II. METHODS AND MATERIALS

Study Site

The study was conducted in the Gulf of Corryvreckan, Firth of Lorn, West Scotland (56° 09' N, 5° 42' W). The Gulf is part of an island chain topography that leads to differences in tidal height between the inshore Sound of Jura and the offshore Atlantic Ocean. The island chain is 50 miles long with Fladda (56° 14' N, 5° 41' W) to the north and Islay to the south (55° 38' N, 6° 11' W). The Gulf of Corryvreckan is an intensely tidal channel that splits the islands of Scarba (north boundary) and Jura (south boundary) with the narrowest point approximately 0.7 nautical miles wide.

The Gulf of Corryvreckan is an east-west channel that separates the Inner Hebridean islands of Scarba and Jura (056° 09'N, 005° 42'W). Through glacial age processes, the channel has reached an average depth of 120 metres. There is even a 219m deep pit at the eastern end of the Gulf. The topographical shape of the islands about the Firth of Lorn and the Sound of Jura create tidal differences in the sea-level heights at either end of the Gulf. This produces currents that can exceed 8 knots in velocity. These currents would otherwise flow unimpeded through the channel, but an extrusive ridgeline off Scarba has left a wall stretching a third of the way across the Gulf. It rises steeply from the seabed at a depth of 120m, to 70m below sea level; with a prominent pinnacle reaching to within 29m of the surface. The tidal flow is forced up and over the ridge, where it then plummets down to fill the resultant vacuum. The accelerated velocity causes these down-wellings to 'bounce' off the seabed and rush back up to the surface. The resultant upwellings visibly burst at the surface and a combination of returning water, lateral current and prevailing wind create the whirlpools.

Additionally, the shorelines of Jura and Scarba affect the tidal stream. Jura creates tailings of the current that stretch out into the mid-stream flow, as well as Scarba's 'curvaceous' shoreline causing other stream disturbances. The result at a fine scale is a multi-faceted environment that displays a variety of tidally induced features.

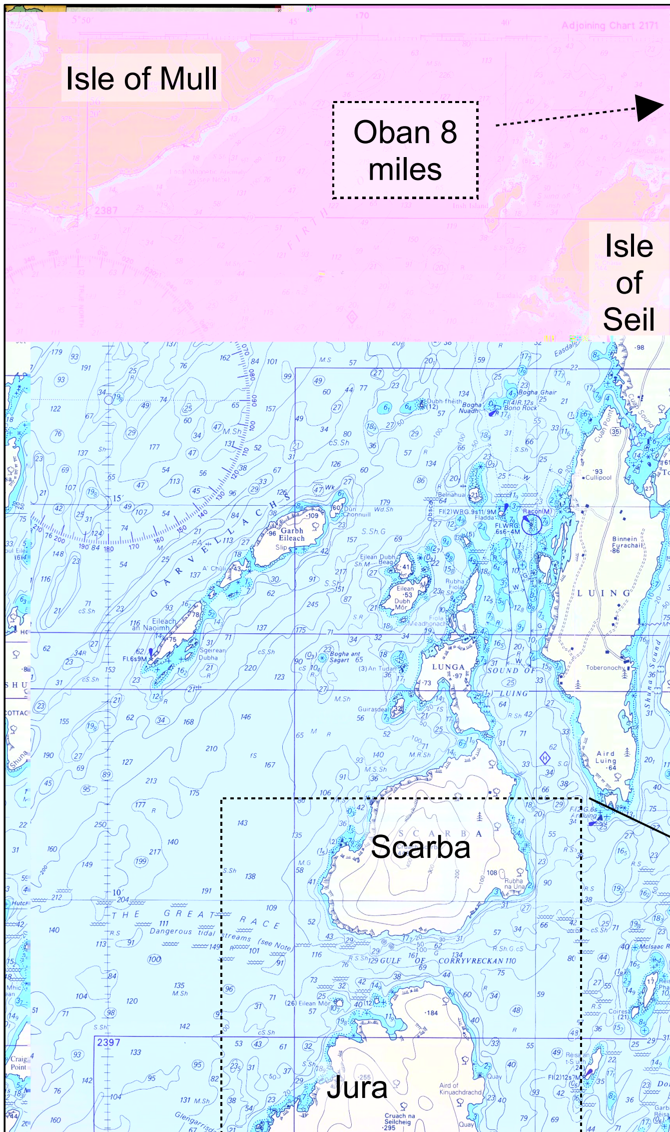

Figure 1a*. The Firth of Lorn and southern approach of Mull.

