat associations and behaviours observed | | X | **X** |
| Provides fine-scale assessments | | X | |
| Suitable for surveys of complex/ high relief habitat | | X | |
| High manoeuvrability | | X | |
| Suitable in high turbidity | X | | |
| Bait used | Sometimes | | |

[2]Carroll et al. 2018

- Video system towed behind vessel
- Pros: Rapid assessments across regions
- Cons: Not suitable for fine-scale / high-relief

[1]Sward, D., Monk, J., & Barrett, N. (2019). A Systematic Review of Remotely Operated Vehicle Surveys for Visually Assessing Fish Assemblages. Frontiers in Marine Science, 6.
[2]Carroll et al. 2018. Marine sampling field manual for towed underwater camera systems. In *Field Manuals for Marine Sampling to Monitor Australian Waters*, Przeslawski R, Foster S (Eds). National Environmental Science Programme (NESP). pp. 131-152.

# Baited Remote Underwater Video Systems (BRUVS)




https://introduction-field-manual.github.io/#
Langlois, et al. (2020). A field and video annotation guide for baited remote underwater stereo-video surveys of demersal fish assemblages. Methods in Ecology and Evolution, 11, 1401-1409

- Stationary method that uses bait to attract fish to the camera's field of view
- Pro: Can increase abundance -> Power to detect change

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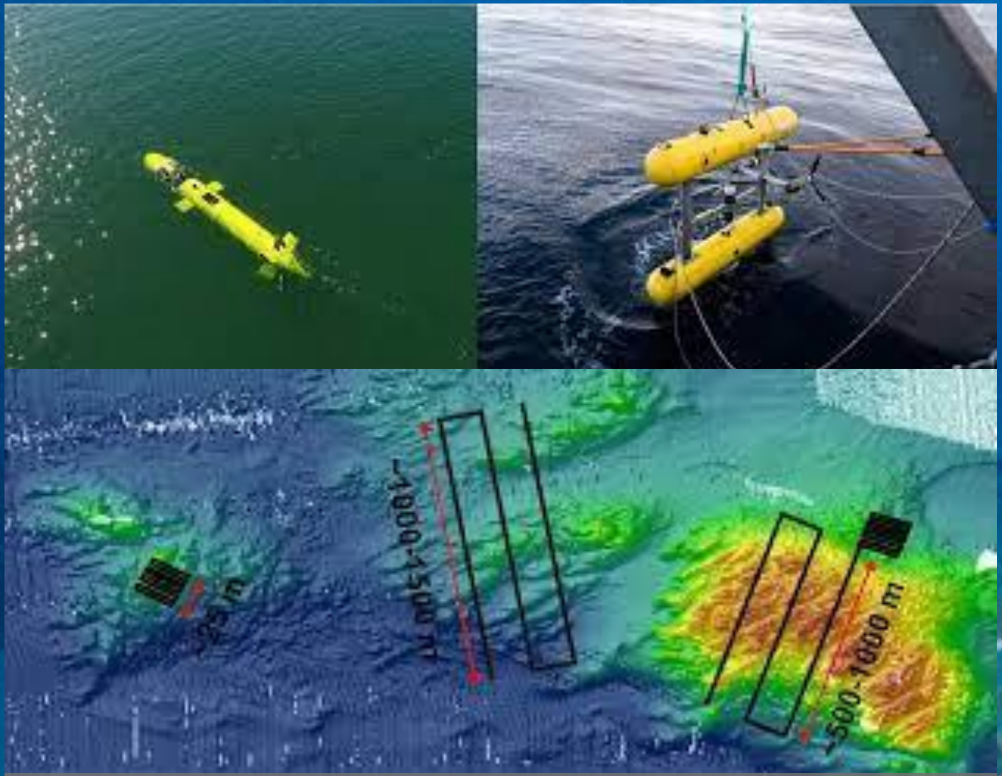
| Non-destructive | | X | X | **X** | | | |
| Habitat associations and behaviours observed | | X | X | **X** | | | |
| Provides fine-scale assessments | | X | | **X** | | | |
| Suitable for surveys of complex/ high relief habitat | | X | | **X** | | | |
| High manoeuvrability | | X | | | | | |
| Suitable in high turbidity | X | | | | | | |
| Bait used | Sometimes | | | **X** | | | |

- Bait-related biases: ([2]Harvey et al. 2007)
  - Attraction of individuals to non-preferred habitat
  - Unequal attraction of individuals (e.g. carnivores vs herbivores, adults vs juveniles)
- Relative abundance vs abundance metrics

[1]Sward, D., Monk, J., & Barrett, N. (2019). A Systematic Review of Remotely Operated Vehicle Surveys for Visually Assessing Fish Assemblages. Frontiers in Marine Science, 6.
[2]Harvey, E.S., Cappo, M., Butler, J.J., Hall, N., & Kendrick, G.A. (2007). Bait attraction affects the performance of remote underwater video stations in assessment of demersal fish community structure. Marine Ecology Progress Series, 350, 245-254

# Autonomous Underwater Vehicles (AUVs) & Manned Submersibles




https://introduction-field-manual.github.io/#
Monk, et al. (2018). Marine sampling field manual for autonomous underwater vehicles (AUVs) In *Field Manuals for Marine Sampling to Monitor Australian Waters*, Przeslawski R, Foster S (Eds). National Environmental Science Programme (NESP). pp. 65-81.


GEOMAR Helmholtz-Zentrum für Ozeanforschung. (2017). Manned submersible „JAGO“. Journal of large-scale research facilities, 3, A110. http://dx.doi.org/10.17815/jlsrf-3-157

- AUVs – Underwater vehicles with pre-programmed deployment paths
- Manned submersibles – Underwater vehicle controlled by onboard pilot

# Autonomous Underwater Vehicles (AUVs) & Manned Submersibles

Summary of underwater survey methods used to survey demersal fish (Sward et al. 2019)[1]

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|---|---|---|---|---|---|---|---|
| Suitable in deep-water (>40 m) | X | | X | X | **X** | **X** | |
| Non-destructive | | X | X | X | **X** | **X** | |
| Habitat associations and behaviours observed | | X | X | X | **X** | **X** | |
| Provides fine-scale assessments | | X | | X | **X** | **X** | |
| Suitable for surveys of complex/ high relief habitat | | X | | X | **X** | **X** | |
| High manoeuvrability | | X | | | | | |
| Suitable in high turbidity | X | | | | | | |
| Bait used | Sometimes | | | X | | | |

- Pro: Fine-scale assessments across depth without biases associated with bait
- Con: Cost and limited manoeuvrability

[1]Sward, D., Monk, J., & Barrett, N. (2019). A Systematic Review of Remotely Operated Vehicle Surveys for Visually Assessing Fish Assemblages. Frontiers in Marine Science, 6.

