Intertidal and Subtidal Benthic Seaweed Diversity of South Georgia

Report for the South Georgia Heritage Trust and Joint Nature Conservation Committee

Survey September 2011

Shallow Marine Survey Group

E Wells[1], P Brewin and P Brickle

[1] Wells Marine, Norfolk, UK

SHALLOW MARINE SURVEYS GROUP

po box 598
stanley
falkland islands
ph: +500 54542
http://smsg-falklands.org

Executive Summary

South Georgia is a highly isolated island with its marine life influenced by the circumpolar currents. The local seaweed communities have been researched sporadically over the last two centuries with most species collections and records documented for a limited number of sites within easy access. Despite the harsh conditions of the shallow marine environment of South Georgia a unique and diverse array of algal flora has become well established resulting in a high level of endemism.

Current levels of seaweed species diversity were achieved along the north coast of South Georgia surveying 15 sites in 19 locations including both intertidal and subtidal habitats. In total 72 species were recorded, 8 Chlorophyta, 19 Phaeophyta and 45 Rhodophyta. Of these species 24 were new records for South Georgia, one of which may even be a new record for the Antarctic/sub-Antarctic. Historic seaweed studies recorded 103 species with a new total for the island of 127 seaweed species. Additional records of seaweed to the area included both endemic and cosmopolitan species. At this stage it is unknown as to the origin of such species, whether they have been present on South Georgia for long periods of time or if they are indeed recent additions to the seaweed flora. It may be speculated that many have failed to be recorded due to the nature of South Georgia, its sheer isolation and inaccessible coastline. However given the increased levels of tourism, human activity and transportation it is equally plausible that many have been introduced in more recent years. There are still a number of species yet to be identified and indeed collected from these remote places but continued research is imperative to enable accurate baseline data from which to monitor future changes in species composition and distributional shifts particularly in light of climate changes.

Acknowledgments

Much thanks goes to the South Georgia Heritage Trust and Joint Nature Conservation Committee for their support in this project. Taxonomic assistance was also offered by Professor Margaret Clayton of Monash University, Melbourne, Australia, who provided a valuable insight to some of the endemic species of the Antarctic. Gratitude also goes to Ali Massey of the King Edward Point research station who assisted with intertidal surveys. Additional support came from the British Antarctic Survey, the Government of South Georgia and South Sandwich Islands, the Falkland Island Fisheries Department and a Darwin Initiative (DEFRA) grant.

Introduction

South Georgia is an isolated island in the Southern Ocean and is the second largest of the circum-Antarctic islands. It is the Circumpolar Antarctic Current that dominates the area placing significant influence over the benthic flora (Luning, 1990) whereby;

1. The prevailing ocean current has greater significance for the distribution of seaweeds;
2. The seaweed floras inhabiting the temperate and Polar Regions show a more pronounced geographical isolation.

Figure 1. South Georgia's northern coastline at the entrance of Cumberland East Bay.

To date, biological exploration of this island has been limited to a few bays on the more sheltered north east coast with most seaweed surveys conducted primarily within the intertidal. As a consequence, the algal flora, particularly of the shallow sublittoral, has remained little known.

The first documented studies of Antarctic seaweed began in the 19^{th} century by Reinsch (1888, 1890) based on material collected by the 1882-1883 German International Polar Year Expedition. These research studies were continued in the early 20^{th} century by Gain (1912), Skottsberg (1907, 1921, and 1923) and Kylin (Kylin and Skottsberg, 1919) who produced important accounts of the taxonomy and biogeography of these cold water seaweeds. Subsequent qualitative studies include those of Nueshul (1965), Delepine (1966), Zaneveld (1966, 1968), Lamb and Zimmermann (1976) and the valuable work of Papenfuss (1964) who catalogued the work of Skottsberg, Reinsch, Hariot and Kylin. The most recent accounts of seaweed diversity in the Antarctic are those of John et al (1994) and Wiencke and Clayton (2002) producing the most comprehensive species lists of South Georgia to date. It is from a collection of these studies that a historical species list of South Georgia can be compiled and used as both a reference and comparison within the current study. However many of these still remain littoral with most sublittoral collections achieved through dredging.