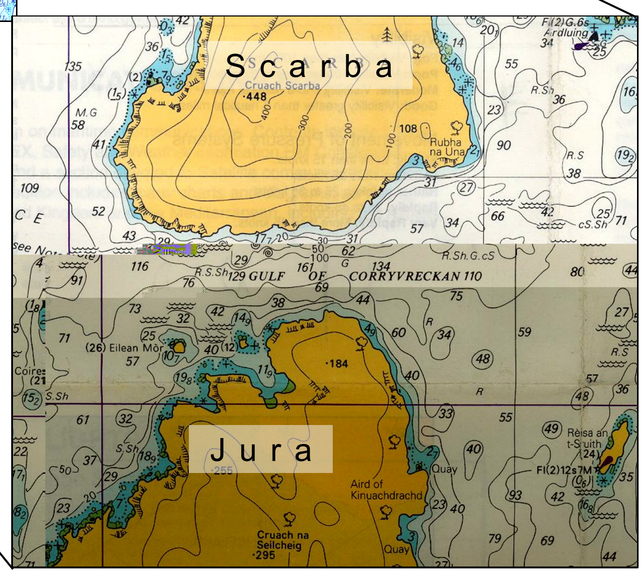

Figure 1b*. The Gulf of Corryvreckan, Scarba and Jura.

* Figures taken from Admiralty chart SC 2169.

Survey Design

The study site was divided into 12 different sized sectors. These sectors were individually labelled A to F (East to West), in conjunction with N or F (Near or Far), e.g. AF is the eastern and far sector, while FN is the western and near sector. Figure 2 details the division of these sectors while Figure 3 shows the panoramic view afforded by the viewpoint position. Each sector was divided by a visual transect, and a defined distance from the viewpoint. A Cooke V22 theodolite was calibrated to magnetic compass bearings, and used to clarify the transect boundaries of the study area.

The optimum location for observing these sectors was a cliff top viewpoint on the island of Jura. The location was 100 metres to the south of the most northerly tip of Jura, and at a height of 120 metres. The ground was flat and stable just ensuring safe working conditions.

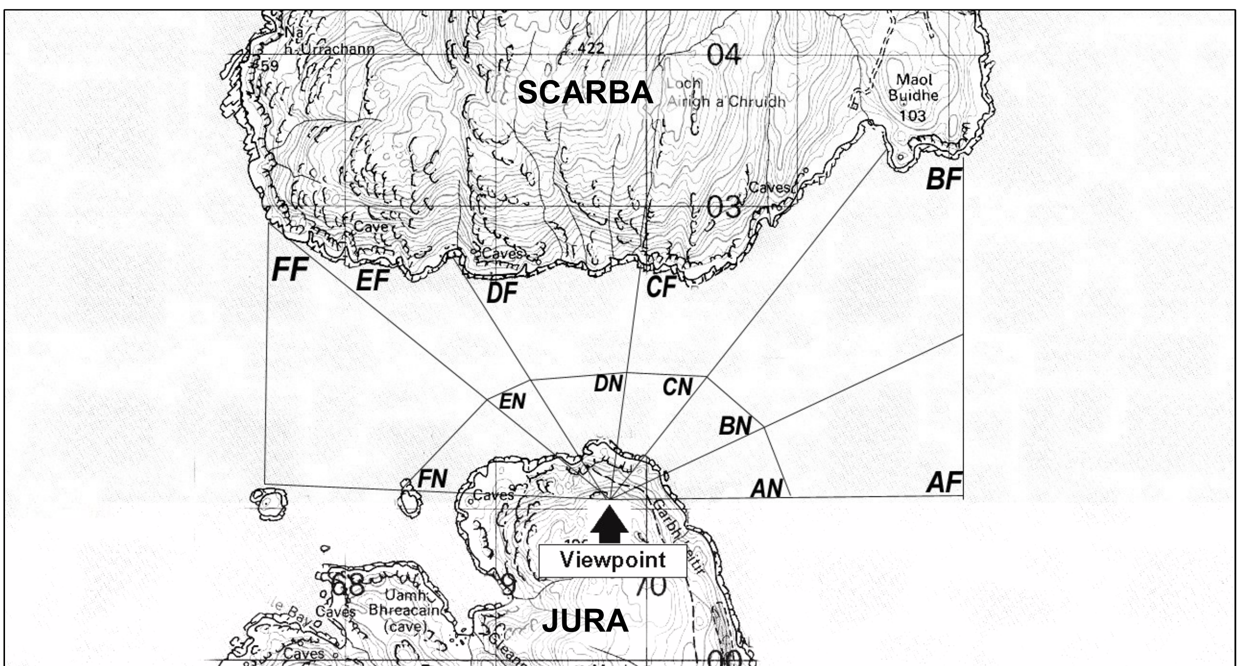

Figure 2. The location of the viewpoint and layout of the sectors (Ordnance Survey 2002).