# Remotely operated vehicles (ROVs)

- Unmanned robotic submersible that transmits video, depth, and compass reading to the researcher at the surface in real-time
- High definition stereo-video footage:
  1. Abundance
  2. Fish lengths -> biomass

# Remotely operated vehicles (ROVs)

Summary of underwater survey methods used to survey demersal fish (Sward et al. 2019)[1]

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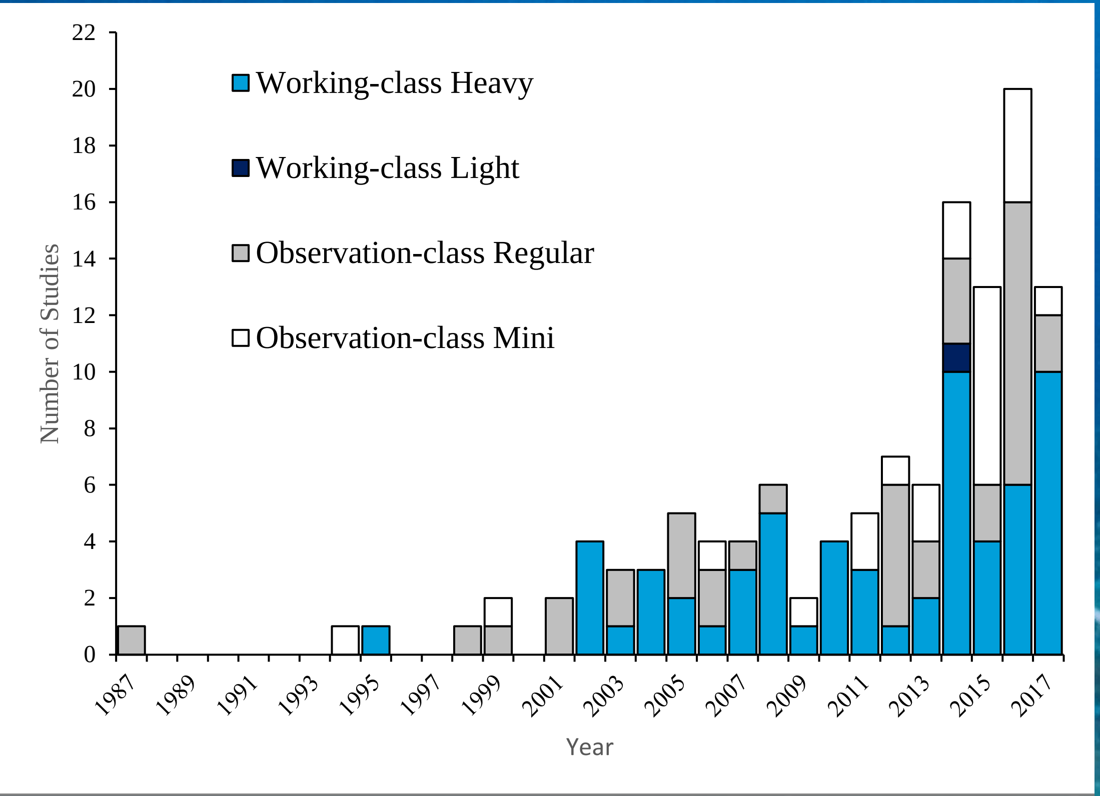
| Non-destructive | | X | X | X | X | X | **X** |
| Habitat associations and behaviours observed | | X | X | X | X | X | **X** |
| Provides fine-scale assessments | | X | | X | X | X | **X** |
| Suitable for surveys of complex/ high relief habitat | | X | | X | X | X | **X** |
| High manoeuvrability | | X | | | | | **X** |
| Suitable in high turbidity | X | | | | | | |
| Bait used | Sometimes | | | X | | | |

Strengths:

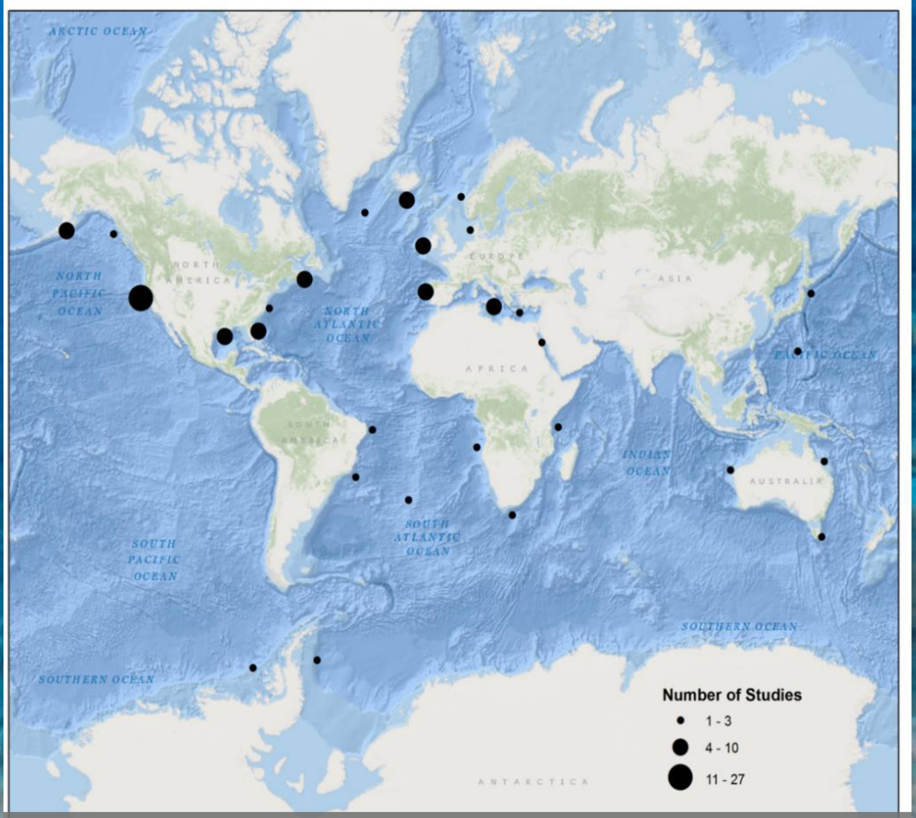
- Non-intrusive / non-destructive, deep-water method
- Quantitative estimates
- Greater manoeuvrability

[1]Sward, D., Monk, J., & Barrett, N. (2019). A Systematic Review of Remotely Operated Vehicle Surveys for Visually Assessing Fish Assemblages. Frontiers in Marine Science, 6.

# Remotely operated vehicles (ROVs)




Temporal trends in ROV publications using observation-class (Mini: White; Regular-sized: Grey) and working-class (Light: Dark Blue; Heavy: Light Blue) (Sward et al., 2019)[1]




Locations of ROV-based studies found using keywords “remotely operated vehicle*” in Google Scholar™ and OneSearch™ databases (n=108 publications) (Sward et al., 2019)[1]

## However, still requires proper evaluation and standardization!

[1]Sward, D., Monk, J., & Barrett, N. (2019). A Systematic Review of Remotely Operated Vehicle Surveys for Visually Assessing Fish Assemblages. Frontiers in Marine Science, 6.

