New possibilities for research on reef fish across the continental shelf of South Africa

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Subtidal research presents numerous challenges that restrict the ability to answer fundamental ecological questions related to reef systems. These challenges are closely associated with traditional monitoring methods and include depth restrictions (e.g. safe diving depths for underwater visual census), habitat destruction (e.g. trawling), mortality of target species (e.g. controlled angling and fish traps), and high operating costs (e.g. remotely operated vehicles and large research vessels).[1] Whereas many of these challenges do not apply or are avoidable in the shallow subtidal environment, the difficulties grow as one attempts to sample deeper benthic habitats. This situation has resulted in a paucity of knowledge on the structure and ecology of deep water reef habitats around the coast of South Africa[2,3], and in most marine areas around the world[4,5]. Furthermore, the inability to effectively survey deep water benthic environments has limited the capacity of researchers to investigate connectivity between shallow and deep water habitats in a standardised and comparable fashion.[6]

With the recent advent of sophisticated and cost-effective remote sampling methods suitable for deep water research,[1] ecologists have been able to describe finer-scale patterns of reef ecosystems in both deep and shallow waters. This ability has led to the identification of ecological drivers of shallow and deep water fish community structure in a standardised and comparable manner.[7-16] The baited remote underwater stereo-video system (stereo-BRUVs; Figure 1) has been at the forefront of these developments[17-19], and has emerged as the most comprehensive, precise and cost-effective tool to measure the ecosystem effects of fisheries[14,20], and patterns in fish abundance[7,8,15,21].

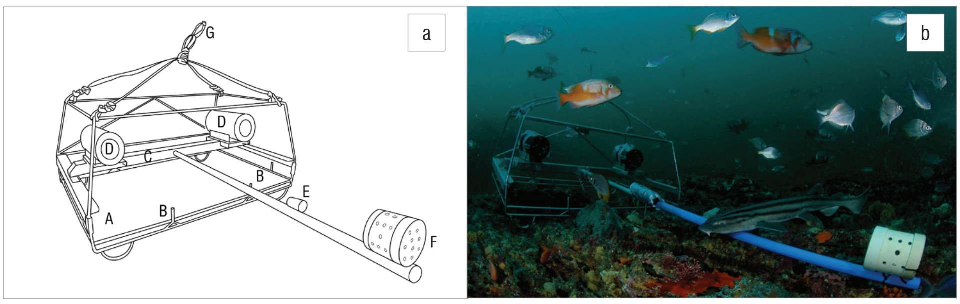

Figure 1: (a) Schematic of a baited remote underwater stereo-video system (stereo-BRUVs) showing stainless steel frame (A) with pins to mount additional weights (B) and rigid centre bar (C) that holds the housed digital high-definition cameras (D). Extending perpendicularly from the centre bar is a pole that holds the synchronising diode (E) and the bait container (F). The system is linked to the surface by a buoy and rope system that attaches to the stainless steel frame (G). (b) Stereo-BRUVs deployed at a depth of 20 m on Rheeders Reef off Storms River, Tsitsikamma National Park Marine Protected Area (photo: Steve Benjamin).

For the first time in South Africa, through a collaborative project of the Elwandle Node of the South African Environmental Observation Network (SAEON), the South African Institute for Aquatic Biodiversity (SAIAB), Rhodes University, the University of Western Australia, and Curtin University (Australia), stereo-BRUVs research on reef fish assemblages is being conducted within the Agulhas Ecoregion from the shallow subtidal area to the edge of the continental shelf. The purpose of this piece is to place in context the necessity of standardised research on the populations of reef fish across the continental shelf of South Africa, to put forward the case for employing stereo-BRUVs in this research, and to introduce the South African marine science community to the research possibilities available with stereo-camera systems.

Video sampling techniques

Although there is some variation in how different studies have approached video sampling,[22-27] the techniques can broadly be grouped as (1) unbaited remote underwater video systems (RUVs), (2) baited RUVs (BRUVs), (3) diver-operated video systems (DOVs), (4) stereo-RUVs, (5) stereo-BRUVs and (6) stereo-DOVs. In addition, remotely