Figure 3. This panoramic view of the Gulf of Corryvreckan, on an ebb flow tide, covers 270° (west) through North to 90° (east), with Scarba clearly visible at the centre. The breaking waves of the disturbed current off the headland are clearly visible in the foreground.

Timings of the s [illegible] en 0800 and 2000 BST. This was to prevent loss of visib [illegible] ninimise any variation caused by different behaviours as [illegible] mes of day but display different activity patterns with ch [illegible] F., personal communication).

The tides are di [illegible] run in one direction through the Gulf for approximately [illegible] 'slack tide' period that differ from 5 to 50 minutes (Mike F [illegible] ation). This depends on the lunar phase or wind strength [illegible]

Each Session w [illegible] tegory and the Session Start time was based on the mid- [illegible] ce the start time was established, a set-up period was inc [illegible] Start Time had commenced, the first Seabird Observati [illegible] eriod was 5 minutes long. When completed, there would [illegible] e followed by the first Cetacean Observation Period. Th [illegible] ach species Observation Periods were completed. In th [illegible] Seabird and Cetacean OP's, this procedure would allow 25 minutes separating each related OP. Figure 4 is a graphical representation of the timings associated with the tidal categories, sessions and periods.

Using tidal software (Belfield, 2003), tide times for three locations {Oban (56° 25 N, 05° 29 W), Loch Beag (56° 09 N, 05° 36 W) and Glengarrisdale Bay (56° 06 N, 05° 47 W)} were used to calculate 4 tidal categories; High water (HW), Low Water (LW), Ebb Tide (ET) and Flood Tide (FT). Davies (1999) used these ports for calibration of subsurface acoustic and sonar data used for the habitat-mapping project. Appendix B details the timings used for the survey.