Although the work of Wiencke and Clayton (2002) does not solely focus on the seaweed diversity and distribution within South Georgia, their accounts provide a detailed insight into seaweeds of the Antarctic and a valuable source of species descriptions. It is estimated through historical literature that approximately 130 species of seaweed exist in the Antarctic (Wiencke and Clayton, 2002); these levels of diversity are considered low in comparison to temperate and tropical waters and up to a third of this total comprises endemic species, suggesting a rather unique flora for this area. A similar finding was reported by Papenfuss (1964) who suggested that out of 550 species of seaweed recorded from both the Antarctic and subantarctic regions 250 were endemic. It is the sheer isolation of the Antarctic and strong effects of Antarctic circumpolar currents on the dispersal of seaweed propagules that has contributed to this level of endemism (Luning, 1990). However, there are equally a number of cosmopolitan species, up to 20, that are suspected invaders from temperate waters such as *Scytosiphon lomentaria, Petalonia fascia, Ulothrix speciosa*, and *Ulva lactuca.* Many of these species are thought to have been transferred via shipping activity (Wiencke and Clayton, 2002).

Among this mix of endemic and cosmopolitan seaweed species is a community exposed to a harsh and variable environment. Seaweed diversity is considerably lower in the Antarctic than any temperate or tropical region and this is most evident in the intertidal with growth limited to narrow stretches of rocky shore. It is in this littoral and shallow sublittoral that the floral community is most impacted by ice scour (figure 2), precluding seaweed growth down to 2m below tide level (Dhargalkar and Verlecar, 2009). It is this factor together with other environmental parameters such as substrate, wave action (Campana et al, 2009, Barnes and Conlan, 2007, Moe and DeLaca, 1976, Kloser et al, 1993) and changes in salinity, turbidity and light penetration through glacial run-off (Zacher et al, 2009, Wiencke and Clayton, 2009a), that may contribute to this lower species diversity. However, unlike the Arctic the surface micronutrient levels in Antarctic waters are high and persistent throughout the year, therefore rarely limiting macroalgal growth (Wiencke et al. 2009). Those species that do survive in this southern location are adapt to the low sea temperatures and restricted light during winter seasons developing seasonal responders to ensure maximum reproduction and growth (Drew and Hasting, 1992, Kloser et al, 1993, Wiencke et al, 2009, Wiencke, 1996).

Figure 2: Intertidal zone at Prince Olav with some remains of ice from winter 2010.

Objectives

The area under investigation, the north coast of South Georgia, is mountainous, rising steeply from the Antarctic waters of the South Atlantic Ocean. It is a largely barren island covered with glaciers and little in the way of vegetation. As a consequence the intertidal area is very limited and significantly impacted by glaciers and ice scour and the upper few meters of the shallow sublittoral is thought to be relatively devoid of algal growth. However, the marine biodiversity of South Georgia is still poorly understood and remains to be fully investigated for levels of diversity. In terms of marine habitats, it is thought to be the most interesting of the region with an equally unique macroalgae composition and its isolation contributing to a high level of endemism. It is important to fully understand these characteristics of community composition and diversity for monitoring future impacts. With increased fishing and tourism activity in the area and the likelihood of the region being the primary responder to climate change through the loss and shifting of biodiversity or general species redistribution it has become necessary to establish comprehensive baseline data. It is these factors that make the seaweed community of the intertidal and shallow sublittoral the focus of this report.

Although lists of benthic algae species do exist for the Island of South Georgia these are likely to be incomplete due to the restrictions in accessing many of the coastal sites. Therefore, the primary goal of the study is to provide comprehensive seaweed species lists from a number of locations; secondly, to establish current levels of endemism identifying new invasive species to the area and changes in distribution limits through comparisons with historical data records. The current study provided an exceptional opportunity with which to collect a number of specimens from such remote locations to be held for future reference and assist with future species identification, descriptive material, and distribution patterns and ultimately to provide a baseline with which to follow the long term responses to climate change.

Methodology

Prior to this expedition most study locations have been situated close to scientific bases (Clayton et al, 1997). Most shores around South Georgia are steeply shelving or of shingle and pebble substrate and the few areas of significant of fixed stable rocky outcrops are often not easily accessible. However, the facilities provided by the MV *Pharos* SG enabled greater flexibility. Therefore this was a rare opportunity to access a greater diversity of sites and habitats via rigid inflatable boats.

Seaweed specimens were collected from a total of 18 sites at 12 locations, which are given in Figure 3. Of the 18 sites 5 were intertidal and the remaining 13 were subtidal. The depth range at which the surveys took place varied between 5m, 10m and 18m, however time did not allow samples to be collected from each depth at all sites, but the overall range allowed maximum diversity to be recorded. Additional intertidal sites were visited at Maiviken and Royal Bay (Figure 3) for which only photographs of species have been provided at this stage, therefore cannot be validated with regards to identification and have been omitted from the current report.