# Developing ROVs as a platform for video-based surveys of benthic fish

## Main objectives:

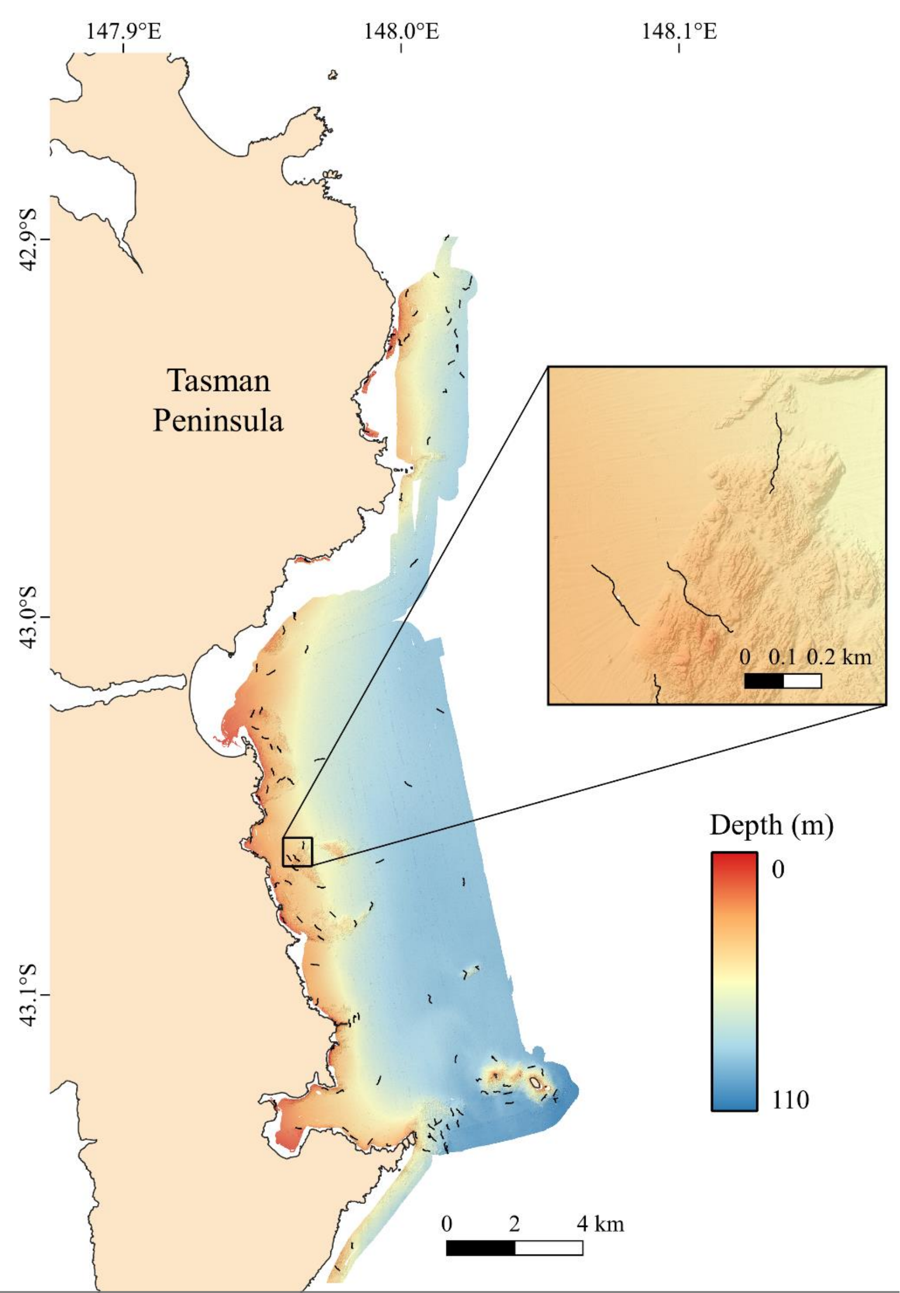
1. Assess the capabilities, limitations, and biases of ROVs as a deep-water survey tool
2. Establish a framework for sampling strategies that provide sufficient power to detect biologically meaningful patterns

# Research Overview

- Many demersal fish species off the coast of Tasmania are undergoing impacts from extractive fishing practices
- Comprehensive monitoring of these impacts should consider:
    1. The spatial scale utilized by the species of interest
    2. The scale at which to effectively monitor and conserve biological communities
- Despite this, surveys have rarely considered habitat associations with seabed topography beyond fine-scale habitat features
- Study objectives:
    1. To evaluate the utility of ROVs for surveying key, fisheries-targeted species across a large region off the coast of SE Tasmania
    2. To improve the ability of species distribution models (SDMs) to detect changes in demersal fish populations by incorporating multi-scale seabed terrain features

# ROV-based sampling strategies

- Balanced adaptive sampling (BAS) (Foster et al. 2014)[1]
  - Allocated 110, 200 m transects
  - Utilized existing multibeam echosounder (MBES) mapping on the Tasman Peninsula (118.182 km$^2$)
  - Spatially balanced approach provides representative sampling across depth / reef habitat
  - Unequal inclusion of reef (80%) and sand (20%) to stratify study sites
- Ultra-Short Baseline (USBL) acoustic positioning system
  - Records the precise deployment path taken by the ROV