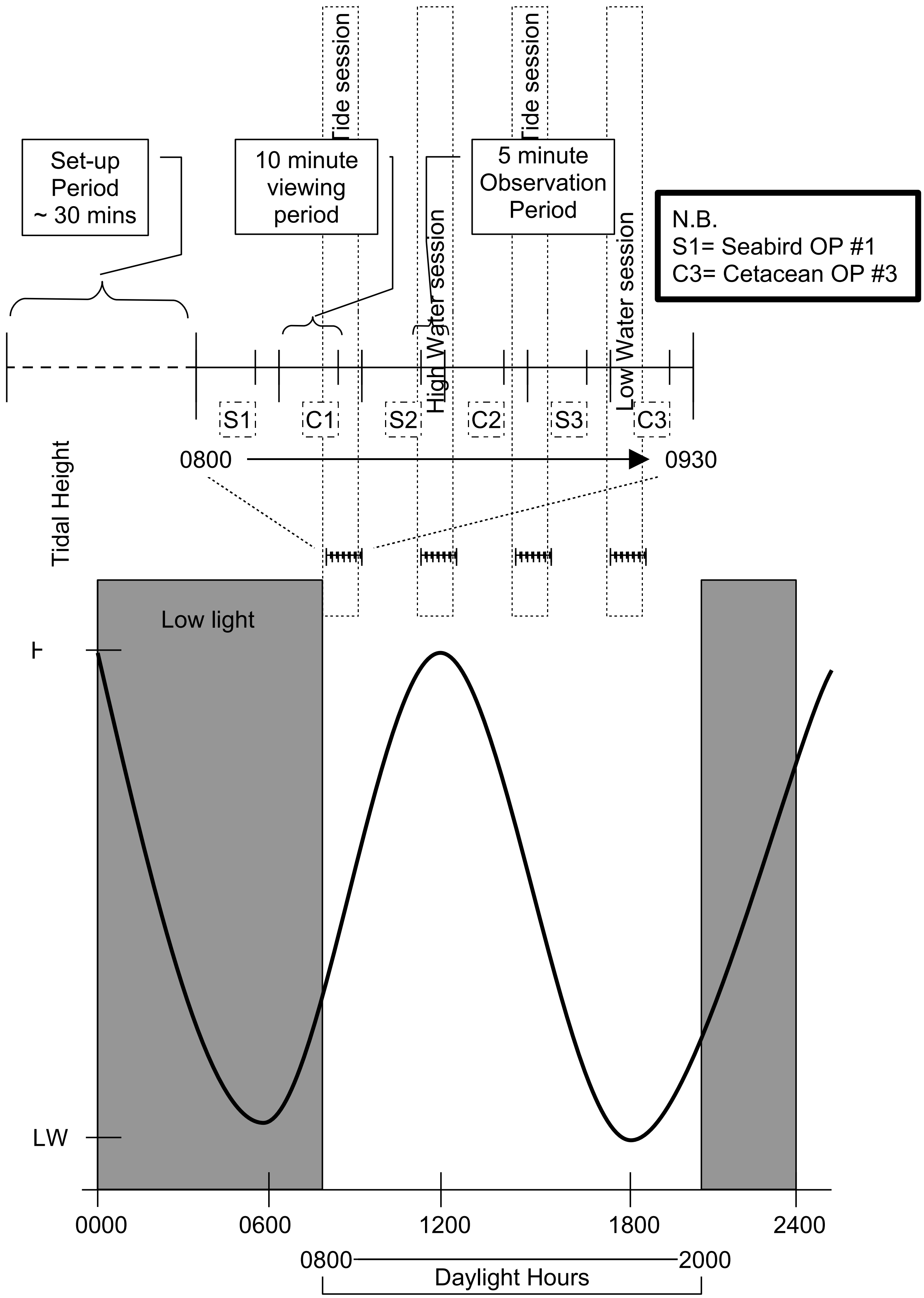

Figure 4. The Session and Period times designed on the tidal categories. Four tide categories were defined using three local ports and session timings centred about the category mid-time. Each session (90 mins) comprised of 6x observation periods-OP (5 mins), each preceded by a viewing period (10 mins).

The daily survey procedure was based upon Session times. Each Session comprised of three Seabird Observation Periods and three Cetacean Observation Periods. An Observation Period (OP) lasted 5 minutes and an 'Instantaneous Scanning Method' (Altmann, 1974) used to collect information on species-group visible, behaviour exhibited and relative abundance. Each OP was preceded by 10 minutes of viewing time. During this viewing time, notes on species and activity were taken. A Yukon 25-50x50 variable focus spotting scope was used to confirm difficult sightings. When the OP time started, each sector was scanned with Bushnell 8x42 all-weather binoculars. Species, abundance and behaviour were coded, to minimise recording time and observations were dictated into a Sanyo voice activated tape recorder. These notes were then compiled on paper after the sessions.

Seabirds

Seabird Activity was deemed as 'any clearly identifiable activity or behaviour by any number of seabird species within the allocated observation period and sector'. Species were designated into five main categories based on the difficulties of accurate identification at distance. Seabirds were categorised into species-groups. These species-groups were defined by similar colouration, behaviour and size.

Personal observations from the viewpoint and from the water (Seafari, Appendix C), prior to the survey were used to define the species-groups of Table 1. Any further species that were clearly identifiable were recorded and entered into the observations.

Table 1. Species-groups, common and Latin names of seabird species likely to be seen in the Gulf of Corryvreckan (Webb *et al.* 1990, *pers. obs.*)

Species-groups	Common Name	*Latin name*
Auks	Common Guillemot	*Uria aalge*
	Razorbill	*Alca torda*
	Puffin	*Fratercula arctica*
Black Guillemot	Black Guillemot	*Cepphus grylle*
Gannet	Gannet	*Morus bassanus*
Large Gulls	Herring Gull	*Larus argentatus*
	Great Black-backed Gull	*Larus marinus*
	Lesser Black-backed Gull	*Larus fuscus*
Shag	Shag	*Phalacrocorax aristotelis*
	Cormorant	*Phalacrocorax carbo*
Small Gulls	Kittiwake	*Rissa tridactyla*
	Common Gull	*Larus canus*

Abundance was recorded as categorical values. Table 2 shows the numbers associated with each abundance category. By categorising abundance, recording of numbers was more efficient as distance, time and visibility reduced the ability to accurately count numbers.

Table 2. Abundance categories used for recording group size and associated numbers.