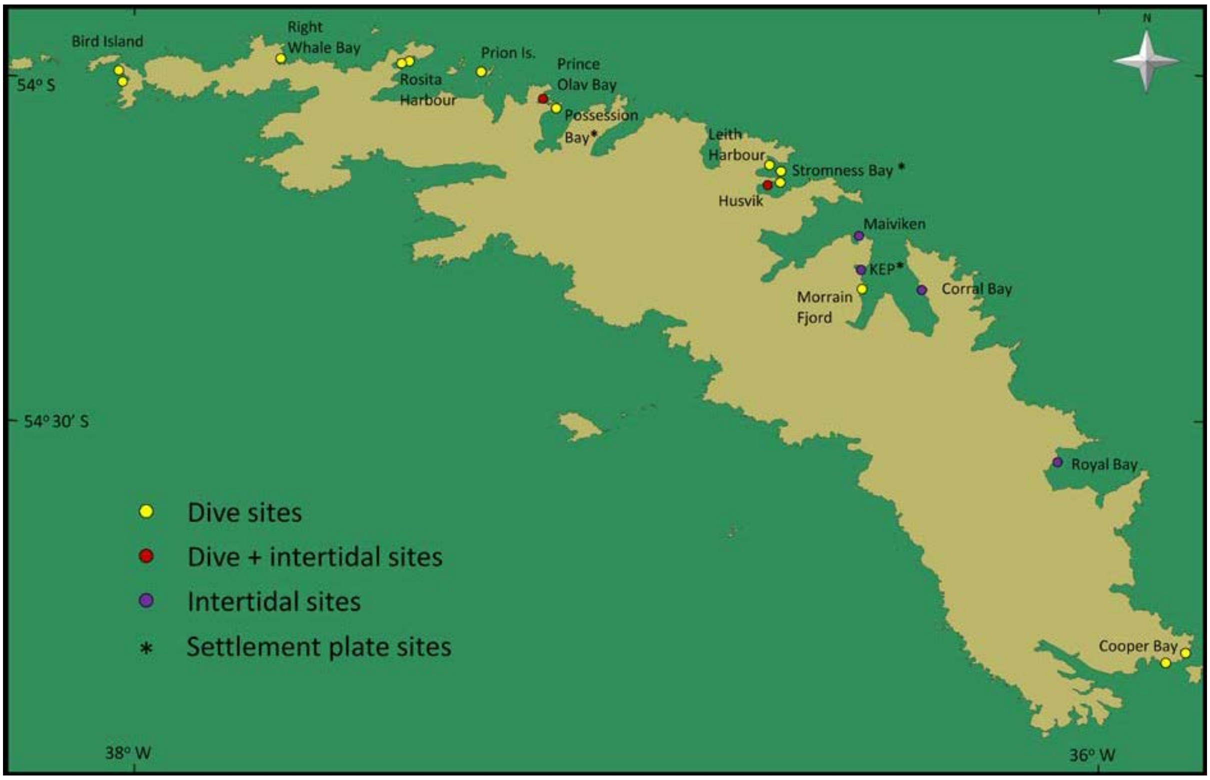

Figure 3: Map of South Georgia detailing the subtidal dive sites and intertidal survey sites on the northern coast. Settlement plates were also fixed at two sites but are not detailed in this report.

Collections of seaweeds were neither systematic nor quantitative; instead specimens were collected from the range of subhabitats visible covering as wide an area as possible within a 30 minute dive time. No time restrictions were applicable to intertidal sites. Sites selection was based on diver and landing access and how well the site represented the overall nature of the Island. Mesh bags were used to collect the specimens and these were later sorted for preliminary identification where possible and pressed for preservation. Subsequent to the expedition, herbarium specimens were used for identification from which the majority of specimens have been successfully identified, with confidence, to species level, but this is still a process that remains on-going to ensure full quality assurance. These herbarium specimens will be deposited at the British Natural History Museum and the South Georgia Heritage Trust. Wiencke and Clayton (2002) was the main source of species description and photographs used for identification purposes but Adams (1994) and Boraso and Zaixso (2008) also provided valuable information to assist with the process. However, due to the limited nature of comprehensive seaweed identification books for this region internet sources were also widely used but come with limited confidence. The validity of seaweed taxa was checked with algaebase (Guiry & Guiry, 2009) in order to update species names and ensure correct nomenclature of both current and historic species lists.

As with the study of any remote location there are logistical difficulties in accessing survey areas and unpredictable weather, which can severely hinder any field work. The limited resources, time restraints and unique laboratory facilities all impacted on the quality of work and examination of specimens. Equally cumbersome diving equipment often impeded the collection of finer filamentous species which is likely to be apparent in the final species list. However, all attempts were made to collect as many seaweed specimens as possible from the combined locations. During dive surveys only those seaweeds with clear attachment to the substrate were removed to ensure a representative sample of the area. Many larger or encrusting species were difficult to collect so were identified in-situ where possible. To further assist with the time consuming process of pressing the seaweed only additional specimens were collected subsequent to the initial survey. Therefore the full species list is a culmination of species collected from a number of sites.