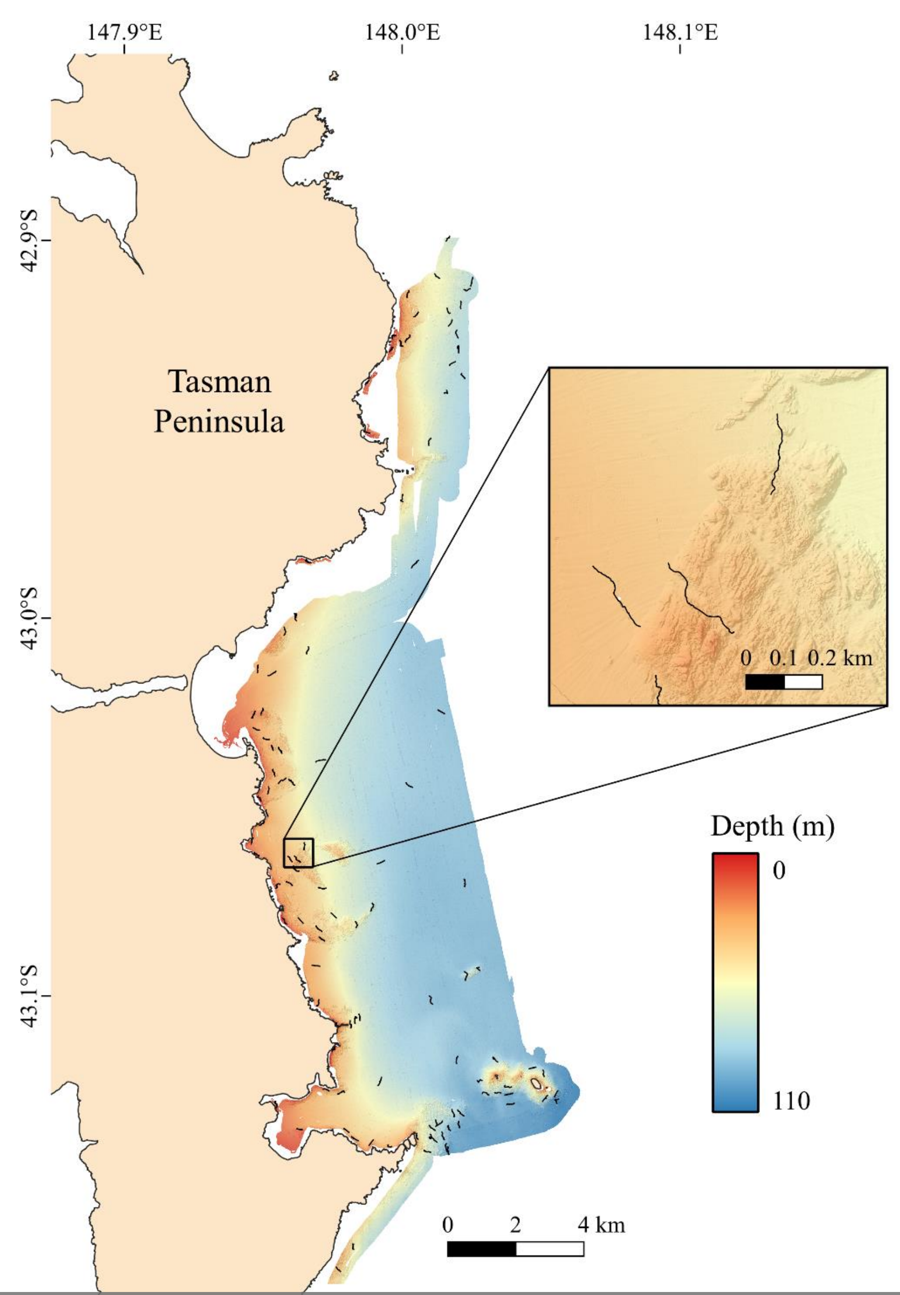



Remotely operated vehicle deployment paths for 110 study sites on the Tasman Peninsula off the east coast of Tasmania, Australia

[1]Foster, S.D., Hosack, G.R., Hill, N.A., Barrett, N.S., Lucieer, V.L., and Spencer, M. (2014). Choosing between strategies for designing surveys: autonomous underwater vehicles. Methods in Ecology and Evolution 5(3), 287-297.

# ROV surveys

- Fisheries-targeted species
  - Banded morwong (*Cheilodactylus spectabilis*)
  - Bluethroat wrasse (*Notolabrus tetricus*)
  - Jackass morwong (*Nemadactylus macropterus*)




Remotely operated vehicle deployment paths for 110 study sites on the Tasman Peninsula off the east coast of Tasmania, Australia

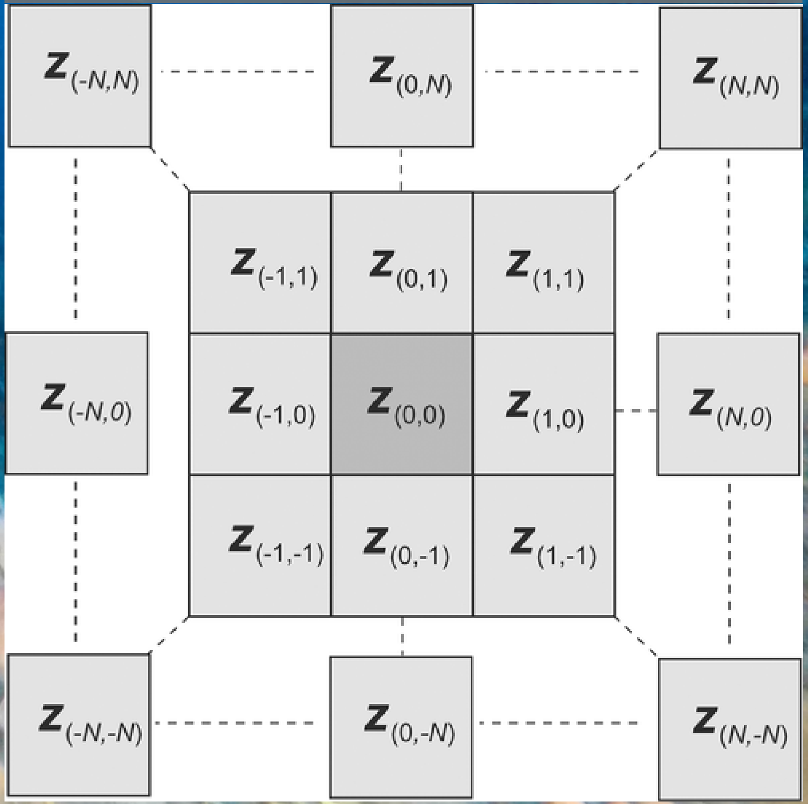
# Multi-scale Species Distribution Models (SDMs)

- Seabed terrain features are calculated from digital elevation models (DEMs) using MBES bathymetry data organized into a grid of cells (Wilson et al., 2007)[1]
  - Terrain values = The difference between the central cell to neighboring cells
  - Typically generated at the smallest scale (3 m x 3 m)

Multibeam echosounder (MBES)-derived seabed terrain features

| Covariate | Description | Transformation |
|---|---|---|
| Depth | Water depth (m) obtained from bathymetric data, which has also been averaged within a defined grid of neighboring MBES cells for multi-scale analyses | None |
| Northness* | The extent in radians to which habitat deviates from a north-facing position (calculated by sin[aspect in radians]), with values closer to 1 indicating a more north-facing location and values closer to -1 indicating a more south-facing location (Wilson et al. 2007) | None |
| Eastness* | The extent in radians to which habitat deviates from an east-facing position (calculated by cos[aspect in radians]), with values closer to 1 indicating a more east-facing location and values closer to -1 indicating a more west-facing location (Wilson et al. 2007) | None |
| Seafloor ruggedness (VRM) | The amount of deviation relative to defined grid of neighboring MBES cells (Riley et al. 1999) | Log |
| Plan curvature* | The variation in curvature relative to contours within a defined grid of neighboring MBES cells (Wilson et al. 2007) | None |
| Profile curvature | The curvature of the surface in the direction of the steepest slope relative to defined grid of neighboring MBES cells (Wilson et al. 2007) | None |

Visualisation of how seabed terrain features are calculated from a grid of cells in digital elevation models (Wilson et al., 2007)[1]