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operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) equipped with video cameras are being used more frequently for research. However, both ROVs and AUVs are expensive and logistically complicated to operate and have been largely restricted to oceanographic (AUVs) or exploratory (ROVs) research. Both RUVs and BRUVs are deployed from a research vessel with the system resting on the sea floor or in the water column, while tethered to a surface marker buoy or to the research vessel. The only distinction between these two approaches is that BRUVs use a food-based attractant to draw fish into the field of view of the camera. DOV is synonymous with underwater visual census (UVC), except that the survey is recorded and the researcher identifies and counts fish post sampling from the video footage, as opposed to identifying and counting the fish while underwater (as in UVC). Stereo-video sampling is a variation of mono-video camera techniques (RUVs, BRUVs and DOVs) that allow for fish lengths to be measured and the survey area to be quantified, greatly increasing the data output per sample and the value of the data for studying the effects of fishing.[14]

Since the mid-1990s there has been an exponential increase in the number of research articles published in peer-reviewed scientific journals that employed BRUVs, RUVs, DOVs or their stereo-video equivalents to collect fish assemblage data from subtidal reefs across continental shelves (Figure 2). Stereo-video sampling techniques first emerged in the early 1980s[28]; however, it was only in the mid-1990s that development of the remote stereo-video approach was initiated by researchers at Otago University and Melbourne University.[24] Only in the last 4 years has the method expanded globally, resulting in a rapid increase in the number of publications based on data collected with this approach (Figure 2). Further growth in the publication rate can be expected over the next few years as the tools become more available and awareness of the new research possibilities they provide increases.

Several studies have compared the benefits and shortcomings of different underwater video sampling techniques,[19,29-31] or contrasted them with more established subtidal sampling techniques such as UVC[18,32,33], controlled angling[14,34], research trawling[25,35] or trapping[35,36]. In general, results show that the stereo-BRUVs technique outperforms all other available methods with the data characterised by low levels of variability, high levels of species richness, high abundances of species targeted by fisheries and accurate information on the size structure of these populations.[14,18,19,24,30,36]

Remote video sampling techniques are flexible in that the systems can be deployed with or without bait, or with the bait type varying between units or deployments, and can be tailored to address a multitude of questions by targeting specific components of the fish community. As such, remote video sampling techniques reduce the research footprint and provide data capable of addressing research and management questions across geographical and depth gradients, within special management areas (e.g. no-take marine protected areas, MPAs) and across different habitats. Importantly, the feasibility of long-term standardised monitoring will be increased significantly by the cost-efficiency of the method.

One of the major advantages of stereo-video over mono-video techniques is that it allows for precise length measurement of fish underwater. This advantage means that the potential for observer error is avoided (compared with UVC) and the need to remove fish from the water, which frequently leads to barotrauma, is eliminated (compared with controlled angling and fish traps).[17,37,38] The size distribution of a fish community is a more sensitive measure of fishing pressure than abundance, as larger individuals of a species are typically more aggressive and caught first when fishing.[1] Research from Western Australia has demonstrated that the size data collected with stereo-BRUVs are comparable to fisheries-dependent data sources and are therefore potentially useful for informing management of stocks.[36,39] In addition, size-based indicators, such as mean length in a population or community, mean maximum length in a community, and the slope and intercept of size spectra, are particularly useful for long-term ecosystem-based fisheries management (EBFM).[40,41] Furthermore, the use of stereo-video also allows the distance from the cameras to a fish to be measured and hence the area sampled can be standardised.[42]

Over the last 4 years, single camera remote underwater video systems (RUVs and BRUVs) have been successfully employed to survey the reef fish communities in the Tsitsikamma National Park, Still Bay National Park and Table Mountain National Park MPAs in South Africa.[31,43,44] The results suggest that BRUVs are highly suitable for obtaining relative abundance data for most of the reef fish species occurring in the Agulhas Ecoregion. Furthermore, data collected in the Tsitsikamma National Park

