Available online at www.sciencedirect.com

ScienceDirect

Journal of Ocean Engineering and Science 1 (2016) 337–353

www.elsevier.com/locate/joes

Original Article

# Installation and operational effects of a HVDC submarine cable in a continental shelf setting: Bass Strait, Australia

John Sherwood[a,*], Scott Chidgey[b], Peter Crockett[b], David Gwyther[c,1], Percival Ho[b], Simon Stewart[e], David Strong[d], Bob Whitely[e], Alan Williams[f]

[a] *School of Life and Environmental Sciences, Deakin University, Warrnambool, Victoria 3280, Australia*
[b] *CEE Consulting, 90 Bridge Road, Richmond, Victoria 3121, Australia*
[c] *Enesar Consulting Pty Ltd, 124 Camberwell Rd, Hawthorn East, Victoria 3123, Australia*
[d] *DSA Consulting, Suite 211, 620 St Kilda Road, Melbourne, Victoria 3004, Australia*
[e] *Coffey Natural Systems Pty Ltd, 126 Trenerry Crescent, Abbotsford, Victoria 3067, Australia*
[f] *Marine Research, CSIRO, Hobart, Tasmania 7000, Australia*

Received 18 May 2016; received in revised form 23 August 2016; accepted 17 October 2016
Available online 5 November 2016

**Abstract**

Despite the many submarine telecommunications and power cables laid world-wide there are fewer than ten published studies of their environmental effects in the refereed literature. This paper describes an investigation into the effects of laying and operating the Basslink High Voltage Direct Current (HVDC) cable and its associated metallic return cable across Bass Strait in South East Australia. Over more than 95% of its length the cable was directly laid into a wet jetted trench given the predominantly soft sediments encountered. Underwater remote video investigations found that within two years all visible evidence of the cable and trench was gone at over a third of the transects at six deep water sites (32–72 m deep). At other deep water transects the residual trench trapped drift material providing habitat for the generally sparsely distributed benthic community. Diver surveys at both of the near shore sites (<15 m deep) on the northern side of the Strait also found the cable route was undetectable after a year. On the southern side, where the cable traversed hard basalt rock near shore, it was encased in a protective cast iron half shell. Ecological studies by divers over 3.5 years demonstrated the colonization of the hard shell by similar species occupying hard substrates elsewhere on the basalt reef. Magnetic field strengths associated with the operating cable were found to be within 0.8% of those predicted from theory with strength dropping rapidly with distance from the cable. Beyond 20 m the field was indistinguishable from background.


*Keywords:* High Voltage Direct Current; Power cable; Magnetic field; Epibenthos; Ecological effects; Video survey.

## 1. Introduction

It was estimated in 2007 that there were ~1 million kilometres of telecommunications cable laid over the sea bed (p29, Carter et al. [6]). While comparable figures for power cables are not available the number of these, as well as their length and capacity is increasing. For example when the Basslink cable was laid in 2005 it was the world's longest High Voltage Direct Current (HVDC) cable. It has now been surpassed by the 580 km Norway – Netherlands system completed in 2008. Improvements in cable design, developments in off-shore energy resources (oil and gas, wind and wave energy) and networked power grids between nations will see further increases in the length of submarine power cables (ICPC [13]).

The environmental effects of submarine cables, and particularly power cables, have been the subject of public concern. Issues include the possible physical and ecological effects of

* Corresponding author. Fax: +61 3 5563 3462.
*E-mail address:* jsher@deakin.edu.au (J. Sherwood).
[1] Present address: Picton Group Pty Ltd, 30 Malpas Drive, Wallington, Victoria 3222, Australia.

http://dx.doi.org/10.1016/j.joes.2016.10.001
2468-0133/

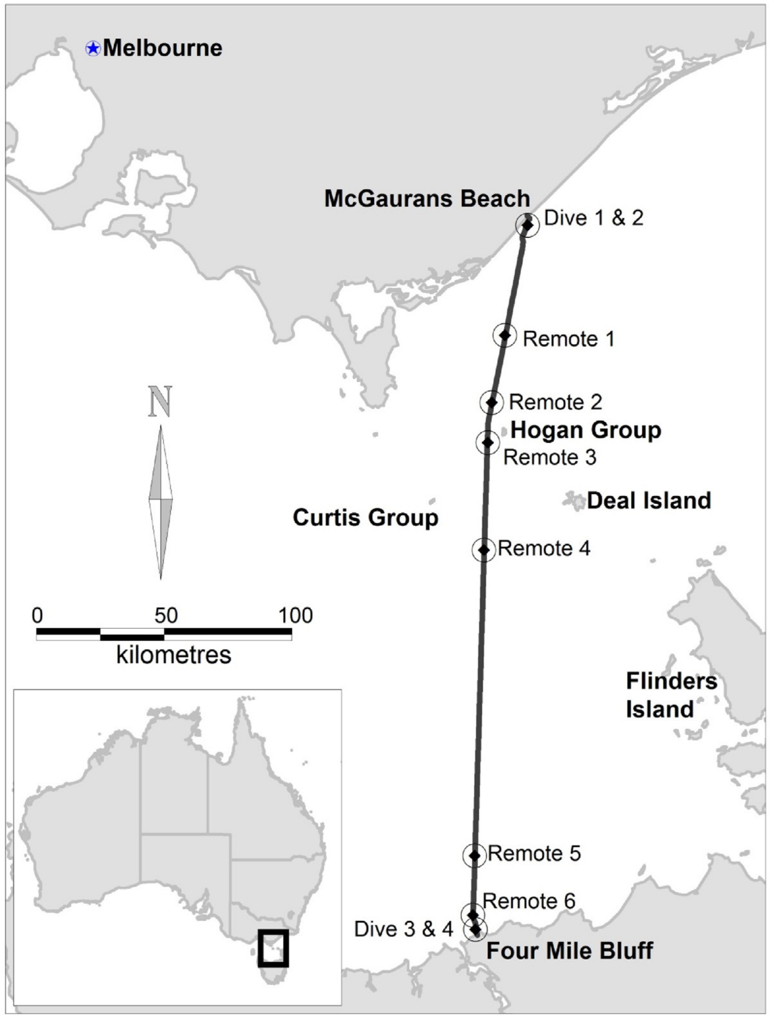



Fig. 1. Cable path showing sample site locations. Inset showing location of Bass Strait, Australia.

cable laying on the seafloor, possible effects of electric and magnetic fields on marine flora and fauna and possible effects on marine infrastructure and navigation (see for example BJAP [2] Dunham [12]). Given this, it is surprising that there are so few (<10) studies on the marine environmental effects of cables in the published 'non-grey' scientific literature see Kogan et al. [18] and Dunham et al. [12].

The present investigation arose from a process by the Tasmanian Government to interconnect the electricity grids of 2 Australian states, Victoria and Tasmania, by running a 290 km submarine HVDC cable across Bass Strait (Fig. 1). An independent Bass Strait Environment Review Committee (BSERC) was established to oversee the monitoring of the environmental effects during the installation and operation of the cable.

A marine monitoring project was designed by the BSERC to inform the assessment of the following predictions made during the environmental approvals process:

1. The species of epibiota that colonise the disturbed area over the cable are the same as those occurring in the adjacent, undisturbed habitats.
2. Within two years, the epibiota that colonise the disturbed area have a composition and area of coverage similar to that of the adjacent areas.
3. The magnetic fields and induced electric fields resulting from the cable during operation reflect predicted field strengths.

Prediction 2 is based on the premise that any on-going effects of the cable operation will have manifested themselves within two years.

We report here the findings of investigations assessing these predictions, including one of the few published in-situ measurements of magnetic fields associated with an operating HVDC power cable. Further detail can be found in the various reports submitted to BSERC and/or Basslink (Williams [27]; CEE [7]; Whitehead [26]; CNS [11]; Strong [23]; Chidgey et al. [9]).

## 2. Methodology

### 2.1. Bass Strait environment and cable alignment

Bass Strait is an area of the continental shelf between the Australian states of Victoria and Tasmania. It is aligned east-west centred along latitude 40°S and measures approximately 250 km from the Victorian coast to the Tasmanian coast (Fig. 1). Much of the central basin of Bass Strait comprises relatively featureless flat, soft seabed with a maximum water depth of approximately 80 m. Island chains associated with King Island in the west and Flinders Island in the east are associated with shallow sills (<50 m deep) that lay across its entrances (Jennings [17])The continental slope extends to depths greater than 1000 m in the Southern Ocean and Tasman Sea west and east of Bass Strait, respectively.

Offshore oil and gas resources have been exploited in the northwest and northeast of the Strait since 1965, and most recently in central Bass Strait. The Strait supports commercial scallop, school and gummy shark, abalone, rock lobster and trawl fisheries as well as recreational fisheries. Most of these natural values are found around the perimeter of the central basin and in the northeast of the Strait. The Bass Strait islands are important refuges and breeding sites for the Australian fur seal (*Arctocephalus pusillus doriferus*) and seabirds including the mutton bird (*Puffinus tenuirostris*) and little penguin (*Eudyptula minor*). The Strait is a migration pathway for cetaceans including the southern right whale (*Eubalaena australis*), humpback whale (*Megaptera novaeangliae*) and pygmy blue whale (*Balaenoptera musculus brevicauda*). It is one of Australia's busiest shipping routes (Larcombe et al. [19]; NOO, [21]).

The Basslink cable is a bundle containing three individual cables – a HVDC cable, a metallic return cable and a fibre optic cable. The HVDC cable and return cable are not concentric. There is thus a residual magnetic field because the cable centres are separated by 14 cm. The Basslink cable bundle was laid in 3 sections commencing in May 2004. Construction was completed in November 2005 and the cable commenced commercial service on 28 April 2006. It can carry a maximum current of 1500 Amperes at a power of 600 MW.

Key criteria for selecting the marine alignment of the Basslink cable included: minimising cable length; using efficient and simple installation methods, and; minimising environmental effects. The shoreline landing points of the cable (and hence minimum cable length) were determined practically by proximity to existing major electricity generating infrastructure in Victoria and Tasmania. Shoreline crossing points were at McGauran's Beach in south eastern Victoria and Four Mile Bluff in north eastern Tasmania (Fig. 1).