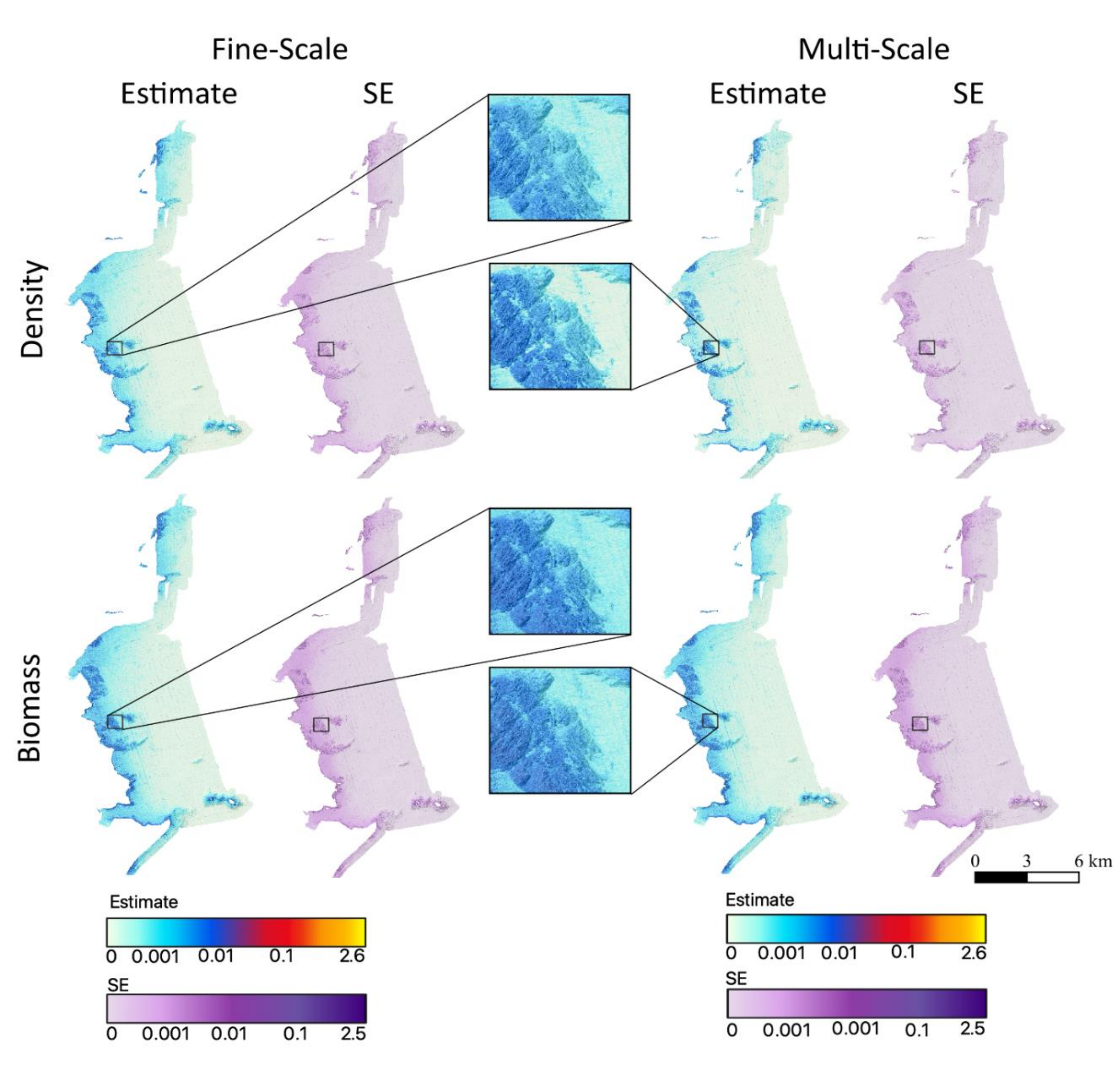

[1]Wilson, M.F.J., O'Connell, B., Brown, C., Guinan, J.C., & Grehan, A.J. (2007). Multiscale Terrain Analysis of Multibeam Bathymetry Data for Habitat Mapping on the Continental Slope. *Marine Geodesy*, *30*, 3-35

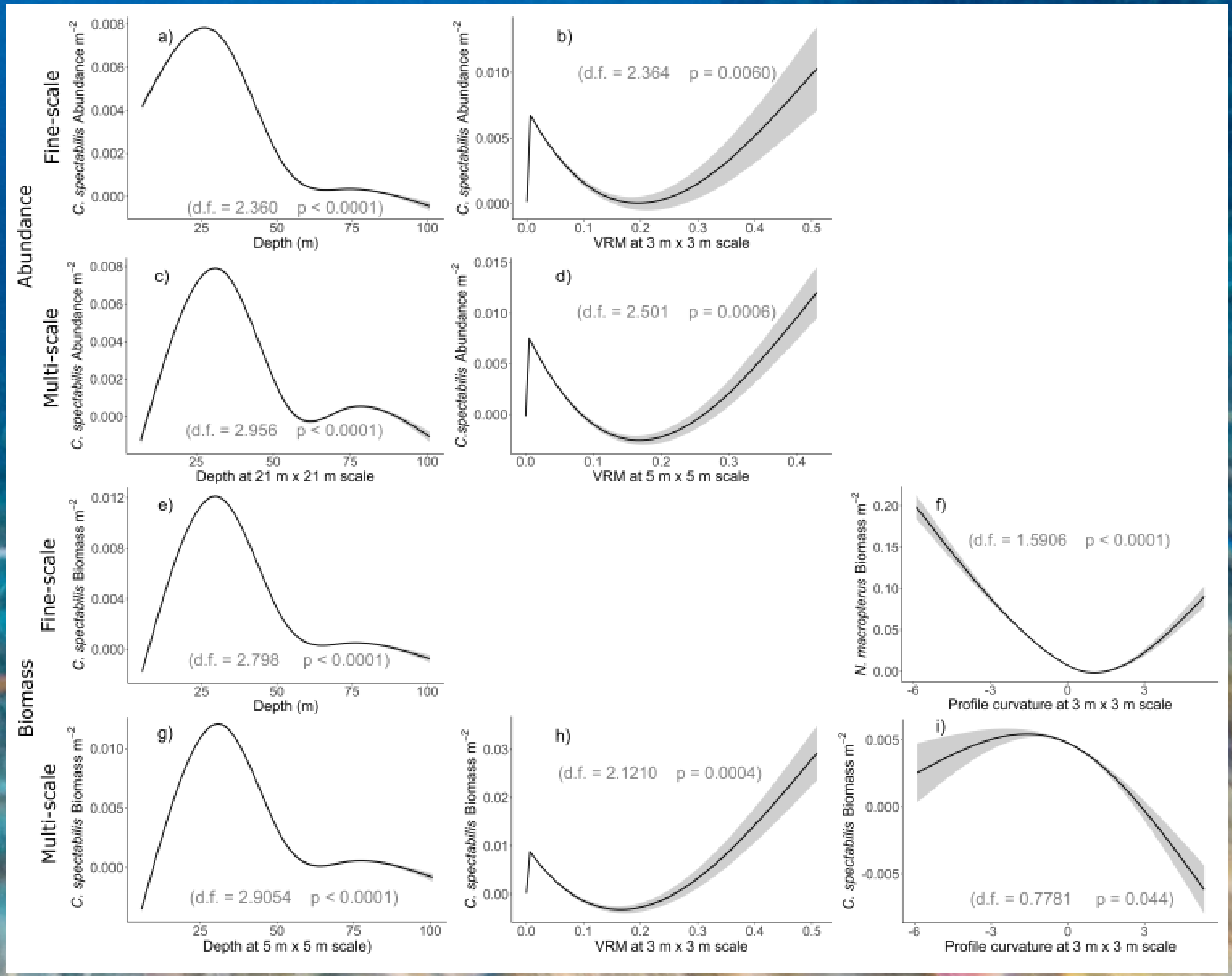
# Multi-scale SDMs

- Establishing methods for accurately predicting population estimates is a key component of monitoring
- Seabed terrain features generated at:
  - fine-scale (3 m x 3 m)
  - multi-scale (3 m x 3 m to 21 x 21 m)
- Generalized additive models (GAMs) to predict the abundance and biomass of key species
- Model fit tested using training and testing datasets
- GAM models evaluated using accuracy and precision metrics