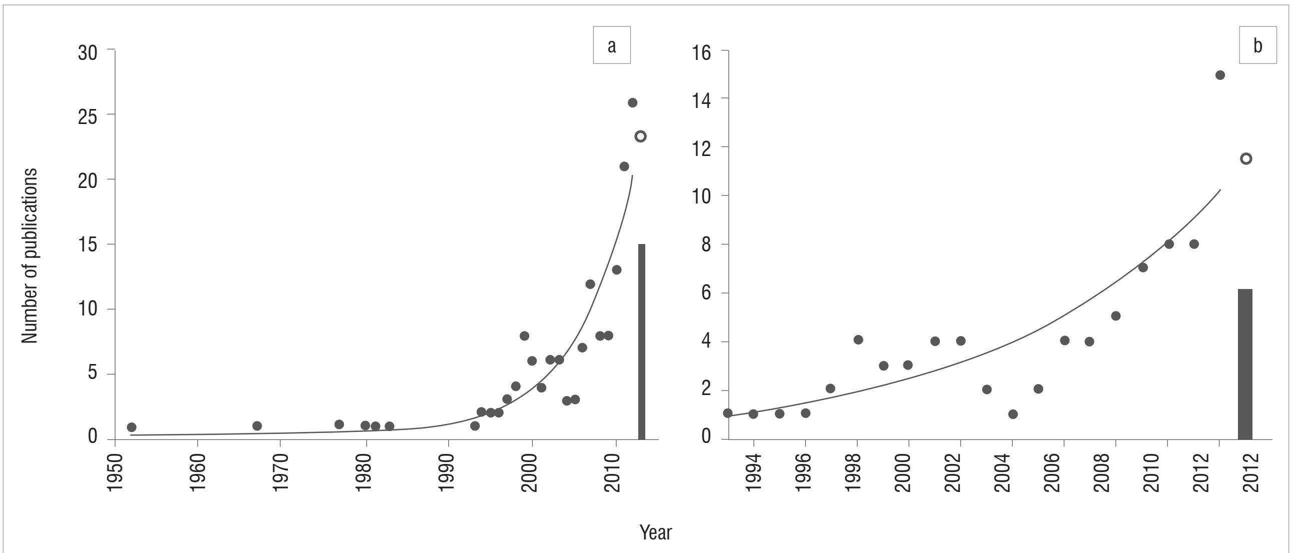

Figure 2: Number of articles published in peer-reviewed scientific journals (a) from 1952 to June 2013 that included use of video sampling techniques and (b) from 1994 that included use of stereo-video sampling techniques. The bars indicate the number of articles published by July 2013, while the open circle indicates the expected number of published articles by the end of 2013. The articles were collated by means of academic publication search engines (Academic Search Premier, Cambridge Journals, CSIRO, ESA, JSTOR, Google Scholar, Inter-Research, Science Direct, Sci-Verse Scopus, Springer Link, Web of Knowledge) and reference list reviews of key literature. Search terms entered included: BRUVs, RUVs, DOVs, remote video and fish. Studies using remotely operated vehicles and autonomous underwater vehicles and those with data collected beyond the continental shelves were excluded.

MPA, using six different techniques, show that BRUVs detected 92% of all bony fish and 71% of all cartilaginous species recorded by the six methods, compared with 68% and 43%, respectively, for the second best method – RUVs (Table 1).[45] Interestingly, in the same study UVC recorded zero cartilaginous species and only 60% of the bony fish species, even though it had three times the sampling effort compared with both RUVs and BRUVs.[45] These results further emphasised the efficiency of BRUVs, with the method requiring only 21 samples per annum to detect a 10% increase in the abundance of important commercial fisheries species, compared with 49 samples required by RUVs and 72 samples required by UVC.[45]

During 2013, stereo-BRUVs were deployed for the first time in South Africa (and Africa), to collect fish assemblage data within the Tsitsikamma National Park MPA. A total of 194 samples, equating to 388 h of video footage, was collected from inside and outside the MPA using four units during 17 sampling days. Sampling depth ranged from 6 m to 80 m, encompassing the deepest extent of the reef habitat inside the MPA and equivalent habitat outside the MPA. All sampling was conducted off an 8-m semi-rigid ski-boat fitted with a simple capstan winch to retrieve the weighted systems. Preliminary analysis of 36 samples has resulted in the detection of 41 species and a total of 3644 size measurements, showing that the stereo-BRUVs not only provide the same benefits as the mono-camera BRUVs, but also produce a considerable amount of length frequency data (±100/sample).