The route for the cable between the two shoreline connection points was selected from pre-construction geophysical surveys. It avoids rocky outcrops including the reefs and islands north of Flinders Island and then traverses the relatively uniform seabed of the central basin of Bass Strait along the shortest route. As a consequence, the chosen alignment had four benefits. It:

- avoided most high environmental value areas (high biodiversity associated with rocky reefs, reef fisheries, and most trawl fisheries and scallop fisheries);
- crossed mostly soft deeper sediment habitats that are widely represented in Bass Strait and characterised by low biodiversity values (Butler et al [5]);
- minimised the need to excavate or flatten any irregular rocky seabed, and;

allowed the cable to be buried using horizontal directional drilling (HDD) at both shoreline crossings and by relatively simple jetting techniques along the entire alignment from the HDD emergence in Victoria almost to the Tasmanian coast. The alignment closer to the Tasmanian coast could not avoid areas of reef and cobble and was the only part of the cable alignment that was not located on predominantly soft sediments. The final alignment across this area was carefully selected to follow a path of low relief cobble between areas of bedrock reef. The cable was laid over the cobble seabed and protected with a cast iron half shell before submerging below the sandy seabed near the HDD shoreline crossing to Tasmania. This process avoided potential environmental stressors associated with excavation in rock reef. These included removal of reef habitat and associated biota; noise from excavation in rock; use of explosives; introduction of other foreign material such as concrete, ballast or rock armouring.

### 2.2. Ecological assessment of epibenthos

The aim of the monitoring program was to assess the effect of cable installation on a variety of the epibenthic communities that might occur along the cable route. The nature of marine epibenthic communities along the route were not specifically described prior to the commencement of monitoring.

#### 2.2.1. Monitoring sites

Preconstruction geophysical surveys and underwater video taken during installation of the cable revealed seabed characteristics. The majority of the alignment was predominantly soft sediments of varying coarseness and shell content, with some areas of consolidation near the seabed surface.

The locations of monitoring sites were selected to represent different combinations of environmental factors that could result in naturally different characteristics of benthic epibiota along the cable route.

Three habitat surrogates were employed to select representative sites for ecological investigation – sediment type, depth and the Interim Marine and Coastal Regionalisation classification (IMCRA). The three data sets are:

1. *Sediment type*: Geoscience Australia has processed sediment data from auSEABED (Jenkins, [16]) and this was compared to the Basslink seabed classification obtained during survey of the proposed cable route. Bedrock, cemented (consolidated) sediments and coarse sediments provide attachment sites for epibiota and are frequently characterised by a greater diversity and higher abundance of epibiota. While the cable path was carefully chosen to maximise intersection of softer sediments, bedrock had

Table 1
Characteristics of sample locations along the cable path.

| Site | Distance (km)[a] | Depth (m) | IMCRA Zone | Sediment | Time[b] (months) |
|---|---|---|---|---|---|
| Dive 1 | 1 | 10 | | Sand | 11, 20 |
| Dive 2 | 5 | 15 | | Cemented sediment, sand | 11, 20 |
| Remote 1 | 48–52 | 46–52 | Twofold Shelf | Shell rubble, shell grit | 19 |
| Remote 2 | 74–78 | 55–58 | Twofold Shelf | Coarse sand, shell rubble and shell grit | 19 |
| Remote 3 | 90–94 | 72 | Flinders | Coarse sand, shell rubble | 19 |
| Remote 4 | 134–138 | 65–66 | Flinders | Fine silt, sand, shell | 12 |
| Remote 5 | 252–256 | 46–52 | Central Bass Strait | Silt and some shell | 7 |
| Remote 6 | 282–284 | 32–43 | Boags | Medium to coarse sand | 7 |
| Dive 3 and 4 | 288–289 | 14–16 | | Bedrock, rubble, sand | 7, 19, 45 |

[a] Along the cable from the Victorian coast.
[b] Time elapsed between cable section being laid and video survey(s).

to be traversed in Tasmanian waters. Cemented sediments were crossed at three sites within 100 km of the Victorian coast. Coarse sand and gravel sediments were also intersected in places.

2. *Depth*: used because of the strong relationship of biotic composition to depth. Analysis of epibiota in eastern Bass Strait (Bax and Williams [3], Bax and Williams [4], Williams and Bax [28]) showed patterns of distribution which were strongly correlated with depth. Noticeable differences were observed in biological communities between the inner shelf zone (sites in 25 and 40 m depths) and the outer shelf zone (80 and 120 m). Depth can also act as a surrogate for other environmental factors that may vary along the cable alignment including wave energy and turbulence, water temperature, ocean currents and light climate. Thus, within each range, similar substrata can be assumed to support similar biota and be combined. While the boundary between zones is not precisely defined in nature, the depth range traversed by the cable route covers the two depth zones.
3. *Interim Marine and Coastal Regionalisation (IMCRA) classification*: an integrated biophysical classification that summarises biological distributions as 'bioregions' on the continental shelf at meso-scales (IMCRA Technical Group [14]). Four IMCRA mesoscale bioregions ('Twofold Shelf', 'Flinders', 'Central Bass Strait' and 'Boags') are crossed by the cable route.

Based on these habitat surrogates six deep water (32–72 m) sites were selected (Table 1; the remote sites of Fig. 1). For all surveys Basslink supplied co-ordinates defining the cable position as laid.

### 2.2.2. Monitoring methods

Survey methods were developed that recognised the nature of the likely seabed biological communities, the practicalities of surveying epibiota over a range of water depths and the difficulty in detecting the exact position of the buried cable at any particular location. Two survey methods were chosen.

(1) In depths <20m: diver operated quantitative video recording on sections of the cable crossing at two near shore dive locations in Victoria (1 and 5 km offshore) and Tasmania (within 1.5 km of the shore).
(2) In water depths from 32 to 72 m: towed remote video recording on sections of the buried cable in soft or consolidated sediments.

*2.2.2.1. Diver-based survey methods.* The effects of the installation of the cable on the seabed habitat and epibiota were predicted to be a temporary disturbance of soft sediments and a localised effect on hard seabed. Using video a comparison was made of ecosystem conditions directly along the cable alignment with conditions on parallel transects 10 and 50 m to one side of the cable.

The position of the cable was accurately plotted at 1 m intervals during installation. However, the cable was installed in mobile sands in the near shore area in Victoria leaving no visible indication of its presence in some surveys. Hence, a custom-marinised Sony SD CCTV with real time output to a video screen on the boat was towed across the known positions of the cable at Victorian sites to determine whether or not the cable or trench was visible. Where the cable alignment was not visible, the transect (tape) was laid from the survey boat using GPS positions provided for the alignment. Where the residual trench in the sediment was still visible, divers entered the water and laid a 200 m transect marked at 5 m intervals along the cable alignment. Divers relocated the transect to 10 m parallel to the cable after the first video had been recorded. The third transect 50 m parallel to the cable alignment was laid from the survey boat using GPS to position the transect.

At the Tasmanian site the cable was clearly visible from its protective half-shell cover. Two sets of replicate 200 m transects were placed along and adjacent to the armoured cable in approximately 14 m to 16 m water depth (dive sites 3 and 4 in Fig. 1). Replicates of each transect (i.e., 0, 10 m or 50 m) were linearly aligned and separated by 50 m due to the narrowness of the reef (~500 m). The characteristics of the seabed and associated epibiota along the transects were recorded using a diver-operated Sony 3CCD colour video camera in a Amphibico waterproof housing. The camera had a colour compensated wide angle lens that was held 50 cm above the seafloor and pointed vertically downwards as the diver swam at approximately 30 cm.s$^{-1}$ along each transect.

Near-shore field surveys were undertaken by divers in June 2005 (Victorian dive sites 1 and 2; during cable laying) February and March 2006 (Tasmanian dive sites 3 and 4 and dive sites 1 and 2; after cable completion but before commercial service) February 2007 (dive sites 3 and 4; when the cable was in commercial service) and April 2009 (dive sites 3 and 4; when the cable was in commercial service).

*2.2.2.2. Remote towed video surveys.* Remote sites were surveyed once during February and March 2006. At each of the six remote locations, three sets of four tows were completed perpendicular to the cable alignment. Within each set of 4 tows transects were separated by ~100 m with 2 km separating successive sets. A total of 72 towed video transects was obtained for the remote sites.

The procedure for videoing the seabed at each transects was:

- At approximately 200 m up-drift of the cable the towed CCTV camera was lowered to the seabed
- During the tow along a drift path and videoing, vessel position (by DGPS), camera cable length and angle were recorded.
- The camera was retrieved 100 m after the cable trench had been crossed or the vessel was at least 100 m past the cable position supplied by Basslink.

The general approach to towed video was to maintain the towing vessel at a slow enough speed to maintain the video camera and lights cradle on or close to the seabed and at a slow enough speed to allow reasonable resolution of epibiota on the seabed. A speed of approximately 1 knot (0.5 m.s$^{-1}$) was achieved by controlling the direction and rate of drift of the vessel with respect to local oceanographic currents and prevailing wind and sea conditions.

### *2.2.3. Post survey data treatment*

Three video analysis techniques were used for the diver operated video transect records: qualitative characterisation of seabed habitat and associated biota; counts of sparse biota on sand, and; abundance and diversity estimates of biota on hard seabed.

Video records were compiled into location, group, site and transect. Durations of each transect record were noted for cross referencing with GPS records. The records were initially analysed to determine the:

- extent and nature of the physical impact of the cable installation on the seabed
- qualitative extent and nature of the impact of the cable installation on seabed biological assemblages
- suitability of the video records for quantitative analysis of the extent and nature of the impact of the cable on seabed biological assemblages by quantifying the abundance of organisms within still frames.

Qualitative observations and descriptions, derived from viewing the video footage, were prepared for each site surveyed using the remote video technique. Where densities of epibiota were sufficient for quantitative analysis (only the Tasmanian diver transects) the video records were analysed for the occurrence of taxonomic groups under 250 systematically dispersed point intercepts along each site transect. This form of sampling generally follows that used for the long term monitoring of the Great Barrier Reef (Sweatman et al. [24])

The process for quantitative analysis of the video record was:

- Each of the video transects was screened and the time-clock intervals of the transect ends logged.
- Fifty equally spaced time sample points from the total transect clock-time were calculated.
- Five dots were placed on a video screen as point intercepts.
- The tape was advanced to each predetermined clock-time sample point and the tape paused.
- At each time point, the biological taxa and/or seabed category under each of the five intercept points was logged from the paused digital image. This generally had better quality than a grabbed image (at least 72dpi).

To investigate variability along transects the biological taxa and seabed categories were compiled into 40 m lengths. Data from the two dive sites (i.e., 3 and 4) were combined for each of the cable, 10 m and 50 m transects. Each 40 m subset was thus based on ten sample points (five from each replicate).Means and standard deviations for abundance of the key taxa or seabed categories were determined for each 40 m subset.