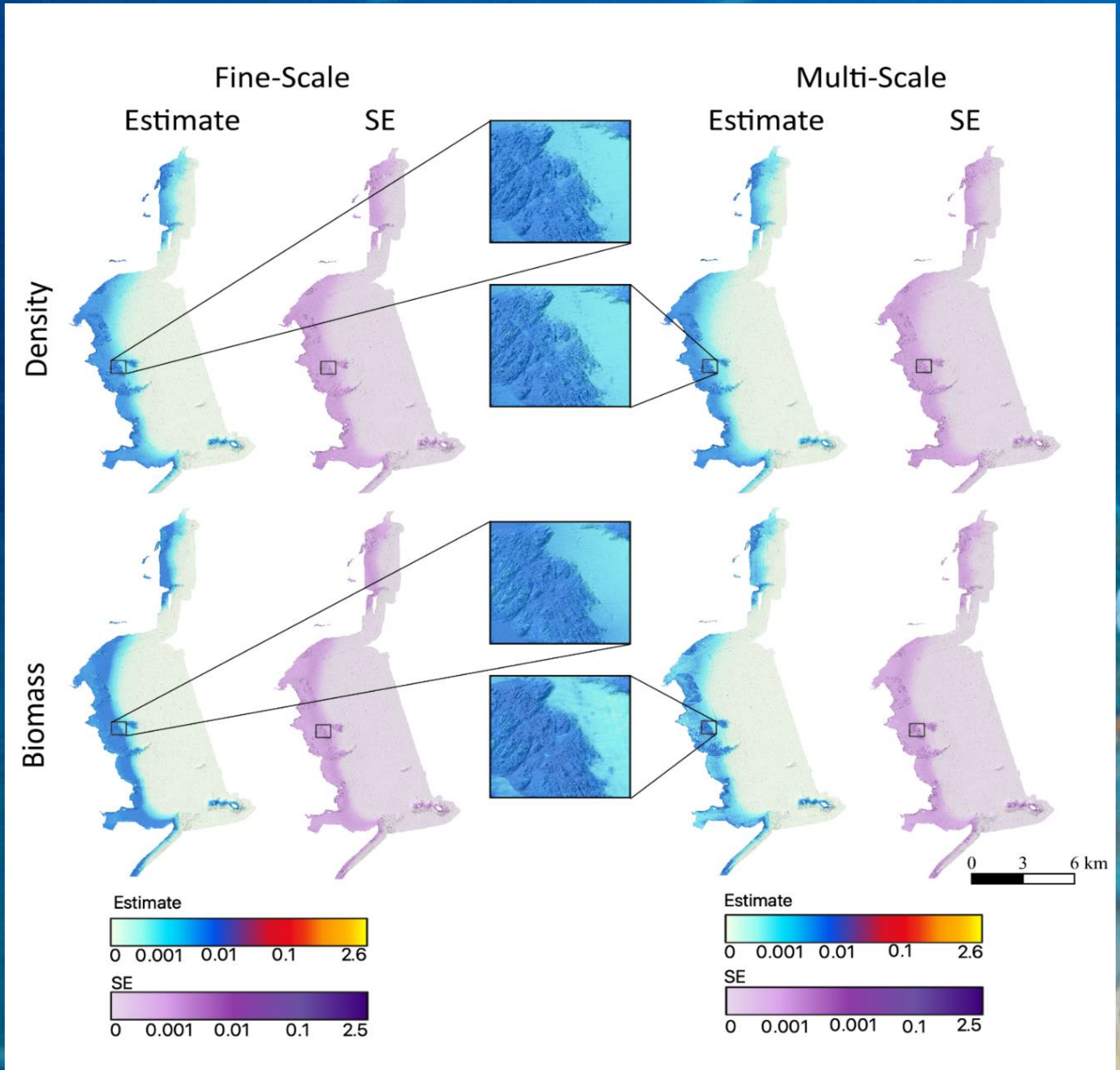
| | | Fine-scale GAM | Multi-scale GAM |
|---|---|---|---|
| **Jackass morwong** (*Nemadactylus macropterus*) | | | |
| Density estimated for region (individuals per $m^2$) | | 0.01714 | 0.00905 |
| Accuracy | Explained deviance | 0.346 | 0.367 |
| | AIC | 1464.441 | 1451.780 |
| | RMSE of training dataset | 5.938 | 5.895 |
| | RMSE of test dataset | 5.917 | 5.862 |
| Precision | Coefficient of variation | 0.1441 | 0.1407 |
| Average biomass estimated for region (kg per $m^2$) | | 0.00738 | 0.00613 |
| Accuracy | Explained deviance | 0.303 | 0.325 |
| | AIC | 1513.857 | 1499.211 |
| | RMSE of training dataset | 6.487 | 6.487 |
| | RMSE of test dataset | 6.503 | 6.494 |
| Precision | Coefficient of variation | 0.1595 | 0.1572 |