Historical records of seaweed from South Georgia were also collated for use as a reference and from which to later compare species richness and composition. One of the main sources of information was Algaebase (Guiry & Guiry 2011). Algaebase was established in 1996, initially as an attempt to list all the marine algae reported from Ireland and Britain but was later extended to include marine algae from around the world to form a more comprehensive list and currently contains more than 85% of marine macroalgae worldwide. This also allows relevant papers to be sourced as well as correct nomenclature for updating much of the historical species lists.

Results

In total 72 species were identified from the survey with 8 Chlorophyta, 19 Phaeophyta and 45 Rhodophyta. The complete list of these can seen below including sites from which specimens were collected. Some species identification remains tentative but this preliminary list indicates the range of algae collected and the overall composition of the flora at this time. An additional 8 seaweed specimens require further investigation and cannot even be provisionally identified at this stage.

* Indicates new record for South Georgia.
[H] Indicates herbarium specimen collected.

Chlorophyta

[H]**Acrosiphonia sp.** *J. Agardh*
Rosita Harbour 10m, Prince Olav intertidal, Hope Point intertidal
Likely to Spongomorpha pacifica (synonym A. pacifica) but unclear at this stage

* **Blidingia minima** *(Nageli ex Kutzing) Kylin*
Prince Olav intertidal

* **Enteromorpha compressa** *(Linnaeus) Nees*
Rosita Harbour 10m

Enteromorpha sp. *(Link) Nees*
Prince Olav intertidal, Susa Point intertidal

* **Monostroma hariotii** *Gain*
Prince Olav intertidal

[H] **Prasiola crispa** *(Lightfoot) Kutzing*
Prince Olav intertidal
Could possibly be previously recorded subsp. antarctica

* **Ulothrix speciosa** *(Carmichael) Kutzing*
Prince Olav intertidal

[H] **Ulva lactuca** *Linneaus*
Husvik 5m, Susa Point intertidal

Phaeophyta

[H] **Adenocystis utricularis** *Bory de Saint-Vincent*
Husvik intertidal, Susa Point intertidal

*[H] **Antarctosaccion applanatum** *(Gain) Delepine*
Rosita Harbour 10m
Growing epiphytically on Plocamium hookeri

[H] **Caepidium antarcticum**. *Agardh*
Husvik intertidal, Prince Olav intertidal

[H] **Desmarestia confervoides** *(Bory de Saint-Vincent) Ramirez & Peters*
Rosita Harbour 10m, Husvik 5m, Copper Bay 18m

[H] **Desmarestia menziesii** *J. Agardh*
Cooper Bay 18m, Prion Island 5m

*[H] **Desmarestia viridis** *(O.F. Muller) J.V. Lamouroux*
Rosita Harbour 10m
Similar to D. willii which has been previously recorded from South Georgia by John et al

[H] **Durvillaea antarctica** *(Chamisso) Hariot*
Prince Olav intertidal

[H] **Ectocarpus fasciculatus** *Harvey*
Cooper Bay 18m

[H] **Geminocarpus austrogeorgica** *Skottsberg*
Prion Island 5m
Growing epiphytically on Desmarestia sp.

[H] **Geminocarpus germinates** *(J.D. Hooker & Harvey) Skottsberg*
Cooper Bay 18m

[H] **Halopteris obovata** *(J.D. Hooker & Harvey) Sauvageau*
Bird Island 10m

Himantothallus grandifolius *(A. Gepp & E.S. Gepp) Zinova*
Prion Island 5m,
Present at most subtidal sites but unrecorded

*[H] **Hincksia granulosa** *(Smith) P.C. Silva*
Rosita Harbour 10m
Species identification tentative

[H] **Macrocystis pyrifera** *(Linnaeus) C. Agardh*
Prion Island 5m
Present at most subtidal sites but unrecorded

*[H] **Microzonia vellutina** *(Harvey) J. Agardh*
Right Whale Bay 18m

[H] **Petalonia fascia** *(O.F. Muller) Kuntze*
Rosita Harbour 10m

[H] **Petroderma maculiforme** *(wollny) Kuckuck*
Husvik intertidal

[H] **Scytothamnus fasciculatus** *(J.D. Hooker & Harvey) A.D Cotton*
Husvik intertidal

[H] **Scytosiphon lomentaria** *(Lyngbye) Link*
Rosita Harbour 10m

Rhodophyta

[H] **Ahnfeltia plicata** *(Hudson) E.M. Fries*
Prion Island 5m

* **Antarcticothamnion polysporum** *R.L. Moe & P.C. Silva*
Location unknown/unrecorded