Distribution of common seabed and biological categories were compared for each survey using one-way analysis of variance (ANOVA) on untransformed data using the SPSS Package. Differences were assessed at the 95% confidence level.

A total of 34 seabed and biological groups were distinguished as categories and quantified from the video records. The most common categories were erect red algae, including foliose and filamentous varieties, coralline encrusting red algae, turfing algae, brown algae (such as *Dictyotales* and *Acrocarpia* sp.) and various small encrusting invertebrates. A mixture of sediment and various indistinguishable biota (living and dead filamentous algae and invertebrates) was also common on the rock and rubble and was termed ‘matrix’ for the purpose of a category description. These six categories formed the basis of statistical analysis because of their greater abundance. Other categories were present in low abundance or patchy distribution resulting in total abundances of less than 1% and were not individually analysed (Table 2).

The field of view of the video camera (approximately 1 m width) along the cable transect included both the cable itself and the surrounding seabed. The cable occupied between 20% and 30% of each image analysed, with the natural seabed accounting for the remaining area of the image. The data from

Table 2
Biological video imagery categories and their relative abundance at Tasmanian near shore dive sites.

| Category | Percent Abundance* |
|---|---|
| Foliose Red Algae | 24 |
| Coralline Encrusting Algae | 17 |
| Red Turf | 12 |
| Unidentified Biota (matrix) | 11 |
| Filamentous Red Algae | 9 |
| Mixed Turf | 5 |
| Brown algae-*Dictyotales* sp. | 4 |
| *Thamnoclonium* sp. | 1 |
| *Acrocarpia* sp. | 0.8 |
| Brown algae - non-*Ecklonia* kelp | 0.8 |
| Encrusting sponge | 0.7 |
| *Caulerpa* sp. | 0.7 |
| Soft Coral | 0.5 |
| *Ecklonia radiata* | 0.5 |
| Brown algae – *Fucales* sp. | 0.5 |
| *Tryphyllozoan moniliferum* | 0.4 |
| Erect coralline algae | 0.4 |
| Massive sponge | 0.3 |
| Solitary Sponge | 0.3 |
| *Codium* sp. | 0.3 |
| Solitary Ascidian | 0.3 |
| Cup Sponge | 0.2 |
| Plate Sponge | 0.1 |
| Papillate Sponge | 0.1 |
| Flabellate Sponge | 0.1 |
| Sea Urchin | 0.1 |
| *Codium pommoides* | 0.1 |
| Echinoid (Sea star) | 0.03 |

* Barren substrate constituted 9.8% of the imagery

the cable transects therefore is a composite of both habitat types.

A different method was used to assess the abundance of the sea urchin *Heliocidaris erythrogramma* during the April 2009 survey. The number of urchins were counted in the video footage along each transect. Along the cable conduit, urchins were counted separately if they were visible under the cable conduit or visible on the seabed alongside it. Along the 10 m and 50 m east locations all visible urchins were counted.

In addition to quantitative analysis of the abundance of biological categories, the abundance of different seabed types was also determined from the video record. The seabed types present along the transects at each location were classified as:

- Bedrock/boulder reef
- Cobbles
- Bedrock with cobbles
- Rock with sand
- Cobbles with sand

### 2.3. Magnetic field measurement

#### 2.3.1. Field survey

The magnetic field surveys took approximately 2 h on 11 June 2006 when power was flowing from Tasmania to Victoria. During this time the operating power of the cable varied irregularly between 121 MW and 237 MW as current fluctuated under a constant 400 kV. This was significantly below the maximum operating power (600 MW). Each magnetic profile run took 10 min or less and the power operating at the time of each run was later identified from data supplied by Basslink.

As the natural earth's magnetic field varies diurnally due to the level of solar plasma entering the ionosphere it was necessary to correct with respect to time for these natural occurrences. This was achieved by monitoring with a fixed a land-base station magnetometer. This recorded the external magnetic field variations at 10 s intervals throughout the duration of the marine magnetic tests.

Marine magnetic data were acquired along 3 sets of crossings of the cable on the Tasmanian side of the Strait using a towed magnetometer. Each set involved multiple passes in each direction at different magnetometer sensor elevations above the seafloor. The crossing sets were separated by 100–200 m and each involved elevations of 5, 10, 15 and 20 m above the sea floor. Due to the potential to damage the instrument from sea floor impacts it was decided not to attempt measurements at lower elevations above the seafloor. Vessel position was determined using a sub-metre grade DGPS MAX receiver utilising two marine beacon reference stations. During operations a vessel speed of about 2-3 knots was maintained. This gave a magnetic measurement interval of about 0.15 m along the vessel track. Surveys were conducted when swell was $\leq$1 m.

A high resolution Caesium vapour fast sampling (10 Hz) marine magnetometer from Geometrics Inc. (Model G- 882) was used for the magnetic measurements. This instrument directly measured the magnitude of the total magnetic field. It was equipped with an altimeter to monitor elevation above the sea floor and with depth transducers to allow real-time monitoring and control of the underwater sensor position during field operations.

#### 2.3.2. Post survey data treatment

The raw magnetic field measurements required some additional processing. Initially, vessel track-plot and DGPS position information were integrated with the magnetometer data using navigation reduction software. Pre-processing software was used to import the base station data and apply diurnal corrections due to solar activity to the survey data prior to standard filtering processes that included:

(a) Filtering position and magnetics data with spline and range despiking.
(b) Repositioning data, smoothing GPS, re-interpolation of positions.
(c) Gridding and de-striping to eliminate heading errors associated with survey direction.
(d) Output to display software, for input into presentation and analysis software.

Magnetic field strength data for each crossing was standardised:

- taking into account any diurnal corrections from the base station magnetometer,
- after application of a background level of 61.6 microTesla (μT) for the Earth's magnetic field,
- based on the maximum power load (237MW) during field operations (different power levels operated for each survey), and
- for a fixed crossing orientation (line direction) to the cable alignment (337°) as drift paths differed slightly).

To adjust the magnetic fields for each crossing to the same current (i.e. 592.5 Amperes at 237 MW) theoretical calculations of magnetic field for the actual current and 592.5 Amperes were divided to get a correction factor. This was then applied to the measured magnetic fields to give an adjusted field strength at 237 MW.

The standardisation calculations have resulted in small differences (≤0.5μT) in background magnetic field levels between the measured and tabulated data.

Fig. 2. Cable trench in cemented sediment at dive site 2 in June 2005, approximately 12 months after cable laying. The linear feature in the trench is a measuring tape (Photo: CEE Consulting).

## 3. Results and discussion

### 3.1. Physical impact of cable laying

Cable laying commenced on the Victorian side of the Strait. The first 100 km was emplaced between May and July 2004, the second between February and March 2005 and the final length between June and July 2005. Because the cable was laid in three sections between May 2004 and July 2005 the various video surveys occurred at different times after cable emplacement. Time elapsed between cable emplacement and survey is shown for each site in parentheses in the following discussion and in Table 1.

Within 2 years (i.e. post the first cable laying May–July 2004) there was no surface trace of the cable at the two near shore dive sites in Victoria. The seabed at both had returned to the natural condition of medium grained sand. At dive site 1 the cable was not visible in either the first or second survey (i.e. June 2005 (+11 months) or March 2006 (+20 months)). At dive site 2 a rocky trench visible in 2005 (Fig. 2) was covered by sand in 2006. Strong currents (up to 1 $m.s^{-1}$) along the Victorian coast result in megaripples (James and Bone [15], p. 181) and substantial longshore drift. Estimated gross sand drift at Lakes Entrance, ∼10 km NE of the cable is >100,000$m^3.a^{-1}$ (Martin [20]). This sand movement likely resulted in relatively rapid burial of the trench.

On the Tasmanian side the cable path was obvious due to the cast iron half shell sitting on cobble over bedrock.

The cable trench was visible to varying degrees at the remote video survey sites in February 2006 (Fig. 3):

- Remote site 1 (+19 months): The cable trench was visible as a sharp or shallow depression depending on the nature of the seabed at the site. The seabed was mostly covered with shell rubble and shell grit. The trench edges and depressions were slightly elevated and comprised of broken rock and fine sand, respectively. Disturbed seabed was visible within ∼1.5 m of the trench.
- Remote site 2 (+19 months): There was a mound of material approximately 40 cm high extending to approximately 1.5 m either side of the trench. The seabed immediately beyond the mound appeared similar to that elsewhere along the transects.
- Remote site 3 (+19 months): A trench was not visible in any of the 3 sets of transects (located approximately 2 km apart).
- Remote site 4 (+12 months): The cable alignment was evident on nine of the twelve transects as a relatively indistinct shallow depression in the soft seabed.
- Remote site 5 (+7 months): The alignment of the cable was identifiable as a shallow depression containing drift biota and adjacent low mounds of sediment to a distance approximately 1.5 m either side of the trench.
- Remote site 6 (+7 months): The cable trench was visible on three of the twelve transects as a shallow depression with accumulated drift material. There was no visible disturbance to the seabed on other transects.