Importance of standardised monitoring

Over the last few decades it has become evident that both management and monitoring of fish resources have been inadequate, or inappropriate, to ensure the conservation of biodiversity and sustainable utilisation of target species.[46-49] The single or multi-species approach to traditional management is considered by many to be outdated, particularly for reef fish, and there is a drive to implement holistic EBFM.[3,47,48,50] Similarly, the assumption that managers can rely on resource users to abide by regulations has been repeatedly disproved, compelling managers to adopt approaches that are feasible to manage and enforce, such as no-take MPAs.[3,48,49]

Ecosystem-based fisheries management requires sound knowledge on the ecology of the natural systems being managed.[50,51] Because of the vulnerable nature of populations of over-exploited fish species, monitoring methods need to be non-destructive to remove the possibility of additional impacts on stocks. Furthermore, many reef fish species occupy broad depth ranges during the course of their life histories.[52-54] In South Africa, this applies for most of the important endemic reef dwelling species targeted in the line-fishery industry, with some occupying a depth range in excess of 150 m.[52,53] This is true for species such as carpenter (*Argyrozona argyrozona*), dageraad (*Chrysoblephus cristiceps*), red stumpnose (*C. gibbiceps*), roman (*C. laticeps*), black musselcracker (*Cymatoceps nasutus*), blue hottentot (*Pachymetopon aeneum*), hottentot seabream (*Pachymetopon blochii*), red steenbras (*Petrus rupestris*), scotsman (*Polysteganus praeorbitalis*) and panga (*Pterogymnus laniarius*), many of which are considered over-exploited and are listed by the South African Sustainable Seafood Initiative as species of concern or as unsustainable.[48,49,55] Adequate monitoring across these broad distributional ranges in a standardised and comparable fashion is required to provide data that promotes effective management of such species. The remote underwater stereo-video system, whether baited or unbaited, offers an opportunity to meet this need.

Conclusions

There is a growing global recognition that high-resolution, non-destructive and in-situ stereo-video techniques can provide improved understanding of fine-scale ecology on deep and shallow reef habitats, and deliver data that support effective EBFM. Preliminary work in South Africa has proved that the method can be cost-efficiently employed by small research teams working off small vessels. The stereo-video research platform developed at SAIAB and SAEON will be able to operate down to depths of 250 m, covering the entire depth range of the continental shelf of South Africa, and will open an extensive array of new research possibilities to scientists based at tertiary education facilities and research institutes in South Africa. The next step is to implement priority research projects that, for example, provide data necessary to develop an understanding of the ecology of shallow- and deep-water habitats and their connectivity, and to determine the spatial patterns of abundance and biomass distributions of vulnerable and endemic fish species. This will support the implementation of effective EBFM and form the basis of long-term monitoring programmes that inform adaptive EBFM.

Beyond the scientific value, hours of video footage will be available for educational purposes to raise awareness regarding the vulnerability of reef fishes and the role of no-take MPAs in protecting reef ecosystems. This material can be used to stimulate interest in marine biology amongst the younger generation and inform communities on the importance of MPAs and fisheries regulations.

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References

1. Murphy HM, Jenkins GP. Observational methods used in marine spatial monitoring of fishes and associated habitats: A review. Mar Freshwater Res. 2010;61:236–252. http://dx.doi.org/10.1071/MF09068
2. Griffiths CL, Robinson TB, Lange L, Mead A. Marine biodiversity in South Africa: An evaluation of current states of knowledge. PLoS ONE. 2010;5:e12008. http://dx.doi.org/10.1371/journal.pone.0012008
3. Sink KJ, Attwood CG, Lombard AT, Grantham H, Leslie R, Samaai T, et al. Spatial planning to identify focus areas for offshore biodiversity protection in South Africa. Final report for the Offshore Marine Protected Area Project. Cape Town: South African National Biodiversity Institute; 2011.
4. Miller K, Neil H, Tracey D. Recent advances in deep-sea coral science and emerging links to conservation and management of deep-sea ecosystems. Mar Ecol Prog Ser. 2009;397:1–5. http://dx.doi.org/10.3354/meps08452

Table 1: Fish species sampled by means of controlled angling (CA), fish trap (FT), remotely operated vehicle (ROV), remote underwater video systems (RUVs), baited RUVs (BRUVs) and underwater visual census (UVC) in the Tsitsikamma National Park Marine Protected Area during a simultaneous method comparison.[45] Each method was allocated two randomly selected days for data collection within a 24-day sampling period.

	Method (number of samples)					
Common name (total number of species recorded with all six methods)	**CA (16)**	**FT (25)**	**ROV (7)**	**RUVs (10)**	**BRUVs (10)**	**UVC (30)**
Jawless fishes (1 species)		1				
Cartilaginous fishes (7 species)	3	4	1	3	5	0
Bony fishes (25 species)	11	5	9	17	23	15

5. Quattrini AM, Ross SW, Carlson MCT, Nizinski MS. Megafaunal-habitat associations at a deep-sea coral mound off North Carolina, USA. Mar Biol. 2012;159:1079–1094.