*[H] **Antithamnion pectinatum** *(Montagne) J. Brauner*
Prion Island 5m

[H] **Ballia callitrichia** *(C. Agardh) Kutzing*
Prion Island 5m

[H] **Callophyllis atrosanginea** *(J.D. Hooker & Harvey) Hariot*
Prion Island 10m, King Edward Point 5m, Rosita Harbour 10m, Prince Olav intertidal

[H] **Callophyllis variegata** *(Bory de Saint-Vincent) Kutzing*
Prion Island 5m, King Edward Point 5m, Rosita Harbour 10m

[H] **Ceramium virgatum** *(Roth) J.D. Hooker & Harvey*
Rosita Harbour 10m

*[H] **Delesseria lancifolia** *(J.D. Hooker) J. Agardh*
Possession Bay 10m

[H] **Delesseria salicifolia** *Reinsch*
Possession Bay 10m, Prion Island 5m

[H] **Delisea pulchra** *(Greville) Montagne*
Right Whale Bay 10m

*[H] **Erythroglossum undulatissimum** *(J. Agardh) Kylin*
King Edward Point, 5m
Tentative species identification (Figure 4 below)

*[H] **Gelidium crinale** *(Hare ex Turner) Gaillon*

Right Whale Bay 10m, Possession Bay 10m
Species identification tentative

[H] **Georgiella confluens** *(Reinsch) Kylin*
Rosita Harbour 10m, Prion Island 5m, Cooper Bay 18m

*[H] **Gigartina skottsbergii** *Setchell & N.L. Gardner*
Prion Island 5m

[H] **Gymnogongrus turquetii** *Hariot*
King Edward Point

*[H] **Herposiphonia sullivaniae** *(J.D. Hooker & Harvey) Falkenberg*
Prion Island 5m

[H] **Heterosiphonia merenia** *Falkenberg*
Rosita Harbour 10m, Prion Island 5m

*[H] **Hymenena laciniata** *(J.D. Hooker & Harvey) Kylin*
Husvik intertidal

[H] **Hymenocladiopsis crustigena** *R.L Moe*
Prion Island 18m

[H] **Hymenocladiopsis prolifera** *(Reinsch) M.J. Wynne*
Bird Sound 5m

[H] **Iridaea cordata** *(Turner) Bory de Saint-Vincent*
King Edward Point 5m

[H] **Microrhinus carnosus** *(Reinsch) Skottsberg*
Prion Island 5m
Tentative species identification

*[H] **Myriogramme manginii** *(Gain) Skottsberg*
Rosita Harbour 10m

[H] **Myriogramme smithii** *(J.D. Hooker & Harvey) Kylin*
Bird Sound 10m, King Edward Point 5m

[H] **Neuroglossum ligulatum** *(Reinsch) Skottsberg*
Prion Island 5m, Bird island 5m, Cooper Bay, 18m

*[H] **Notophycus fimbriatus** *R.L. Moe*
Prion Island 5m, Rosita Harbour 10m, Right Whale Bay 10m

*[H] **Pachymenia orbicularis** *(Zanardini) Setchell & N.L. Gardner*
Prion Island 5m

[H] **Palmaria decipiens** *(Reinsch) R.W. Ricker*
Rosita Harbour 10m

[H] **Pantoneura plocamiodes** *Kylin*
Right Whale Bay 10m, Husvik 5m, Rosita Harbour 10m

[H] **Phycodrys quercifolia** *(Bory de Saint Vincent) Skottsberg*
Possession Bay 10m

[H] **Phyllophora antarctica** *A. Gepp & E.S. Gepp*
Bird Sound 10m (Figure 5 below)

[H] **Piconiella plumosa** *(Kylin) J. De Toni*
King Edward Point 5m, Prion Island 5m

[H] **Plocamium hookeri** *Harvey*
Right Whale Bay 10m, Rosita Harbour 10m, Cooper Bay 18m,
Right Whale Bay 18m

[H] **Plocamium secundatum** *(Kutzing) Kutzing*
Rosita Harbour 10m

*[H] **Polysiphonia abscissa** *J.D. Hooker and Harvey*
Rosita Harbour 10m
Identification needs further verification

[H] **Porphyra endiviifolia** *(A. Gepp & E.S. Gepp) Y.M Chamberlain*
Prince Olav intertidal, Bird sound 10m, Hope Point intertidal

*[H] **Porphyra Plocamiestris** *R.W. Ricker*
Husvik intertidal, Bird Sound 10m

[H] **Porphyra umbilicalis** *Kutzing*
Husvik 5m (Figure 6 below)