Filling of the trench was evident at sites 4 and 6 within one year of cable emplacement with no visual indication of the presence of the cable trench on one or more of the 12 transects. After 19 months all surface trace of the cable was gone at Site 3. At other transects the presence of the cable trench was obvious as a localised (< ∼4 m wide) area of disturbance to the surrounding habitat. The nature of the disturbance was related to the seabed composition at the location. At all sites the undisturbed seabed was relatively flat to undulating with no major rock outcrops or reefs. In harder seabed, a distinct vertical walled trench was visible with a narrow strip of broken rock along the sides of the trench to approximately 1.5 m either side. In softer seabed, the trench where present, was observed as a shallow depression with slight mounds of fine

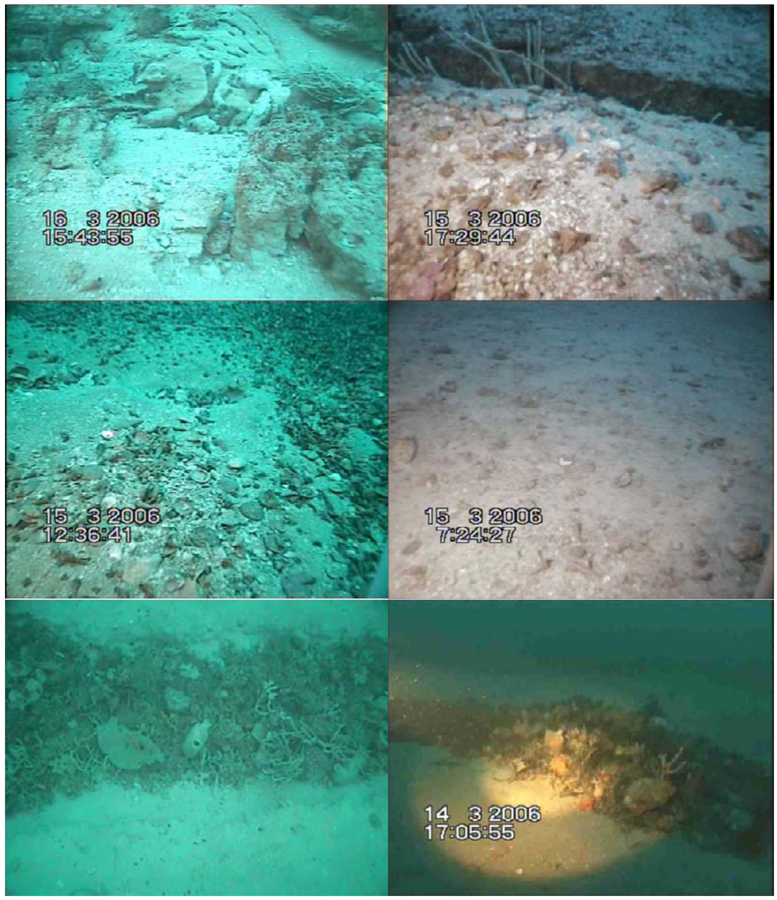



Fig. 3. Video screen images of the cable alignment from the remote sites. Images are: top row -site 1 (left); site 2 (right) middle row- site 3(left); site 4 (right) bottom row – site 5 (left) and site 6 (right) The cable trench is visible for the transects of sites 2, 5 and 6(Images: CEE Consulting).

material spreading to approximately 1.5 m either side of the trench. In both seabed types the total area disturbed was less than 4 m wide.

### *3.2. Observations of epi-biota at Victorian near shore dive sites 1 and 2*

During the June 2005 and March 2006 surveys no sedentary epibiota were visible on the sandy seabed at dive site 1. At dive site 2 in June 2005 swimming anemones (*Phlyctenactis tuberculosa*) were attached to rock associated with the trench (Fig. 2). In March 2006 the trench was covered with sand and epibiota were very sparse with the soft coral *Pseudogorgia godffreyi* and the starfish *Luida australiae* observed in very low numbers. Statistical analysis of the video records was not undertaken because of the low numbers of epibiota.

### *3.3. Observations of epi-biota at remote sites*

Video records from transects (Fig. 3) revealed sparsely distributed epibiota at remote sites:

- Remote site 1: Epibiota consisted of very small sea urchins (which were difficult to detect amongst the shell rubble) and individual sponges. The trench depression had accumulated drift material including invertebrates (urchins and sponges).
- Remote Site 2: Very small sea urchins and individual sponges were identified. The trench contained sponges and drift material. It could not be determined whether the sponges were living or drifted debris.
- Remote Site 3: Dead mollusc shell and rubble scattered across the seabed made it difficult to distinguish epibiota.
- Remote Site 4: The cable alignment was marked by a shallow depression in which small sponges appeared to have drifted. Benthos was rare on the surrounding seafloor.
- Remote Site 5: Epibiota comprised sparsely scattered, small bundles of mixed sponges. The shallow depression above the cable contained drift biota comprising mixed small sponges. Other biota, including solitary ascidians and sea stars appeared to have colonised the loose material in the trench. The mounds on either side of the trench were bare of biota.
- Remote Site 6: Sparsely scattered sponges and green algae (*Caulerpa*) were present. The cable trench was visible on some transects in some places as a shallow depression with accumulated drift material. Drift material in the trench included sponges, ascidians and algae. Some of the biota appeared to have become established and were

actively growing on material in the trench. The biota in the trench were distinct from those of the surrounding seabed, i.e., the difference in biological assemblage was due to the physical presence of the trench.

Epibiota on the deeper seabed sites of Bass Strait (>30 m) were sparse, which is typical of deeper soft seabed habitats of central Bass Strait (Chidgey [8]). There were insufficient numbers of epibiota to justify statistical comparison of affected and non-affected parts of the transects. There were visible physical differences between the cable trench area and the surrounding unaffected seabed at many sites. The change in physical habitat was easy to detect, so use of habitat as a secondary indicator of potential biological effect was considered a more sensitive indicator than biological abundance in this environment.

Biological effects of the installation of the cable in the deeper waters of Bass Strait can be summarised as:

- Habitat modification where a trench was still present.
- Accumulation of drift biological material within the shallow depression where the presence of the cable trench was still detectable.
- Growth of some epibenthic species on the biological material accumulating in the trench.

Accumulation and possibly slumping of sediment in the low energy cable trench environment had already removed all evidence of it along some transects within 12 months. This process will be on-going and so these biological effects are expected to be ephemeral as sedimentation infills the remaining depressions.

### *3.4. Tasmanian near shore dive sites 3 and 4*

In contrast to the other sites along the alignment, the short (~500 m) rubble and reef habitat traversed by the cable between 800 m and 1300 m offshore was characterised by a relatively rich ecological community of macroalgae and invertebrates. Data from transects at this site were analysed in greater detail.

#### *3.4.1. Qualitative observations of epibiota*

*3.4.1.1. February 2006 Survey (+7months).* The divers observed no visible differences in the general nature of the assemblages close to the cable compared to those of the transects 10 and 50 m from the alignment during the February 2006 survey. The half-shell did not appear to have physically affected the seabed except for the immediate substratum that it covered when laid 7 months previously. There was no growth on the cast iron conduit. Various fish including southern hula fish (*Trachinops caudimaculatus*) and long snout boarfish (*Pentaceropsis recurvirostris*) were observed close to the cable. There was biological growth including sponges and algae on the rubble and rock within centimetres of the perimeter of the conduit. Large long-lived invertebrate species such as sponges had persisted along the cable alignment.

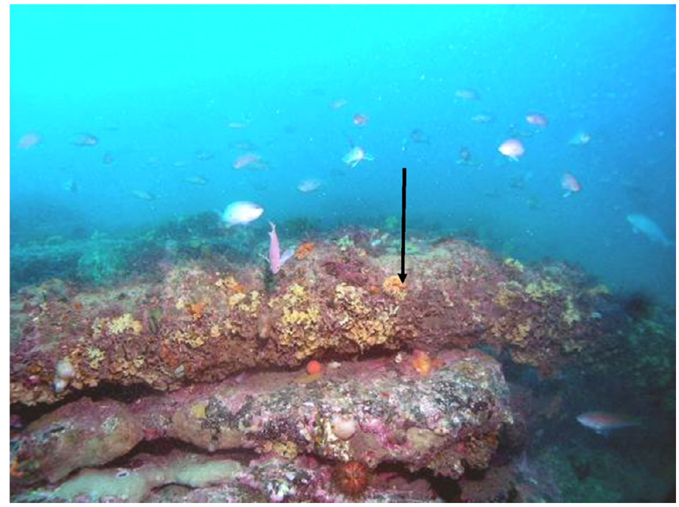


Fig. 4. Video still image of the half shell (arrowed) and its surrounding reef at theTasmanian dive site in April 2009 (Photo: CEE Consultants).

*3.4.1.2. February 2007 survey (+19months).* A range of seaweeds and invertebrates was growing prolifically on the half-shell. Most of the growth on the top of the conduit comprised turfing algae and filamentous and foliose red algae. Invertebrates such as lace bryozoans encrusted the bottom side of the conduit. Biological growth on the conduit comprised species similar to those on natural seabed in the area. There were moderate numbers of the purple sea urchin (*Heliocidaris erythrogramma)* present along the cable alignment.

Various fish were associated with the structure including southern hula fish, leatherjackets (such as rough leatherjacket - *Scobinichthys granulatus*) latchet (*Pterygotrigla polyommata*) perch (*Caesioperca* sp.) and the Victorian scalyfin (*Parma victoriae*). The presence of a diversity of invertebrates on and under the half-shell suggested that the structure had not moved.

*3.4.1.3. April 2009 survey (+45 months).* In April 2009 the cable conduit had been in place for approximately 3 ½ years and epibiota on the cast-iron half shell was well established. The cast-iron conduit provided a stable substrate for growth of marine organisms as demonstrated by the heavy encrustation by algal and invertebrate species (Fig. 4). Algae including turfing species and red, brown and green algae were all common on the conduit's upper surface. Other organisms (such as lace-bryozoans, ascidians and sponges) were largely confined to the underside of the cable. The difference in the epibiota on the conduit is influenced by various physical and ecological factors. The key factors are likely to be:

- The top of the conduit receives direct sunlight and is therefore a more favourable position for marine plants (such as seaweeds) that require light for photosynthesis.
- The underside is less suitable for plants due to the lower light conditions and therefore encrusting organisms which do not require sunlight can successfully survive.

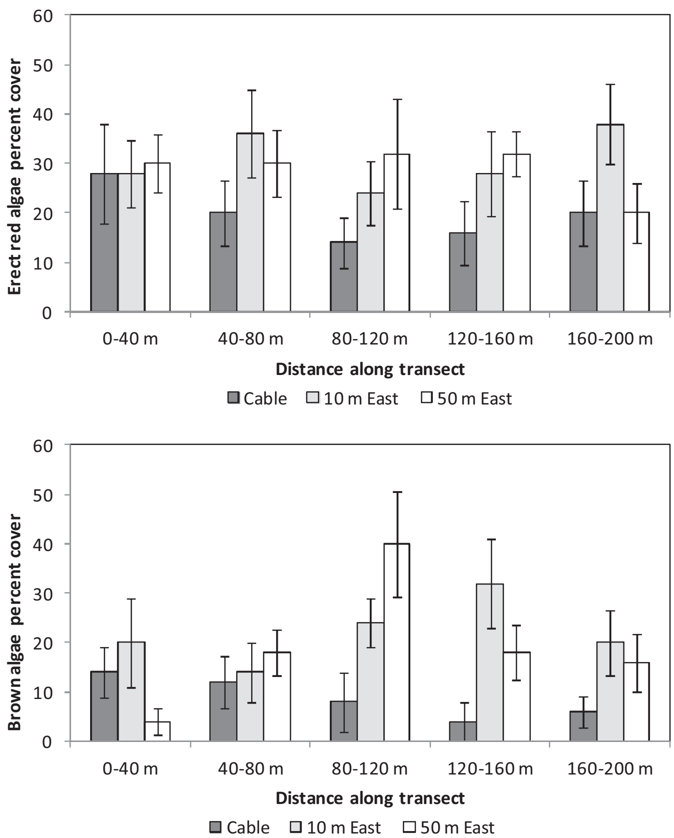



Fig. 5. Average variation of Erect Red (top) and Brown algae (bottom) percentage cover along 200 m transects. Abundances have been grouped in 40 m length intervals. Error bars represent one standard deviation.