6. Levin LA, Dayton PK. Ecological theory and continental margins: Where shallow meets deep. Trends Ecol Evol. 2009;1142:606–617. http://dx.doi.org/10.1016/j.tree.2009.04.012

7. Moore CH, Harvey ES, Van Niel KP. Spatial prediction of demersal fish distributions: Enhancing our understanding of species-environment relationships. ICES J Mar Sci. 2009;66:2068–2075. http://dx.doi.org/10.1093/icesjms/fsp205

8. Moore CH, Harvey ES, Niel K. The application of predicted habitat models to investigate the spatial ecology of demersal fish assemblages. Mar Biol. 2010;157:2717–2729. http://dx.doi.org/10.1007/s00227-010-1531-4

9. Moore CH, Van Niel K, Harvey ES. The effect of landscape composition and configuration on the spatial distribution of temperate demersal fish. Ecography. 2011;34:425–435. http://dx.doi.org/10.1111/j.1600-0587.2010.06436.x

10. Watson DL, Anderson MJ, Kendrick GA, Nardi K, Harvey ES. Effects of protection from fishing on the lengths of targeted and non-targeted fish species at the Houtman Abrolhos Islands, Western Australia. Mar Ecol Prog Ser. 2009;384:241–249. http://dx.doi.org/10.3354/meps08009

11. Malcolm H, Jordan A, Smith SD. Testing a depth-based habitat classification system against reef fish assemblage patterns in a subtropical marine park. Aquat Conserv Mar Freshwater Ecosyst. 2011;21:173–185. http://dx.doi.org/10.1002/aqc.1165

12. Mcilwain JL, Harvey ES, Grove S, Shiell G, Al Oufi H, Al Jardani N. Seasonal changes in a deep-water fish assemblage in response to monsoon-generated upwelling events. Fish Oceanogr. 2011;20:497–516. http://dx.doi.org/10.1111/j.1365-2419.2011.00598.x

13. Harvey ES, Dorman SR, Fitzpatrick C, Newman SJ, McLean DL. Response of diurnal and nocturnal coral reef fish to protection from fishing: an assessment using baited remote underwater video. Coral Reefs. 2012;31:939–950. http://dx.doi.org/10.1007/s00338-012-0955-3

14. Langlois TJ, Harvey ES, Meeuwig JJ. Strong direct and inconsistent indirect effects of fishing found using stereo-video: Testing indicators from fisheries closures. Ecol Indic. 2012; 23:524–534. http://dx.doi.org/10.1016/j.ecolind.2012.04.030

15. Langlois TJ, Radford BT, Van Niel KP, Meeuwig JJ, Pearce AF, Rousseaux CSG, et al. Consistent abundance distributions of marine fishes in an old, climatically buffered, infertile seascape. Glob Ecol Biogeogr. 2012;21:886–897. http://dx.doi.org/10.1111/j.1466-8238.2011.00734.x

16. Zintzen V, Anderson MJ, Roberts CD, Harvey ES, Stewart AL, Struthers CD. Diversity and composition of demersal fishes along a depth gradient assessed by baited remote underwater stereo-video. PLoS ONE. 2012;7:e48522. http://dx.doi.org/10.1371/journal.pone.0048522

17. Harvey ES, Shortis M. A system for stereo-video measurement of sub-tidal organisms. J Mar Tech Soc. 1995;29:10–22.

18. Watson DL, Harvey ES, Anderson MJ, Kendrick GA. A comparison of temperate reef fish assemblages recorded by three underwater stereo-video techniques. Mar Biol. 2005;148:415–425. http://dx.doi.org/10.1007/s00227-005-0090-6

19. Langlois TJ, Harvey ES, Fitzpatrick B, Meeuwig JJ, Shedrawi G, Watson DL. Cost-efficient sampling of fish assemblages: Comparison of baited video stations and diver video transects. Aquat Biol. 2010;9:155–168. http://dx.doi.org/10.3354/ab00235

20. McLean DL, Harvey ES, Meeuwig JJ. Declines in the abundance of coral trout (*Plectropomus leopardus*) in areas closed to fishing at the Houtman Abrolhos Islands, Western Australia. J Exp Mar Biol Ecol. 2011;406:71–78. http://dx.doi.org/10.1016/j.jembe.2011.06.009

21. Fitzpatrick BM, Harvey ES, Heyward AJ, Twiggs EJ, Colquhoun J. Habitat specialization in tropical continental shelf demersal fish assemblages. PLoS ONE. 2012;7:e39634. http://dx.doi.org/10.1371/journal.pone.0039634

22. Francour P, Liret C, Harvey ES. Comparison of fish abundance estimates made by remote underwater video and visual census. Naturalista Siciliana. 1999;XXIII(suppl):155–168.