*[H] **Pseudophycodrys phyllophora** *(J. Agardh) Skottsberg*
Right Whale Bay 10m, Prion Island 5m

Tentative identification yet to be confirmed

[H] **Pterothamnion simile** *(J.D. Hooker & Harvey) Nageli*
Prion Island 5m, Cooper Bay 10m

*[H] **Ptilonia magellanica** *(Montagne) J. Agardh*
Prion Island 5m

*[H] **Rhodymenia dichotoma** *J.D. Hooker and Harvey*
Right Whale Bay 10m

[H] **Schizoseris condensata** *(Reinsch) R.W. Ricker*
Prince Olav intertidal, Husvik intertidal

[H] **Synarthrophyton patena** *(J.D. Hooker & Harvey) R.A Townsend*
Prion Island 5m

[H] **Trematocarpus antarcticus** *(Hariot) Fredericq, Moe & Ramirez*
Rosita Harbour 10m

Figures 7 - 12: Herbarium specimens collected at various sites on the north coast of South Georgia that will be held within the Natural History Museum and the South Georgia Heritage Trust.

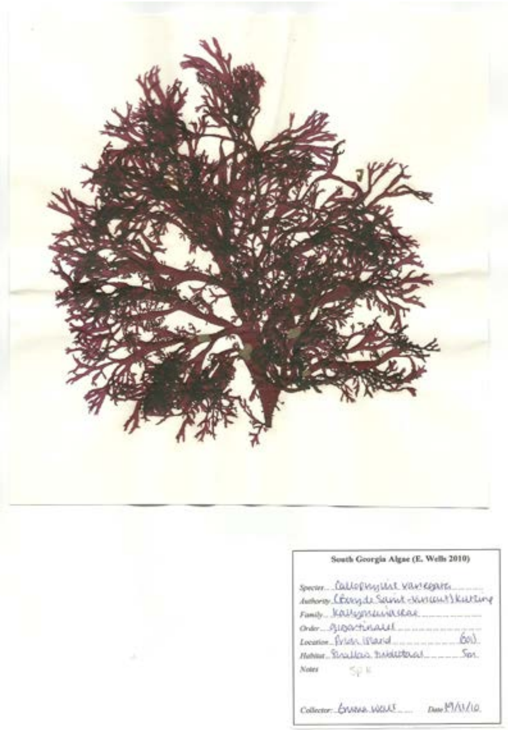

Figure 7: *Callophyllis variegata*

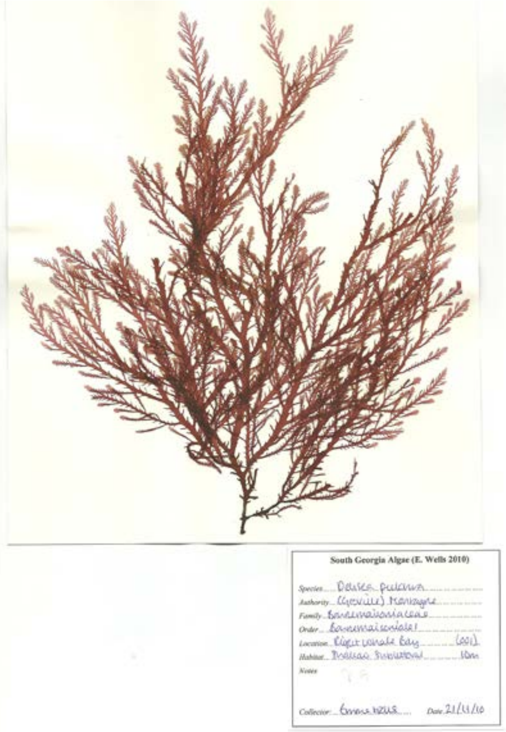

Figure 8: *Delisea pulchra*

Figure 9: *Hymenocladiopsis crustigena*

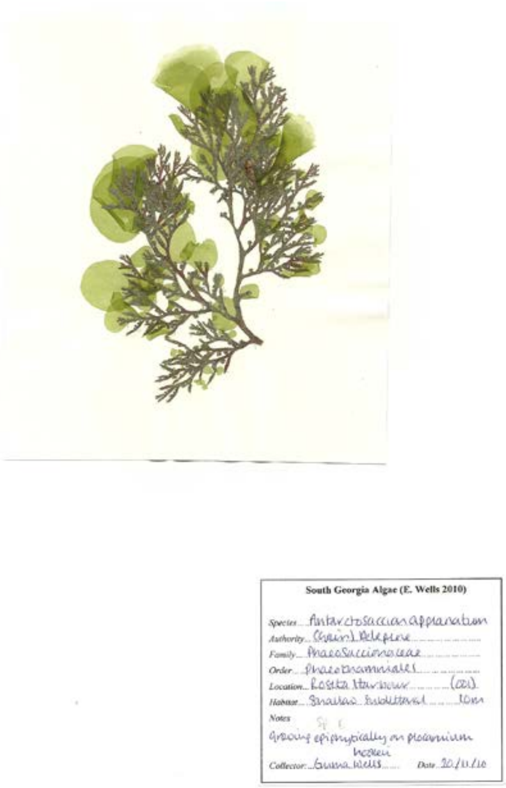

Figure 10: *Antarctosaccion applanatum*

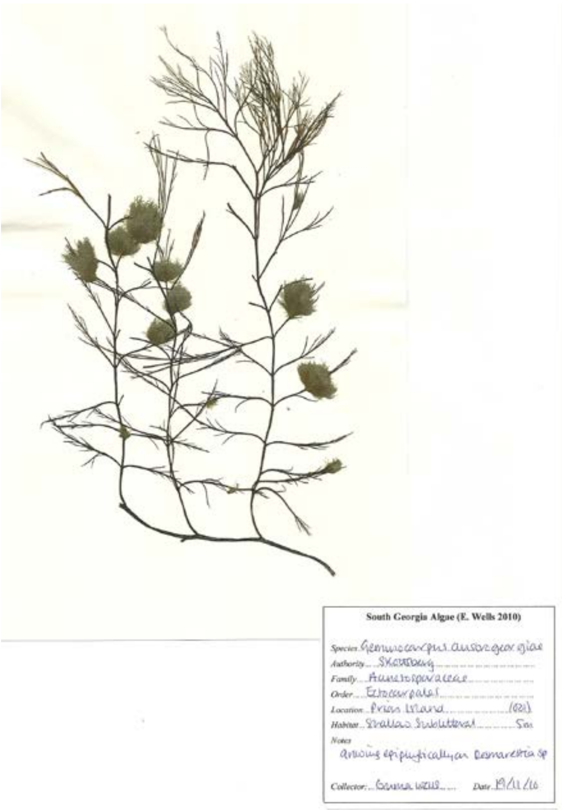

Figure 11: *Geminocarpus austrogeorgica* living epiphytically on *Desmarestia menziesii*

Figure 12: *Phycodrys quercifolia*

General intertidal and subtidal observations

The intertidal at Prince Olav and Husvik locations consisted of rocky platforms and few rockpools with the lower littoral descending steeply into the sublittoral making this area relatively inaccessible for species collection. However, the sublittoral fringe was visibly covered with an abundance of large Phaeophyta and many large foliose Rhodophyta species. There was an overall lack of subhabitats and little overall algal coverage, most of which was restricted to crevices and some small pools. The intertidal was dominated by small common filamentous and foliose Chlorophyta such as *Enteromorpha, Acrosiphonia* and *Prasiola* as well as *Adenocystis* and *Caepidium* with