- The ‘crevice’ habitat under the conduit may provide protection to some species (such as snails and urchins) that are susceptible to predation from larger species (such as fish).

As in previous surveys a number of fish were associated with the cable. They included the southern hula fish, barber perch (*Caesioperca rasor*) and Victorian scalyfin.

During the April 2009 survey divers noted a narrow strip of seabed along much of the cable where seaweed growth was less abundant than on top of the cable and the seabed near the cable. This strip extended less than half a metre either side of the conduit. Review of the 2009 video footage along the cable alignment revealed that this pattern was also evident along the edges of natural reefs in the area. In both cases, there were large numbers of the purple sea urchin (*H. erythrogramma*) associated with the cable and the natural reef. These urchins are voracious grazers of marine algae on the seabed and they tend to shelter from predators by hiding under suitable rocks. It was concluded that these urchins used the cable as shelter and graze algae on the seabed alongside the cable alignment, producing the strip of lower epibiotic growth.

### 3.4.2. Quantitative analyses

Flora and fauna of the reef was both diverse and abundant. Quantification of the video imagery was undertaken to investigate community composition on and immediately adjacent to the cable compared with the natural seabed 10 and 50 m to its east.

*3.4.2.1. Variability along transects.* The natural seabed at the Tasmanian dive location comprises sand, cobble, boulders and solid bedrock reef. The proportion of these seabed characteristics varied along and between transects. Table 4 shows differences in the proportion of different seabed types along

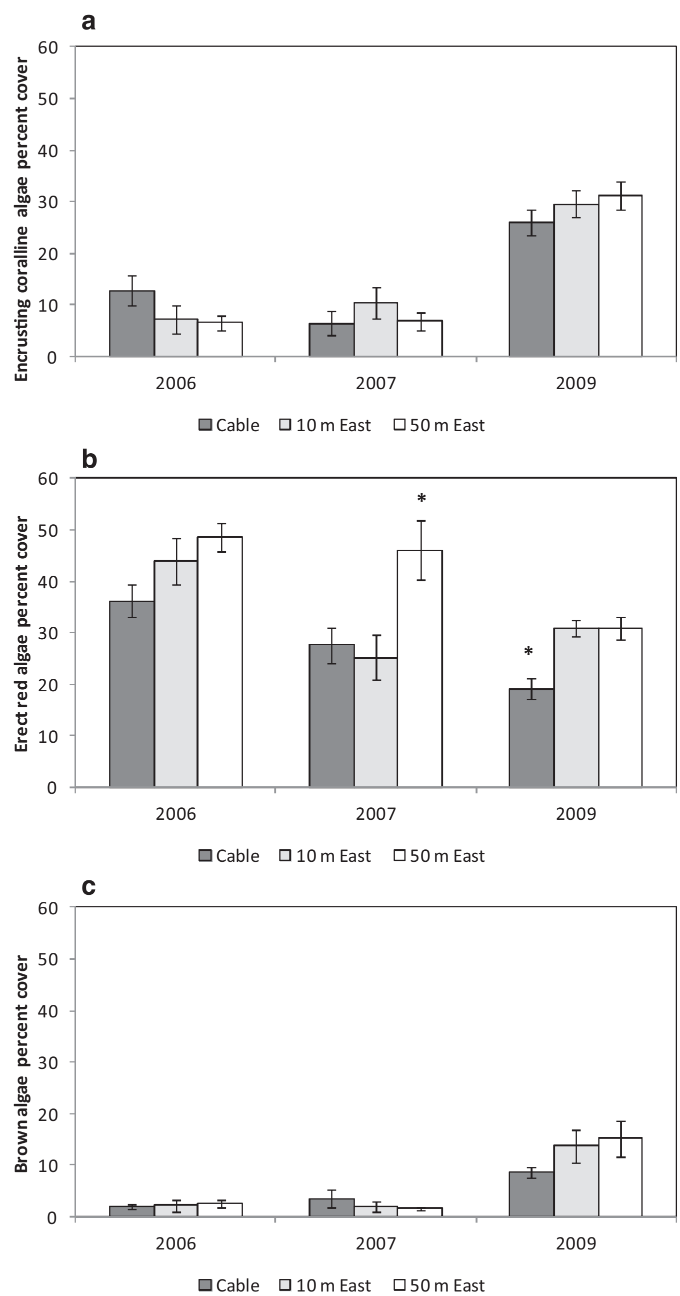
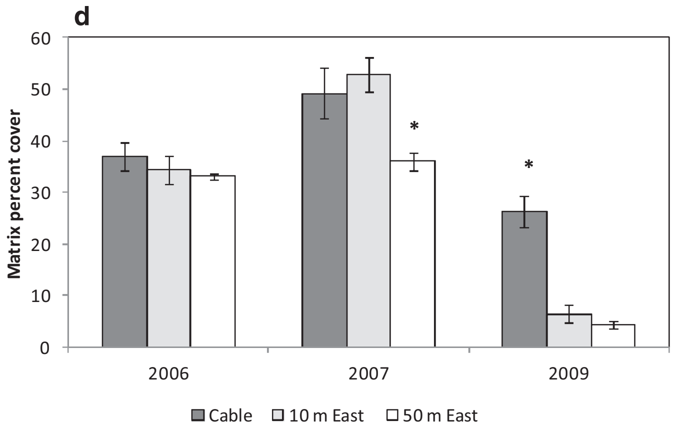



Fig. 6. Relative abundance of various biological categories in video surveys of the near shore Tasmanian site in 2006, 2007 and 2009. From top to bottom the categories are; (a) encrusting coralline algae, (b) red algae (filamentous and foliose) (c)brown algae, (d) matrix and (e) invertebrates. Statistically significant abundances are indicated by asterisks above chart columns.



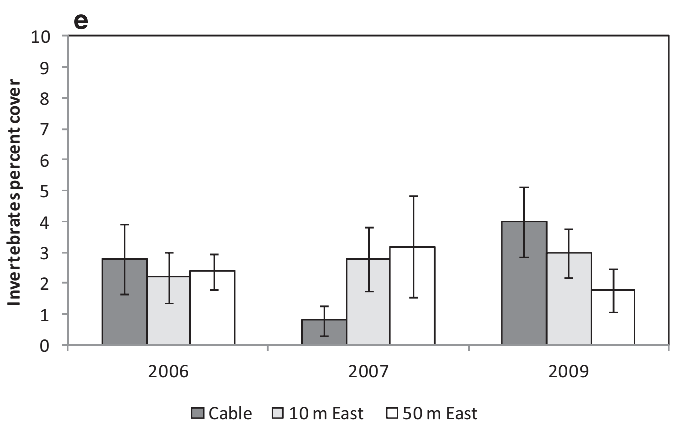




Fig. 6. Continued

the 2009 transects at the cable, 10 m east of the cable and 50 m east of the cable. Rock and cobble comprise over 80% of each transect. The proportions differed slightly from survey to survey. In contrast, the half shell provides a relatively uniform substrate.

Along each transect the abundance of particular taxa was quite variable. For example Fig. 5 shows spatial variability for erect red algae and brown algae with abundance averaged in 40 m blocks. Red algae cover varied from 15% to 39%, brown algae cover from 5% to 40%. Standard deviations ranged from ∼5% cover to ∼10% cover for each category. Benthic macroalgal assemblages and invertebrate assemblages are influenced by physical seabed characteristics and biological interactions. The nature of the seabed (such as its rugosity or 3D complexity) and its stability (ease of mobilisation by waves and erodability) are key factors determining the nature of biological communities on hard seabeds. Biological factors such as shading of small algae by taller species or herbivore abundance may also contribute to the observed variability.

Species assemblages on unstable substrate (cobbles and sand) are likely to be more variable over time (particularly seasonally) due to frequent disturbance resulting in predominantly short life-span epibiota (Chidgey et al. [10]). The cable conduit provides habitat similar in its stability and relief to areas of reef and boulder.

*3.4.2.2. Intra-annual variability among dominant biological categories.* For each survey transect data were combined for each of the dominant biological categories. ANOVA analysis of these data was designed to test for differences between the cable biological populations and those increasingly further away (Fig. 6 and Table 3).

The findings for each biological category were:

(a) The encrusting coralline algae category included various species of calcified red algae, which form encrusting coral-like growth over hard surfaces. They are generally long lived and robust species but may be removed from rock surfaces during storms when cobble is mobilised by waves. Fig. 6a shows the abundance of encrusting coralline algae on each transect, in each survey. The abundance of these algae was consistently high at all transects in April 2009. Within each year, there was no significant difference between the abundance of these algae on each transect (Table 3).

(b) Erect (filamentous and foliose) red algae are the most abundant biological groups on the seabed at the nearshore Tasmanian locations. The ecological and taxonomic distinction between red foliose and red filamentous algae is likely to be minor. The species are intermingled, provide similar biogenic habitat, provide food to similar groups of biota (molluscs and echinoderms) are ephemeral and grow over the same time period (Chidgey et al. [10]). Hence, the abundances of filamentous and foliose groups were combined for the purposes of this analysis. For this group, significant differences were recorded between transects in 2007 and 2009 (Fig. 6b and Table 3). In 2007, the abundance at the 50 m east transect was significantly higher than at the cable and 10 m east transects. In 2009, the 10 m east and 50 m east abundances were significantly higher than the cable transect. In 2006 there was no significant statistical difference across transects.

(c) A wide range of brown algal species were distributed patchily across the seabed on all transects. Brown algae included *Ecklonia radiata* (common kelp), *Sargassum* spp., *Cystophora* spp., *Acrocarpia paniculata,* various *Dictyotales* species, *Xiphophora* sp., *Seirococcus* sp. and *Padina* sp. Brown algal abundance in 2006 and 2007 was low. In all three surveys there were no significant differences between abundances of this group on transects (Fig. 6c and Table 3).