Abundance Category	*Numbers*
Individual	1-2
Few	3-9
Some	10-24
Many	25-74
Abundant	75-200
Superabundant	200+

Behaviour of species was recorded for each observation. Table 3 shows the behaviours recorded. When the individual periods were pooled to full Sessions, these behaviour observations were no longer applicable. However, individual species analysis is planned for future work.

Table 3. Behaviour categories used to define activity of seabird species.

Feeding	Resting
Dipping	Preening
Surface pecking	Multi-species Feeding Aggregation
Deep plunging	Single Species Feeding Group
Shallow plunging	Association with cetaceans
Pursuit diving or bottom feeding	Association with upwelling
Actively searching	Association with front \ line in the sea
	Association with fishing vessel

Cetaceans

Cetaceans are regular visitors within the Gulf and Appendix C shows the data collected on sightings of cetaceans in 2003. All cetaceans were looked for and the difficulties associated with each species accounted for (Gordon 2001, Grellier & Wilson 2003, Hastie *et al.* 2003a 2003b, Raum-Surayan *et al.* 1998, Weir *et al.* 2001). Table 4 shows those species that could have been sighted.

During cetacean observation periods, species, visible number and activity were recorded by sector. If possible, theodolite recordings of position were made, with an aim to identifying an approximate location.

Table 4. Cetaceans that could be sighted in the Firth of Lorn (Weir *et al.* 2001, Barne *et al.* 1997, Elliott *pers. obs.*).

Common Name	*Latin Name*
Harbour Porpoise	*Phocoena phocoena*
Bottlenose Dolphin	*Tursiops truncatus*
Minke Whale	*Balaenoptera acutorostrata*
Common Dolphin	*Delphinus delphis*
Long-finned Pilot Whale	*Globicephala melas*

Due to the natural behaviour of cetaceans, it was harder to maintain constant visual contact during the viewing time. Therefore, constant scanning was employed and where possible, a theodolite recording made. Then at the Observation Period, a methodical scan of all sectors was conducted and any sightings recorded. Recordings outside of the area or observation period were recorded separately. Binoculars were used for the scanning procedure and the spotting scope employed for confirmation of species. If individuals were had been recorded previously in the Observation period, they were then ignored. Behaviour categories included feeding, playing, breaching, basking and fast swimming (Evans & Wang, 2002). Cetaceans were often associated with seabird activity and these associations were recorded.

Meteorological Conditions

Due to the effect of meteorological conditions on both biotic and abiotic factors within the Gulf, the various recordings were of those within the local area. Observations were made before each Session.

Wind speed was recorded using a digital anemometer and was recorded as Beaufort wind scale. The wind direction was monitored using a wind vane and was recorded by direction. Sea state was observed and recorded on the Beaufort scale. The nature of water movement within the Corryvreckan meant that some areas would be a sea state some levels above that of another area less than a quarter of a mile away. Therefore sea state was recorded as the conditions experienced in greater than 60% of the study area. Cloud cover was measured in eighths of cover, and precipitation by definition of the conditions. Visibility was defined by the ability to see Craobh Haven marina 12 miles away. Excellent and Good were when there was a clear view, moderate was usually associated with haze or overcast conditions, and poor or bad were associated with no data collection.

Data Analysis

All data was entered in a spreadsheet, and using a query solution, each observation was attributed meteorological and tidal data. Due to the huge number of data sets (observations), the individual periods (seabird and cetacean) were pooled and averaged by single sessions. The abundance values for species were averaged for each session. By reducing the data size, this allowed the use of the PRIMER (**P**lymouth **R**outines **I**n **M**ultivariate **E**cological **R**esearch {Clarke & Gorley, 2001}).

Prior to any further analysis, the BIOENV procedure was run on all the data. Table 5 shows the output from this, and the following factors (had a strong effect on the species assemblages.

Table 5. BIOENV results showing the number of variables, associated levels of correlation and variables (Variables and numbers shown in Table 6).