the lower littoral displaying a band of the much larger *Durvillaea* and *Palmaria*. *Durvillaea* was found in abundance in the lower littoral and sublittoral fringe most frequently in exposed areas on relatively steep rock faces. There was a much greater proportion of Chlorophyta and Phaeophyta species with few Rhodophyta species present. Of those species present within the intertidal many can be considered cosmopolitan dominating similar shores around the world.

Figure 13: The intertidal at Prince Olav showing a distinct zonation pattern consisting of an upper green band (*Enteromorpha sp*.) followed by some filamentous and foliose red species most likely to be *Palmaria decipiens.*

Figure 14: The dense band of *Durvillaea antarctica* on the lower littoral and subtidal fringe replacing the band of Laminaria found on the intertidal of the northern hemisphere.

In comparison the sublittoral was dominated by Rhodophyta species and large swathes of *Himantothallus grandifolius* forming a canopy for the underlying blanket of foliose and filamentous species. It is a characteristics trait of the Antarctic sublittoral seaweed vegetation that the Laminariales are absent and that the dominating canopy algae have been taken over by the Desmarestiales including *Desmarestia sp.* and *Himantothallus*.

Figure 15: The large swathes of *Himantothallus grandifolius* found in the shallow sublittoral covering the sea bed like a blanket.

In other areas the base of *Macrocystis* beds provided ideal attachment for many species of *Desmarestia, Delesseria, Ballia* and *Gigartina.* The overall coverage of algae varied considerably between sites due to the substrate. Some finer substrates were relatively scarce in terms of algal abundance with attachment restricted to larger boulders and the holdfasts of some *Macrocystis*. In comparison a number of sites had dense patches of foliage covering vast areas of substrate; these sites were dominated by foliose red algae and species of *Desmarestia*.