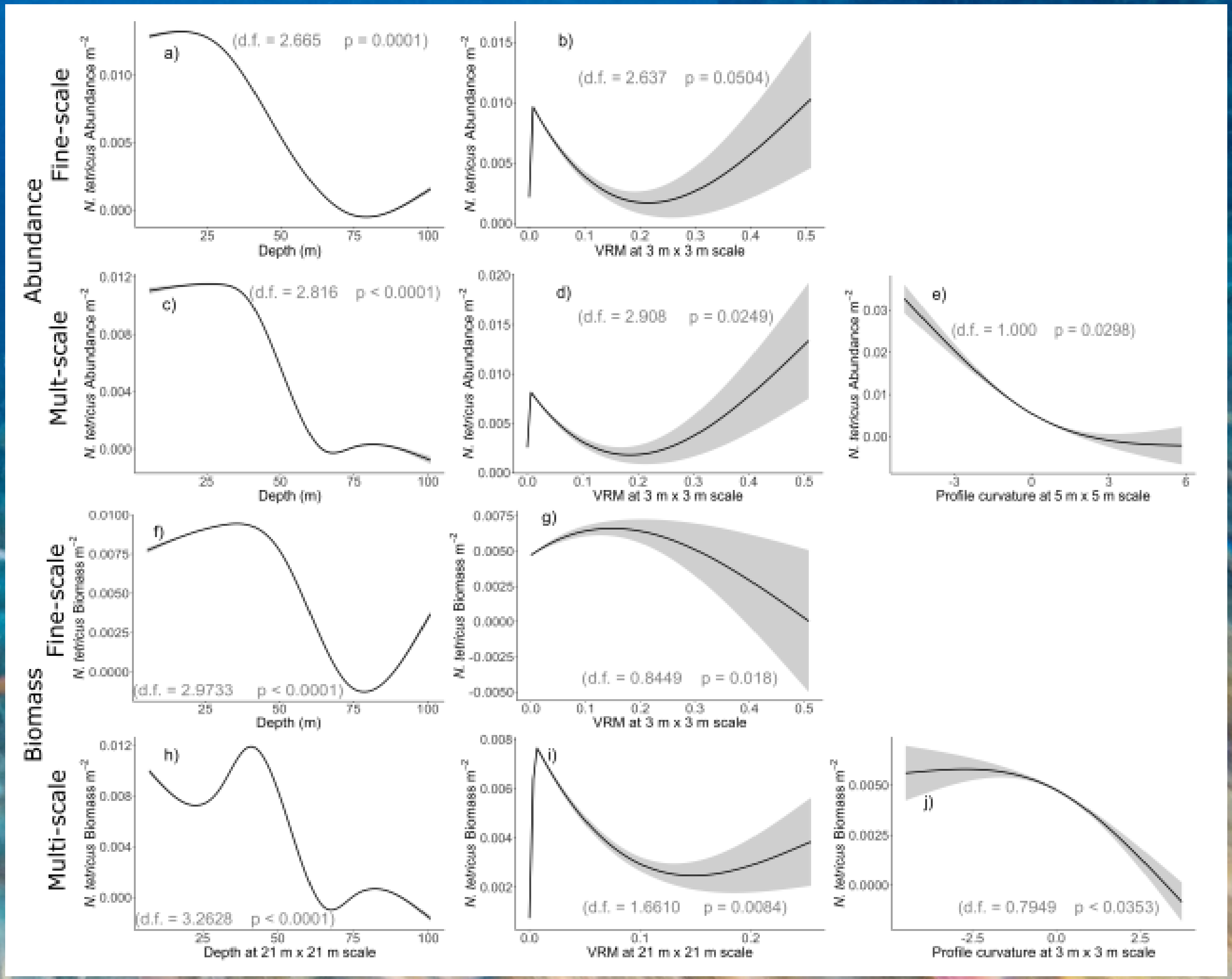
# Banded Morwong (*Cheilodactylus spectabilis*)