(d) Intermingled small turfing and filamentous algae and unidentifiable invertebrates (including hydroids and tube worms) that form a thin layer over the substrate were pooled as a single 'matrix' category. For this group, significant differences were recorded between transects in 2007 and 2009 (Fig. 6d and Table 3). In 2007, the abundance at the 50 m east transect was significantly lower than the cable and 10 m east transects. In 2009, the 10 m east and 50 m east transects were significantly lower than the cable transect. In 2006 there was no significant statistical difference across the transects. The

Table 3
Analysis of variance (ANOVA) for the abundance of encrusting coralline algae, erect red algae, brown algae, matrix and invertebrates for 3 surveys at the Tasmanian Dive sites 3 and 4. ‘df’ = degrees of freedom for the variables ‘site’ and ‘error’; ‘MS’ = Mean Square; ‘F’ = the F statistic. For the tests of significance confidence levels used are indicated by the asterisks: $^{*}p \le 0.05$, $^{**}p \le 0.01$, $^{***}p \le 0.001$.

| Source of variation | | df | Encrusting coralline algae | | Erect red algae | | Brown algae | | Matrix | | Invertebrates | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | | | MS | F | MS | F | MS | F | MS | F | MS | F |
| 2006 | Site | 2 | 116.93 | 2.00 | 392.93 | 3.18 | 3.73 | 0.14 | 37.73 | 0.49 | 0.93 | 0.12 |
| | Error | 27 | 58.50 | | 123.41 | | 26.67 | | 77.70 | | 7.54 | |
| 2007 | Site | 2 | 24.27 | 0.78 | 647.47 | 6.03* | 22.40 | 0.86 | 391.20 | 5.23* | 8.27 | 1.27 |
| | Error | 12 | 30.93 | | 107.33 | | 26.13 | | 74.80 | | 6.53 | |
| 2009 | Site | 2 | 70.93 | 1.07 | 448.53 | 11.96*** | 483.73 | 1.56 | 1452.13 | 30.62*** | 12.13 | 1.53 |
| | Error | 27 | 66.07 | | 37.51 | | 310.16 | | 47.42 | | 7.91 | |

Table 4
Seabed character along the April 2009 Transects at the Tasmanian dive site. The percentages of various substrate categories are shown for transects alongside and 10 and 50 m distant from the cable.

| | Percentage of Frames Analysed | | |
|---|---|---|---|
| Substrate | Cable | 10 m | 50 m |
| Rock/Boulder | 32 | 41 | 42 |
| Cobble | 55.5 | 44 | 39 |
| Rock and Cobble | 2 | 8 | 15 |
| Rock and Sand | 3 | 4 | 0 |
| Cobble and Sand | 7.5 | 3 | 4 |

pattern of this group is the opposite to the pattern of the erect algae. We attribute this to erect algae obscuring the presence of the lower forms grouped as matrix during periods of high algal abundance.

(e) Permanently attached soft coral, sponge, bryozoan, mollusc, and ascidian species occur sparsely on the seabed in the study area (Table 2). Sponges were the most abundant organisms in this category. They are often large and up to 50 cm high. The abundance of these attached organisms was combined as “Invertebrates” for the purpose of analysis (Fig. 6e). The abundance of this group was low (less than 5% cover). There were no significant differences in attached invertebrate abundance between transects (Table 3).

The data also show that there was large-scale variation between surveys particularly for coralline algae, brown algae and matrix. These variations were consistent across transects. Similar inter-annual variations have been observed in a long-term monitoring program (1989 to 2014) elsewhere on the north coast of Tasmania (Chidgey et al. [10]) and may be attributed to factors such as grazing pressure or storminess unrelated to cable installation.

*3.4.2.3. Sea urchin abundance.* Divers first noted the presence of a grazed strip on the seabed alongside the cable in 2009. It was decided to investigate whether this effect could be attributed to sea urchins. The number of sea urchins was counted from the 2009 video records. Abundance along the cable transect was divided into urchins under the conduit ($N = 119$) and urchins on the natural seabed alongside the conduit ($N = 91$). The abundance along the near cable transects was similar to that of the 50 m transect ($N = 208$), but was almost twice that of the 10 m transect ($N = 127$). These counts underestimate the true abundance of sea urchins which may be present under rocks, alga and half-shell and so are not visible on the video record.

*Heliocidaris erythrogramma* is strongly associated with habitat where it can conceal itself during the day, and tends to aggregate in such areas. The seabed along the cable is predominantly cobble (55%), but this transect had a relatively high abundance of urchins (total 210). The division of the urchin counts into those under the cable and those on the seabed shows that more than half of the urchins were sheltering under the cable conduit. The cable conduit is therefore likely to be providing refuge habitat for this grazing invertebrate, with important implications for other components of the seabed biological community alongside the cable. *Heliocidaris erythrogramma* graze on seaweed algae and invertebrates from the seabed and are also known to consume drift algae (Valentine and Johnson [25]). ‘Urchin barrens’ are formed where urchins are numerous. They graze other biota from the seabed resulting in largely bare seabed apart from encrusting coralline algae (Valentine and Johnson [25]; Wright et al. [29]). The comparable abundances of urchins at the cable and 50 m east is possibly due to high rugosity of the natural seabed at the latter The absence of a clearly visible grazing effect at the 50 m transect may be linked to the random distribution of sea urchins and algae on its natural rugose habitat. The cable provides strongly linear urchin habitat and so a more concentrated grazing effect.

*3.4.2.5. The cable half shell as substrate.* Successive surveys documented the successional and seasonal growth of marine biota on the cable shell, with:

- little or no growth ~7 months after the cable had been installed (February 2006;
- abundant algal growth on the top of the cable shell and invertebrate growth on the underside of the cable shell ~19 months after installation (February 2007); and,

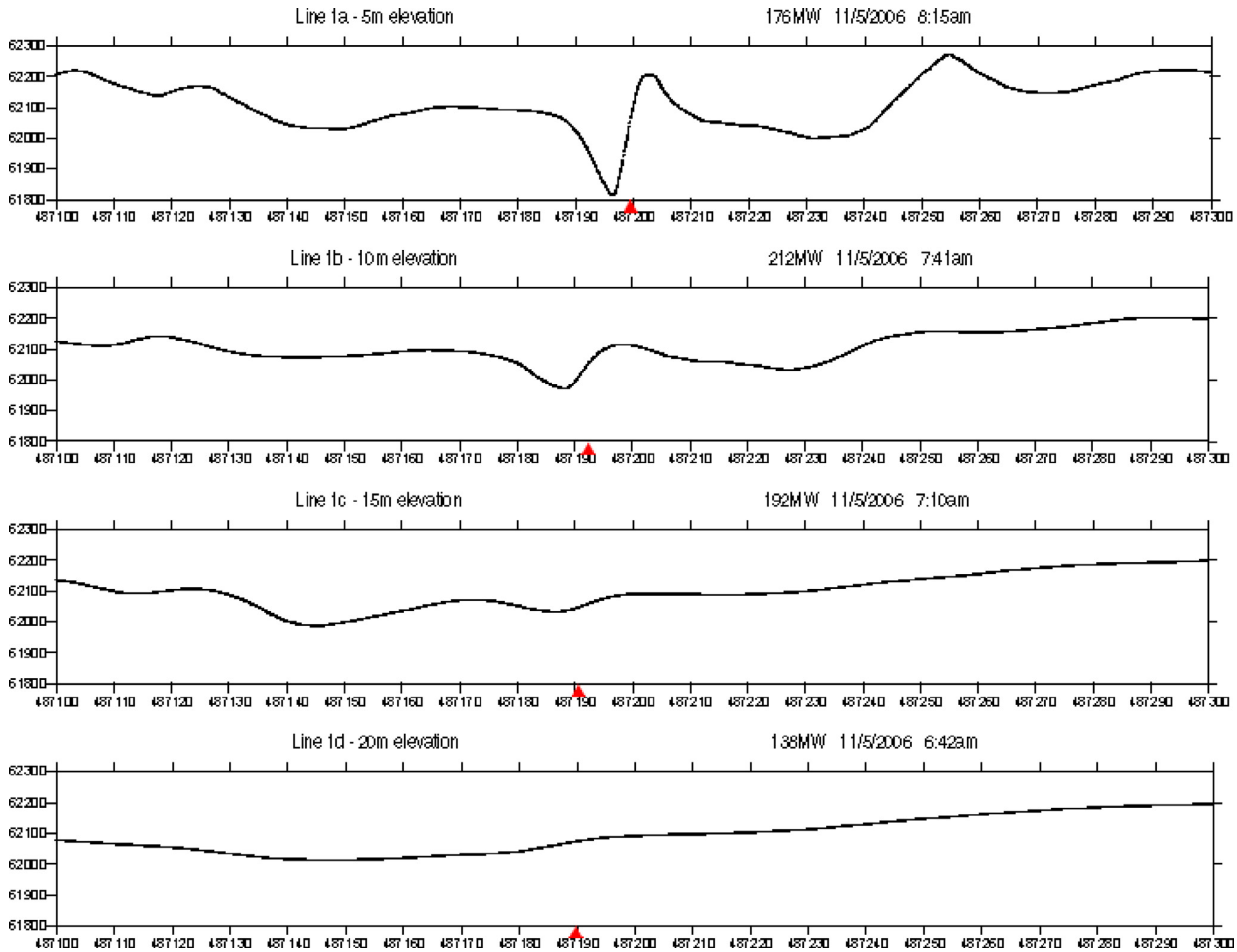



Fig. 7. Magnetic profiles for one of three crossing sets. Red triangles mark the inferred cable position of each transect. *Y* axis is magnetic field strength in units of nanoTeslas (nT), *x*-axis is Eastings (metres). The time and cable power for each transect is also shown.

- lower algal abundance on the seabed but abundant invertebrate growth on the underside of the cable shell ∼45 months later (April 2009; see Fig. 4).

The cable conduit provides habitat of similar stability and complexity to bedrock and boulder habitat . It also provides a linear artificial habitat which is distinct from the randomly patchy natural reef habitats. Species growing on the cable shell were typical of common species growing on nearby cobble and reef seabed. The composition of species on the cable shell varied along its length over transects and between surveys. The half shell appeared to provide a more favourable habitat for turf forming biota (matrix) than the surrounding cobble seabed. Large sponges that were observed sparsley distributed on the nearby seabed were absent from the cable protective shell. This may reflect hydrodynamic factors on the curved shell or a greater establishment time for these species. Overall, therefore, biota comprising the seaweeds, bryozoans, ascidians, small sponges and sea urchins that totally covered the shell or occupied the seabed beneath the shell by the third (2009) survey were similar to those of the surrounding area.