23. Willis TJ, Babcock RC. A baited underwater video system for the determination of relative density of carnivorous reef fish. Mar Freshwater Res. 2000;51:755–763. http://dx.doi.org/10.1071/MF00010

24. Harvey ES, Fletcher D, Shortis M. Estimation of reef fish length by divers and by stereo-video: A first comparison of the accuracy and precision in the field on living fish under operational conditions. Fish Res. 2002;57:255–265. http://dx.doi.org/10.1016/S0165-7836(01)00356-3

25. Cappo M, Speare P, De'ath G. Comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park. J Exp Mar Biol Ecol. 2004;302:123–152. http://dx.doi.org/10.1016/j.jembe.2003.10.006

26. Pelletier D, Leleu K, Mallet D, Mou-Tham G, Hervé G, Boureau M, et al. Remote high-definition rotating video enables fast spatial survey of marine underwater macrofauna and habitats. PLoS ONE. 2012;7:e30536. http://dx.doi.org/10.1371/journal.pone.0030536

27. Santana-Garcon J, Leis JM, Newman SJ, Harvey ES. Presettlement schooling behaviour of a priacanthid, the Purplespotted Bigeye *Priacanthus tayenus* (Priacanthidae: Teleostei). Environ Biol Fishes. 2013;97:277–283. http://dx.doi.org/10.1007/s10641-013-0150-6

28. Dill LM, Dunbrack RL, Major PF. A new stereophotographic technique for analyzing the three-dimensional structure of fish schools. Environ Biol Fishes. 1981;6:7–13. http://dx.doi.org/10.1007/BF00001793

29. Harvey ES, Cappo M, Butler JJ, Hall N, Kendrick GA. Bait attraction affects the performance of remote underwater video stations in assessment of demersal fish community structure. Mar Ecol Prog Ser. 2007;350:245–254. http://dx.doi.org/10.3354/meps07192

30. Watson DL, Harvey ES, Fitzpatrick BM, Langlois TJ, Shedrawi G. Assessing reef fish assemblage structure: How do different stereo-video techniques compare? Mar Biol. 2010;157:1237–1250. http://dx.doi.org/10.1007/s00227-010-1404-x

31. Bernard ATF, Götz A. Bait increases the precision in count data from remote underwater video for most subtidal reef fish in the warm-temperate Agulhas bioregion. Mar Ecol Prog Ser. 2012;471:235–252. http://dx.doi.org/10.3354/meps10039

32. Colton MA, Swearer SE. A comparison of two survey methods: Differences between underwater visual census and baited remote underwater video. Mar Ecol Prog Ser. 2010;400:19–36. http://dx.doi.org/10.3354/meps08377

33. Pelletier D, Leleu K, Mou-Tham G, Guillemot N, Chabanet P. Comparison of visual census and high definition video transects for monitoring coral reef fish assemblages. Fish Res. 2011;107:84–93. http://dx.doi.org/10.1016/j.fishres.2010.10.011

34. Willis TJ, Millar RB, Babcock RC. Detection of spatial variability in relative density of fishes: Comparison of visual census, angling and, baited underwater video. Mar Ecol Prog Ser. 2000;198:249–260. http://dx.doi.org/10.3354/meps198249

35. Priede I, Bagley P, Smith A, Creasey S, Merrett N. Scavenging deep demersal fishes of the Porcupine Seabight, north-east Atlantic: Observations by baited camera, trap and trawl. J Mar Biol Assoc UK. 1994;74:481–498. http://dx.doi.org/10.1017/S0025315400047615

36. Harvey ES, Newman SJ, McLean DL, Cappo M, Meeuwig JJ, Skepper CL. Comparison of the relative efficiencies of stereo-BRUVs and traps for sampling tropical continental shelf demersal fishes. Fish Res. 2012;125–126:108–120. http://dx.doi.org/10.1016/j.fishres.2012.01.026

37. Shortis MR, Ravanbakskh M, Shaifat F, Harvey ES, Mian A, Seager JW, et al. A review of techniques for the identification and measurement of fish in underwater stereo-video image sequences. Proc SPIE. 2013;8791. http://dx.doi.org/10.1117/12.2020941