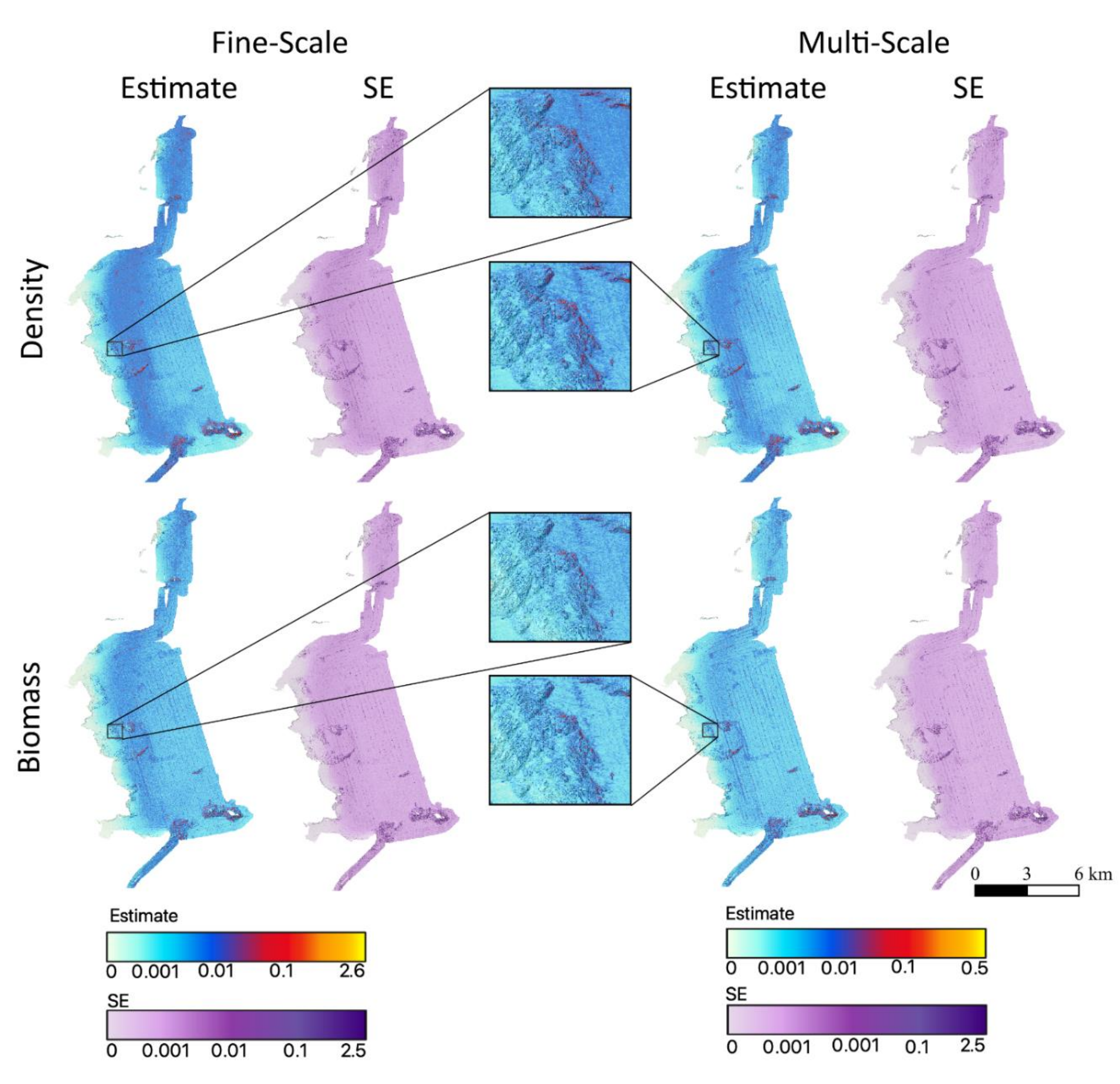



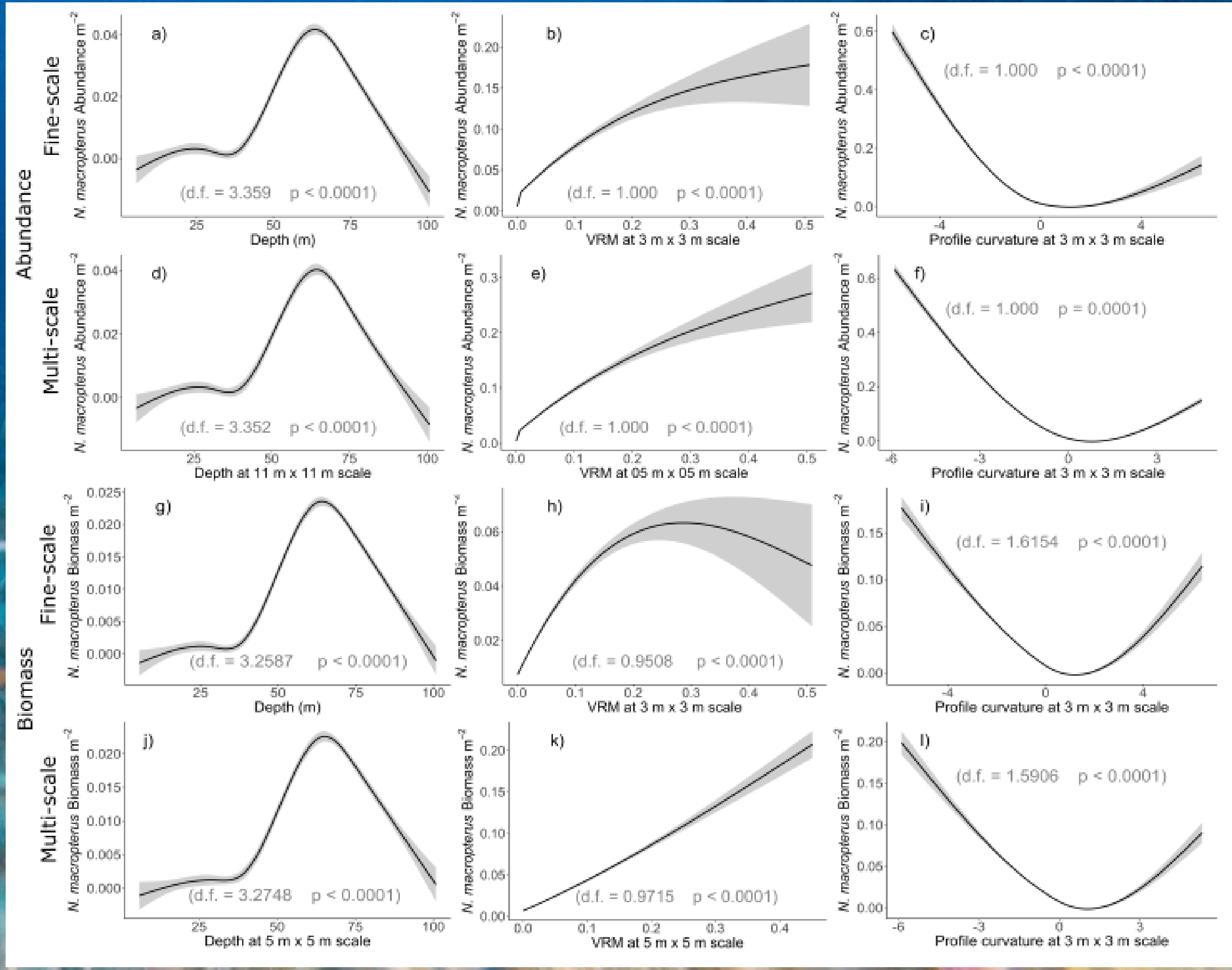
# Blue Throat Wrasse (*Notolabrus tetricus*)



# Jackass Morwong (*Nemadactylus macropterus*)



# Conclusions

- Seabed terrain attributes generated at larger scales
  - Improved the accuracy and precision of nearly all models for jackass morwong & blue throat wrasse
  - Varying results for banded morwong
- Depth influential across all models
  - Greatest density and biomass at 30 m and greater -> Beyond depths accessible to SCUBA divers
- Differences in the observed distribution patterns were likely due in some part to species-specific site fidelity
- Regional estimates for multi-scale models were consistently lower
- Highlights species-specific approaches and the use of multi-scale seabed terrain attributes in predictive modelling

# Future Research

- Incorporate detection rates into SDMs (Katsanevakis et al., 2007)[1]
- Behavior of fish to ROV
- Long-term studies using Dynamic Occupancy Models (Calvert et al., 2018)[2]
- Comparisons between surveying methods

[1]Katsanevakis, S., Weber, A., Pipitone, C., Leopold, M., Cronin, M., Scheidat, M., Doyle, T.K., Buhl-Mortensen, L., Buhl-Mortensen, P., D'Anna, G., de Boois, I., Dalpadado, P., Damalas, D., Fiorentino, F., Garofalo, G., Giacalone, V.M., Hawley, K.L., Issaris, Y., Jansen, J., Knight, C.M., Knittweis, L., Kröncke, I., Mirto, S., Muxika, I., Reiss, H., Skjoldal, H.R., & Vöge, S. (2012). Monitoring marine populations and communities: methods dealing with imperfect detectability. Aquatic Biology, 16, 31-52

[2]Calvert, J., McGonigle, C., Sethi, S.A., Harris, B., Quinn, R., & Grabowski, J. (2018). Dynamic occupancy modeling of temperate marine fish in area-based closures. Ecology and Evolution, 8, 10192-10205

# General Conclusions

- ROV-based sampling strategies effective for surveying common, commercial species of interest within representative coastal regions across eastern Tasmania

- Demonstrated the value of combining spatially balanced sampling designs, stereo-video-based ROV transects, and MBES mapping as a reliable and robust approach for quantitative surveys of biodiversity

- Establishing effective ROV-based monitoring strategies may better inform fisheries management and conservation of marine ecosystems

# Special thanks to: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- Kym Newberry and Elwood Mantel from the Australian Antarctic Division (AAD) for their assistance and lending us their Seaeye Falcon ROV
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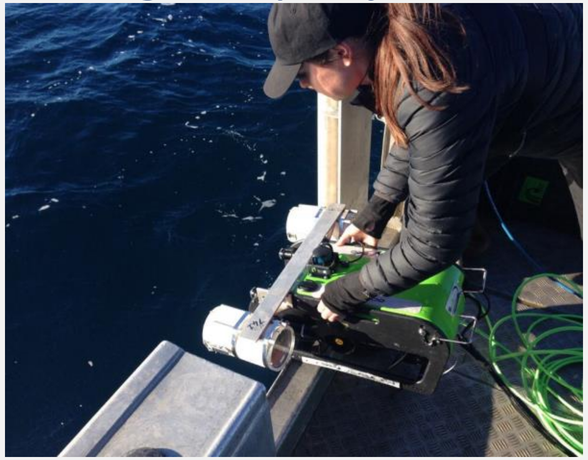
- The many volunteers involved with this project:
  - Justin Hulls
  - Graeme Ewing
  - Léo Mahieu
  - Martin Filleul
  - Kylie Cahill
  - Micheal Porteus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