### 3.5. Magnetic fields

#### 3.5.1. Field Measurements

Fig. 7 shows the magnetic field profiles at the different elevations on one of the three crossings. The location of the Basslink cable is clearly observed as a cross-over anomaly that decreases in magnitude as the elevation of the magnetometer above the sea bed increases. The interpreted position of the Basslink cable from the magnetic response is also marked on each profile. Similar profiles were obtained for all three sets of crossings.

The Earth's magnetic field can be affected by geological deposits leading to localised anomalies. Such anomalies are seen in the profiles of Fig. 7, particularly at 5 m, as irregularities in the profiles away from the cable and were not investigated further.

#### 3.5.2. Comparison to calculated magnetic fields

In order to compare the measured fields to those submitted as predictions to the formal assessment process for approval to construct the cable (NSR [22]) it was necessary to standardise

Table 5
Predicted magnetic field variation at various depths and distances from the Basslink cable (cable direction 337°)operating at 237 MW. The Earth's background magnetic field is assumed to be 61.6 μT .

| Height Above Seabed | Horizontal distance from cable (m) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | –100 | –50 | –20 | –10 | –5 | –1 | 0 | 1 | 5 | 10 | 20 | 50 | 100 |
| | Magnetic Field (μT) | | | | | | | | | | | | |
| 1 | 61.6 | 61.6 | 61.6 | 61.7 | 62.0 | 60.3 | 57.7 | 59.2 | 61.9 | 61.7 | 61.6 | 61.6 | 61.6 |
| 5 | 61.6 | 61.6 | 61.6 | 61.6 | 61.6 | 61.2 | 61.1 | 61.1 | 61.5 | 61.6 | 61.6 | 61.6 | 61.6 |
| 10 | 61.6 | 61.6 | 61.6 | 61.6 | 61.5 | 61.5 | 61.4 | 61.5 | 61.5 | 61.6 | 61.6 | 61.6 | 61.6 |
| 15 | 61.6 | 61.6 | 61.6 | 61.6 | 61.5 | 61.5 | 61.5 | 61.5 | 61.5 | 61.5 | 61.6 | 61.6 | 61.6 |
| 20 | 61.6 | 61.6 | 61.6 | 61.6 | 61.5 | 61.5 | 61.5 | 61.5 | 61.5 | 61.6 | 61.6 | 61.6 | 61.6 |

Table 6
Differences between Standardised and Predicted total magnetic field measured in the vicinity of the cable bundle (assumed 61.6μT background; maximum power transmission of 237MW during field operations; cable direction 337°).

| Height Above Seabed | Horizontal Distance from Cable (m) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | –100 | –50 | –20 | –10 | –5 | –1 | 0 | 1 | 5 | 10 | 20 | 50 | 100 |
| | Magnetic Field Difference(μT) | | | | | | | | | | | | |
| Crossing 1 | | | | | | | | | | | | | |
| 5 | 0 | –0.2 | –0.1 | –0.2 | –0.3 | 0.1 | 0.3 | 0.4 | 0.1 | –0.1 | –0.2 | 0 | 0 |
| 10 | –0.1 | –0.1 | –0.1 | –0.2 | –0.1 | 0 | 0.1 | 0 | 0 | –0.1 | –0.1 | –0.1 | 0 |
| 15 | –0.1 | –0.2 | –0.1 | –0.2 | –0.1 | –0.1 | –0.1 | 0 | 0 | 0 | –0.1 | –0.1 | 0 |
| 20 | –0.1 | –0.2 | –0.2 | –0.2 | 0 | 0 | 0 | 0 | 0 | –0.1 | –0.1 | –0.1 | 0 |
| Crossing 2 | | | | | | | | | | | | | |
| 5 | 0.1 | 0.1 | 0 | –0.1 | –0.3 | 0.2 | 0.4 | 0.5 | 0.2 | 0 | –0.1 | –0.1 | 0 |
| 10 | 0 | –0.1 | 0 | 0 | 0 | 0.1 | 0.2 | 0.1 | 0.1 | 0 | 0 | 0 | 0 |
| 15 | 0.1 | 0 | 0 | –0.1 | 0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 0 | 0 | 0 |
| Crossing 3 | | | | | | | | | | | | | |
| 5 | 0.1 | 0.1 | 0.1 | 0 | –0.3 | 0.4 | 0.5 | 0.4 | –0.2 | –0.2 | 0.1 | –0.1 | 0 |
| 10 | 0.1 | 0.1 | 0.1 | 0 | 0 | 0 | 0.1 | 0 | 0.1 | 0 | 0 | –0.1 | 0 |
| 15 | 0.1 | 0.1 | 0 | 0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0 | –0.1 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 0 | –0.1 | 0.1 |

all data sets to a common set of conditions. It was decided to use the maximum power operating during the field measurements (237 MW) the actual magnetic orientation of the cable (337°) and a background ('natural') magnetic field at the survey site of 61.6 μT. Predicted magnetic field strengths, which also assume a burial depth of 1 m for the cable have been corrected to these conditions (Table 5). The differences between predicted and standardised measured magnetic field strengths for the magnetometer surveys are shown in Table 6. All calculations were rounded to the nearest 0.1 μT.

It should be noted that no attempt has been made to remove the effects of magnetic contributions from the surrounding geological materials that are evident on Fig. 7 as either anomalies away from the cable or magnetic gradients across the cable.

Tables 5 and 6 show that the actual standardised magnetic fields for all crossings of the cable are similar in magnitude to the predicted magnetic fields. The mean and standard deviation of all values in Table 6 (156 values) is $(0.01 \pm 0.13)$ μT with 93.6% of values within $\pm 0.2$ μT of zero. Maximum differences are $+0.5$ μT (5 m depth and horizontal distances of 0 and +1 m) and $-0.3$μT (5 m depth and $-5$ m horizontal distance). These constitute 0.8% and 0.5% respectively of the total magnetic field.

The actual magnetic fields for the profiles in Fig. 7 are slightly different to those in Table 5. For example, in Fig. 7, crossing 1, the measured magnetic field at 5 m elevation, directly above the cable was approximately 62.1μT, while from Table 5 the corresponding standardised value is 61.4 μT. The difference is because graphs in Fig. 7 are plots of raw data while the data in Table 5 have been standardised as outlined in our Methods.

Thus we conclude that the actual total magnetic field surrounding the cable is similar in magnitude (within 0.8%) to the predicted field. Some contribution to the differences between the predicted and the actual magnetic field measurements close to the cable could be accounted for by a different burial depth for the cable at the test location (modelling assumes 1 m), possible twisting of the cable, changes in electric current during profiling or slight variations in depth of the sensor during transects.

### 3.6. Electric fields

Operation of the HVDC cable generates both electric and magnetic fields. An induced electric field is created when seawater (containing ions) moves through a magnetic field. In the vicinity of the cable both the Earth's magnetic field and that resulting from cable operation combine. Increasing seawater velocity (i.e., ocean current) increases the magnitude of the induced electric field. At a distance of 1.2 m above the cable induced electric fields were predicted to be $0.77\mu V.m^{-1}$ for a velocity of $10\,cm.s^{-1}$ and $7.7\,\mu V.m^{-1}$ at a velocity of $100\,cm.s^{-1}$ for the combined magnetic field and maximum operating cable power (600MW; NSR, [22]). An attempt to measure electric fields 1 m above the cable directly using various electrodes 1 m apart gave widely varying results (<1 to 168 $\mu V.m^{-1}$; Whitehead [26]). Similar results were found for sites remote from the cable. High spikes observed in the data were attributed to variable ocean currents, wave action and/or particulate matter in the water column (Whitehead [26]).

Because of the difficulty in obtaining measured electric fields under steady state conditions it was decided to calculate the induced electric field from the measured magnetic field using Eq. (1). This allowed comparison to electric field predictions made for the environmental approval process (NSR [22]).

$$E(\mu V.m^{-1}) = B(\mu T) x \nu (m.s^{-1}) \quad (1)$$

Where:

- E is the induced electric field;
- B is the vertical component of the earth's magnetic field and
- $\nu$ is the speed of the water moving horizontally through the magnetic field.

Electric field strength is directly proportional to magnetic field strength from Eq. (1). Thus, if the induced magnetic field of the cable is less than 1% of the Earth's magnetic field it follows that the cable's induced electric field is also less than 1% of that induced by the Earth for any particular water velocity. Calculation of electric field strength using Eq. (1) is recommended in the absence of a reliable means of directly measuring electric field strength in marine waters. If sea water is flowing horizontally it is the vertical component of the magnetic field that will induce the electric field. At the field survey site the vertical component of the magnetic field is approximately $58.3\mu T$. This reduces to $57.9\mu T$ directly over the cable at 5 m above the seabed for power flow from Tasmania to Victoria. The induced electric field from a seawater flow at a speed of $0.1\,m.s^{-1}$ through the DC magnetic field would be $5.8\,\mu V.m^{-1}$. The variation in induced electric field directly over the cable at 5 m above the seabed with power transfer of 237 MW from Tasmania to Victoria would be 0.7% (Strong [23]).

### 3.7. Major findings and comparisons with other research

This investigation has confirmed predictions made prior to construction of the Basslink cable and is consistent with similar studies (Andrulewicz et al. [1], Kogan et al. [18], Dunham et al. [12]).

#### 3.7.1. Cable route and placement

The selected route, and the decision to bury the Basslink cable reduced the likelihood of long term ecological effects. At all remote locations and the nearshore Victorian sites, epibiota on the undisturbed seabed were too sparse for meaningful statistical analysis. At all locations where a trench or depression was visible, biota (drift or attached) were more abundant in the depression than on the surrounding seabed. A visible presence of habitat change (trench and mounds) was a more sensitive indicator of environmental disturbance than biological abundance (which was sparse) in this environment. Within 1 – 2 years sedimentation had removed all surface trace of the cable from 24 of the 72 remote location transects – including all transects at one site (remote site 3).

Immediately after cable laying, the change in physical habitat was relatively easy to detect at most sites. It was the determining influence in biological distribution differences between the cable alignment and the surrounding seabed. At all locations where a cable trench or depression was visible, the change in physical habitat was confined to within 1.5 m of it i.e. a disturbed area <4 m across at the cable.

Andrulewicz et al. [1] investigated the ecological effects of laying the SwePol HVDC cable between Sweden and Poland. Where it had been buried in sandy sediments there was no surface trace of the SwePol cable twelve months after its emplacement. Kogan et al. [18] studied the environmental impact of an ATOC/Pioneer Seamount coaxial Type SD cable 8 years after its installation off California on the USA west coast. This was a smaller diameter cable (6 cm maximum diameter) designed for relatively small electric currents linked to scientific instruments on the seafloor. The cable had not been operational since 2002 (~1 year before their survey).The ATOC cable was originally laid on the surface but after 8 years sections had self buried to depths up to 27 cm at sediment dominated sites on the continental shelf. Wave action and tidal currents capable of moving sand and/or causing cable movement ("strumming") were responsible for the self-burial.