38. Kerwath SE, Wilke CG, Götz A. The effects of barotrauma on five South African line caught fishes. Afr J Mar Sci. 2013;35:243–252. http://dx.doi.org/10.2989/1814232X.2013.805594

39. Langlois TJ, Fitzpatric BR, Fairclough DV, Wakefield CB, Hesp SA, McLean DL, et al. Similarities between line fishing and baited stereo-video estimations of length-frequency. Novel application of kernel density estimates. PLoS ONE. 2012;7(11):e45973. http://dx.doi.org/10.1371/journal.pone.0045973

40. Shin Y, Rochet M, Jennings S, Field J, Gislason H. Using size-based indicators to evaluate the ecosystem effects of fishing. ICES J Mar Sci. 2005;62:384–396. http://dx.doi.org/10.1016/j.icesjms.2005.01.004

41. Trebilco R, Baum JK, Salomon AK, Dulvy NK. Ecosystem ecology: Size-based constraints on the pyramids of life. Trends Ecol Evol. 2013;28:423–431. http://dx.doi.org/10.1016/j.tree.2013.03.008

42. Harvey ES, Fletcher D, Shortis MR, Kendrick GA. A comparison of underwater visual distance estimates made by SCUBA divers and a stereo-video system: Implications for underwater visual census of reef fish abundance. Mar Freshwater Res. 2004;55:573–580. http://dx.doi.org/10.1071/MF03130

43. De Vos L, Götz A, Winker H, Attwood CG. Optimal BRUVs (baited remote underwater video system) survey design for reef fish monitoring in the Stilbaai Marine Protected Area. Afr J Mar Sci. 2014;36:1–10. http://dx.doi.org/10.2989/1814232X.2013.873739

44. Sanguinetti C. Patterns in reef fish assemblages as determined by baited remote underwater video (BRUV) along the western side of False Bay: effects of site, depth, and protection [MSc thesis]. Cape Town: University of Cape Town; 2013.

45. Bernard ATF. Towards a cost-efficient & standardised monitoring protocol for subtidal reef fish in the Agulhas Ecoregion of South Africa [PhD thesis]. Grahamstown: Rhodes University; 2012.

46. Gray JS. Marine biodiversity: Patterns, threats and conservation needs. Biodivers Conserv. 1997;6:153–175. http://dx.doi.org/10.1023/A:1018335901847

47. Pikitich EK, Santora C, Babcock EA, Bakun A, Bonfil R, Conover DO, et al. Ecosystem-based fishery management. Science. 2004;305:346–347. http://dx.doi.org/10.1126/science.1098222

48. Sink KJ, Holness S, Harris L, Majiedt P, Atkinson L, Robinson T, et al. National biodiversity assessment 2011: Technical report: Volume 4: Marine and Coastal Component. Pretoria: South African National Biodiversity Institute; 2012.

49. Department of Agriculture, Forestry and Fisheries (DAFF). Status of the South African marine fishery resources. Cape Town: Chief Directorate Fisheries Research, Fisheries Branch; 2012.

50. Johnson AF, Jenkins SR, Hiddink JG, Hinz H. Linking temperate demersal fish species to habitat: Scales, patterns and future directions. Fish Fish. 2012;14:256–280. http://dx.doi.org/10.1111/j.1467-2979.2012.00466.x

51. Fletcher WJ, Shaw J, Metcalf SJ, Gaughan DJ. An ecosystem based fisheries management framework: The efficient, regional-level planning tool for management agencies. Mar Policy. 2010;34:1226–1238. http://dx.doi.org/10.1016/j.marpol.2010.04.007

52. Mann BQ. South African marine linefish status reports. Oceanographic Research Institute Special Publication 7. Durban: South African Association for Marine Biological Research; 2000.

53. Mann BQ. South African marine linefish species profiles. Oceanographic Research Institute Special Publication 9. Durban: South African Association for Marine Biological Research; 2013.

54. Collins A, McBride R. Demographics by depth: Spatially explicit life-history dynamics of a protogynous reef fish. Fish Bull. 2011;109:232–242.

55. South African Sustainable Seafood Initiative (SASSI). Consumer seafood pocket guide [document on the Internet]. c2013 [cited 2013 July 01]. Available from: http://www.wwfsassi.co.za/pocketguide.pdf.