No. Variables	Correlation	Selections (Variables)
5	0.133	3,4,12,14,17
5	0.132	3,4,11,14,17
4	0.13	3,4,14,17
5	0.13	3,4,10,14,17
5	0.13	3,4,12,15,17
5	0.13	3,4,7,14,17
5	0.129	3,4,7,10,17
5	0.129	3,4,11,15,17
4	0.129	3,4,15,17
4	0.129	3,4,10,17

BIOENV identifies factors (meteorological or tidal) that are responsible for the levels of similarity between samples. Following the procedure described (Clarke and Gorley, 2001), it was shown that Wind Speed, Sea State and Precipitation were influencing factors. The data was re-addressed and using the experience of past studies (Evans & Hammond 2004, Grellier & Wilson, 2003, Hastie *et al.* 2004, Tasker *et al.* 1984, Zamon 2003), sessions with wind speed greater than Force 5, sea state above ss3 and any precipitation evident were removed. Visibility less than moderate was also removed on account of difficulties experienced during the study.

Table 6. Variable categories and identifying numbers used by BIOENV procedure.

Variable #	Variable category	Category description
1	SeSSION CODE	Daily Session position- 1 to 4
2	SECTOR	Individual Sectors- AF through FF.
3	AnGLE SECTOR	Sectors grouped by angles- A, B, C, D, E or F
4	RANGE SECTOR	Sectors grouped by distance- Near or Far
5	ArEA SECTOR	Sectors grouped by regions- Left, Centre or Right
6	TIDE GROUP	Session categories- HW, LW, FT or ET.
7	TiDE HEIGHT	Index of range calculated using three local ports.
8	TiDE PHASE	Tidal phase on account of height range- Neaps, Mids or Springs.
9	DAILY GROUP	Sessions timing- AM or PM
10	TIDE FLOW	Combination of #11 and #12- categorical
11	TIDAL DIRECTION	Observed direction- slack, easterly or westerly
12	TIDAL STRENGTH	Subjective tide observation- slack, weak or strong
13	WiND EFFECT	Wind direction matched to direction of tide- 0 to 6
14	WiND SPEED	Level of wind speed- calm to F7
15	SeA STATE	Level of sea state- flat to ss5
16	ViSIBILITY	Level of visibility- bad to excellent
17	PrECIPITATION	Level of precipitation- zero to squalls
18	ClOUD COVER	Level of cloud cover- Clear to 8/8

Four categories were chosen to address the hypotheses.

1. Tidal Direction- to assess any distinction between the directions of the tide.
2. Tide Phase- to appraise the effect of the tidal height and associated current speed.
3. Tidal Strength- to evaluate the effect of different levels of observed current speed.
4. Sectors- to evaluate any significant variation in distribution.

Each analysis category (Tidal Direction, Tidal Phase, Tidal Strength and Sector) was run through the ANOSIM (**A**nalysis **O**f **SIM**ilarities) One-way test. This is a non-parametric multivariate permutation procedure (Clarke & Warwick, 2001) that reflects the similarities between samples. It tests for significance of a null hypothesis, and is analogous to the univariate ANOVA or multivariate MANOVA analysis procedures. Neither of these can satisfy the assumptions surrounding multi-species abundance data.

The output returned shows a ‘Sample Statistic’ or ‘Global R’ value (R), and a ‘Significance level of sample statistic’ (%) (Clarke & Gorley, 2001). Global R is a measure of the degree of separation between samples. The closer, R (*rho*) is to 0, the truer the null hypothesis, and R may be inconsequentially small but still retain significance. The significance of the sample test is defined by the sample statistic level %. A result that is greater than 5%, has an equivalent result to that of, p being greater than 0.05. Therefore, if a result is less than 5%, the null hypothesis is rejected. The Global R and Significance % are also applied to the Pairwise test output, and follow the same explanation.

The Post-hoc Pairwise test (Clarke & Gorley, 2001) calculates the significance of species assemblages between the sample categories. The result shows any significance between the different categories and identifies any relationships that should be assessed in the SIMPER procedure.

SIMPER (**SIM**ilarity **PER**centages, Clarke & Warwick 2001) is an abundance matrix analysis procedure that allows the species assemblages to be separated thus allowing identification of those species responsible for differences described in the ANOSIM test. It does not provide any significance results; only average abundance values per sample for categories analysed in the test, and percentage contributions. It is a useful tool in guiding the univariate analysis.

The Chi-square (χ^2) test of association is one of the most widely used statistical tests (Dytham, 1999). It is very useful in the univariate analysis of categorical data, and therefore a preferred test for this data. Single species-groups were tested under each of the four categories. SPSS (LEADTOOLS, 2003) software was used to run the χ^2 test, and observed frequencies were based on number of sightings of species-groups in sessions defined by test categories. Significance is defined by the p-value returned. P-value less than 0.05 shows significance between categories.