Dunham et al. [12] examined the effect of a HVDC cable on a glass sponge reef and associated megafauna off the west coast of Canada and recommended that in order to minimise future impacts on this ecosystem planners look to route cables around sensitive reef and look to stop lateral movement of cable across any sponge reef traversed. The modern practice to achieve these objectives is to bury cables where practicable on continental shelves (Kogan et al. [18]).

#### 3.7.2. Biological effects of the cable

Very sparse epifaunal communities on the Victorian and central Bass Strait sections of Basslink precluded statistical analysis and suggest disturbance of benthic ecosystems would be slight. Some trench depressions had trapped drift material and increased habitat complexity as a result. Such effects will be lost as the trenches gradually infill. On the Tasmanian side, where the cable crosses a rock reef the cable is enclosed in a cast iron half shell. This structure constituted a newly available, linear stable hard surface habitat with basal crevices to act as refugia. Over the 3 years of survey the half shell became colonised with a diverse group of fish, macroalgae and invertebrates, similar species to those inhabiting the adjoining reef.

Andrewicz et al. [1] studied macrozoobenthos collected by box corer from 36 sites sampled before (1999) and after (2000) SwePol installation. Sites were either on the cable route or separated from it by 0.1-1 nautical mile (185–1852 m) – the latter being "distant" reference sites. They found no significant changes in composition, biomass or abundance across 18 taxa which could be related to cable installation. Kogan et al. [18] used video, digital still images and shallow sediment cores to study epifauna and infauna along transects near (<1 m) and distant (~100 m) from the ATOC cable. Statistical analysis of 17 megafaunal groups and 19 infaunal taxa across all sites showed no significant effect due to the cable. At one or more stations actiniarians (sea anemones) and some fishes were more abundant on or near the cable. The former utilised the cable as a hard substrate for colonisation while the latter seemed attracted by the habitat complexity provided by the cable when compared to the surrounding sediment dominated seafloor. Dunham et al. [12] found that glass sponge cover was consistently less along cable transects compared to controls. Cover reached a minimum (~55% decrease) 1.5 years after cable installation before recovering to 85% of control cover after 3.5 years. The effect on mortality extended ~1.5 m either side of the cable. There was no statistical difference between cable and control transects for the diverse megafaunal community associated with the glass sponge reef (representatives from 7 phyla and 14 classes).

All studies indicate that biological effects of cable installation are transient and relatively minor.

#### *3.7.3. Magnetic fields associated with the operating cable*

At 5 m above the seafloor magnetic field strengths measured during the surveys resulted in a variation of less than 1% of the natural background and the variation decreases rapidly at greater distances until it was barely detectable at 15–20 m above the cable. These measurements of actual field strength are very similar (within 0.8%) to calculated values and we believe they provide in-situ validation of such calculations. We note that any such field monitoring of magnetic field strength is effectively only the validation of physical principles. The latter will always be right whereas field monitoring is more difficult and subject to more errors.

Andrewicz et al. [1] investigated the magnetic field of the operating SwePol cable. Like Basslink the SwePol cable has a metallic return and has a similar length (~250 km) and carries a similar maximum current (1300 Amperes). Magnetic induction was measured with a proton magnetometer while changes in declination were measured with a magnetic compass when SwePol was operational. Both measurements were made by divers. These authors did not present their field measurements but reported that "measurements of the underwater magnetic field do not exceed those obtained with the simulations" (Andrulewicz [1] p. 344) and that changes in magnetic inclination due to the cable were not detectable beyond 20 m. Results for the Basslink cable agree with these conclusions.

## 4. Conclusions

We conclude that the ecological effects of the cable installation on epibiota have been transient and minor for soft sediments where the cable is buried. On hard substrate the armoured cable provides a colonisable surface similar to bedrock and is quickly utilised by reef species as new habitat. Magnetic and electric fields generated by the operating cable do not appear to affect this process and within 3.5 years the armoured surface is covered with species comparable to the surrounding reef. These conclusions are consistent with other similar studies of submarine cable systems. The findings should allay some of the community concerns concerning the environmental effects of installation and operation of HVDC monopole cables with metallic return.

## Acknowledgments

Ian Burgwin, Joska Ferencz and Malcolm Eccles (Basslink) provided technical information on the Basslink cable installation and operation. Basslink funded field studies designated by the BSERC.

Don Hough (DEPI; Victoria) contributed insightful discussion and access to records of BSERC. Ms Franzis Alzthaus (CSIRO) prepared Fig. 1.

## References

[1] E. Andrulewicz, D. Napierska, Z. Otremba, J. Sea Res. 49 (2003) 337–345.
[2] Final Panel Report: Basslink – Proposed Interconnector Linking the Tasmanian and Victorian Electricity Grids (Volume 1), Basslink Joint Advisory Panel, Hobart, Tasmania, Australia, 2002, p. 442pp.
[3] N.J. Bax, A. Williams (Eds), Habitat and Fisheries Productivity in the South East Fishery. Final Report to FRDC Project 94/040, CSIRO Marine Research, Hobart, Tasmania, Australia, 495 pp., 2000.
[4] N.J. Bax, A. Williams, Mar. Freshwater Res. 52 (2001) 491–512.
[5] A. Butler, F. Althaus, D. Furlani, K. Ridgeway, CSIRO Marine Research, Hobart, Tasmania, Australia, 2002, p. 64.
[6] L. Carter, D. Burnett, S. Drew, G. Marle, L. Hagadorn, D. Bartlett-McNeil, N. Irvine, Submarine Cables and the Oceans – Connecting the World. UNEP-WCMC Biodiversity Series No. 31. ICPC/UNEP/UNEP-WCMC, 2009.
[7] CEE, Basslink: Marine Biological Monitoring. CEE Consultants, Melbourne, Victoria, Australia, 44 pp., 2007
[8] S. Chidgey, Bass Gas Project: Offshore Baseline Monitoring Programme. CEE Consultants Report to Origin Energy Resources Ltd, CEE Consultants, Melbourne, Victoria, Australia, 24 pp., 2002.
[9] S. Chidgey, P. Crockett, S. Ibbott, Basslink Supplementary Biological Monitoring. CEE Consultants, Melbourne, Victoria, Australia, 31 pp., 2009

[10] S. Chidgey, P. Crockett, S. Ibbott, P. Ho, Pardoe Effluent Outfall: Marine Biological Monitoring Program. August, 2014. CEE Consultants Pty Ltd Report, Tasmanian Water Corporation. 45 pp.

[11] CNS, Marine Magnetometer Monitoring Program: Basslink Project, Devonport, Coffey Natural Systems, Sydney, NSW, Australia, 2008, p. 16. Tasmania. Report No. S22528/01 AD.

[12] A. Dunham, J.R. Pegg, W. Carolsfeld, S. Davies, I. Murfitt, J. Boutillier, Mar. Env. Res. 107 (2015) 50–60.

[13] ICPC, About Submarine Power Cables. International Cable Protection Committee, 2011. (www.iscpc.org/publications/About_SubPower_Cables_2011.pdf)

[14] IMCRA Technical Group, Interim Marine and Coastal Regionalisation for Australia: An Ecosystem-Based Classification for Marine and Coastal Environments. Version 3.3. Environment Australia, Commonwealth Department of the Environment, Canberra, ACT, Australia, 1998.

[15] N.P. James, Y. Bone, Neritic Carbonate Sediments in a Temperate Realm: Southern Australia, Springer Science+Business Media, 2010, p. 268.

[16] C. Jenkins. http://instaar.colorado.edu/~jenkinsc/dbseabed/resources/asource/, 2012.

[17] J.N. Jennings, Proc. Royal Soc. Victoria 71 (1958) 49–71.

[18] I. Kogan, C.K. Paull, L.A. Kuhnz, E.J. Burton, S. von Thun, H.G. Greene, J.P. Barry, Cont. Shelf Res. 26 (2006) 771–787.

[19] J. Larcombe, K. Brooks, C. Charalambou, M. Fenton, M. Fisher, M. Kinloch, R. Summerson, Marine Matters - Atlas of Marine Activities and Coastal Communities in Australia's South-East Marine Region, Bureau of Rural Sciences, Canberra, Australia, 2002.

[20] B.J. Martin, Sand Management Study. Summary and Recommendations. Gippsland Ports, Melbourne, Victoria, Australia, 2004.

[21] NOO, South-east Regional Marine Plan, Implementing Australia's Oceans Policy in the South-east Marine Region. National Oceans Office, Hobart, Australia, 2004.

[22] NSR, Final Integrated Impact Assessment Statement and Supplement to the Draft Integrated Impact Assessment Statement, Report No. CR 898_11_v4, NSR Environmental Consultants Pty Ltd, East Camberwell, Victoria, Australia. 2002.

[23] D. Strong, Bass Strait Environmental Review Committee: Supplementary Technical Addendum. Coffey Natural Systems, Sydney, NSW, Australia, 11pp., 2008.

[24] H. Sweatman, A. Cheal, G. Coleman, B. Fitzpatrick ,I. Miller, R. Ninio, K. Osborne, C. Page, D. Ryan, A. Thompson, P. Tomkins, Long-Term Monitoring of the Great Barrier Reef. Status Report. Australian Institute of Marine Science, Townsville, Queensland, Australia, 2000.

[25] J.P. Valentine, C.R. Johnson, Botanica Marina 48 (2005) 106–115.

[26] D. Whitehead, Measurement of the Induced Electric Field Strengths related to the operating Basslink Undersea High Voltage Direct Current Transmission Cable across Bass Strait. Report to the Bass Strait Environmental Review Committee. University of Queensland, Brisbane, Queensland, Australia, 14 pp., 2007.

[27] A. Williams, Independent Technical Advice on Representative Epibiota Habitat Types in Offshore Commonwealth Waters of Bass Strait and Best Practice Monitoring Techniques Associated with the Proposed Basslink undersea Transmission Table. CSIRO Marine Research, Hobart, Tasmania, Australia, 11 pp., 2004.

[28] A. Williams, N. Bax, Mar. Freshwater Res 52 (2001) 513–536.

[29] J.T. Wright, S.A. Dworjanyn, C.N. Rogers, P.D. Steinberg, J.E. Williamson, A.G.B. Poore, Mar. Ecol. Progr. Ser. 298 (2005) 143–156.