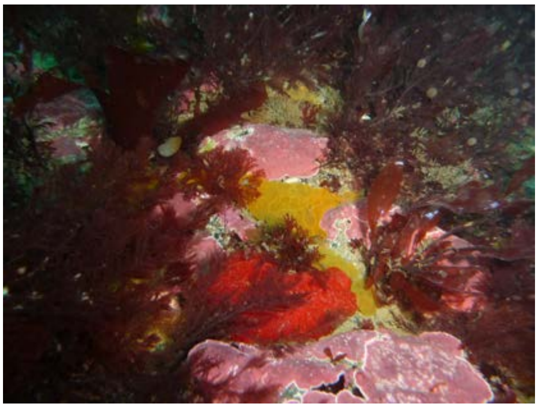

Figure 16: The dominant foliose and filamentous red species of the shallow sublittoral covering last patches of encrusting calcareous red algae.

The Rhodophyta dominated the overall species composition constituting 62.5% of the total sample. Most Chlorophyta were recorded from the intertidal sites, the Phaeophyta also had a large proportion of species from the intertidal. Of the 69 species identified during the study 33% were new records for South Georgia with 4 Chlorophyta, 4 Phaeophyta and 16 Rhodophyta species new to the area.

Table 1: Species lists for all sites, intertidal and subtidal, including totals for the three colour divisions and total species richness.

Site	King Edward Point	Prion Island	Prion Island	Rosita Harbour	Right Whale Bay	Right Whale Bay	Bird Island	Bird Island	Possession Bay	Prince Olav	Prince Olav	Cooper Bay	Cooper Bay	Husvik	Husvik	Correl Bay	Susa Point	Hope Point	Total species richness	New species
Depth	5m	5m	18m	10m	18m	10m	10m	5m	10m	Intertidal	18m	18m	10m	5m	Intertidal	Intertidal	Intertidal	Intertidal		
Species																				
Greens																				
Acrosiphonia sp				1						1								1		
Blidingia minima										1										1
Enteromorpha compressa				1																1
Enteromorpha sp.										1							1			
Monostroma hariotti										1										1
Prasiola crispa						1				1										
Ulothrix speciosa										1										1
Ulva lactuca														1						
																			8	4
Browns																				
Adenocystis utricularis															1		1			
Antarctosaccion applanatum				1																1
Caepidium antarcticum										1					1			1		
Desmarestia confervoides				1								1			1					
Desmarestia menziesii		1										1								
Desmarestia viridis				1																1
Durvilliae antarctica										1										
Ectocarpus fasciculatus												1								
Geminocarpus austrogeorgica		1																		
Geminocarpus germinatus												1								
Halopteris obovata							1													
Himantothallus grandifolius														1						
Hincksia granulosa				1																1
Macrocystis pyrifera		1																		
Microzonia vellutina					1															1
Petalonia fascia				1																
Petroderma maculiforme															1					
Scytosiphon lomentaria				1																
Scytothamnus fasciculatus															1					
																			19	4

Site	King Edward Point	Prion Island	Prion Island	Rosita Harbour	Right Whale Bay	Right Whale Bay	Bird Island	Bird Island	Possession Bay	Prince Olav	Prince Olav	Cooper Bay	Cooper Bay	Husvik	Husvik	Correl Bay	Susa Point	Hope Point	Total species richness	New species
Depth	5m	5m	18m	10m	18m	10m	10m	5m	10m	Intertidal	18m	18m	10m	5m	Intertidal	Intertidal	Intertidal	Intertidal		
Reds																				
Ahnfeltia plicata		1																		
Antarcticothamnion polysporum																				1
Antithamnion pectinatum		1																		1
Ballia callitrichia		1																		
Callophyllis atrosanginea	1	1		1					1	1						1				
Callophyllis variegata	1	1		1																
Ceramium virgatum				1																
Delesseria lancifolia									1											1
Delesseria salicifolia		1							1											
Delisea pulchra						1														
Erythroglossum undulatissimum	1																			1
Gelidium sp. Probably crinale						1			1											1
Georgiella confluens		1		1								1								
Gigartina skottsbergii		1																		1
Gymnogongrus turquetii	1																			
Herposiphonia sullivanae		1																		1
Heterosiphonia merenia		1																		
Hymenena laciniata															1					1
Hymenocladiopsis crustigena			1																	
Hymenocladiopsis prolifera							1													
Iridaea cordata	1									1										
Microrhinus carnosus		1																		
Myriogramme manginii				1																1
Myriogramme smithii	1						1													
Neuroglossum ligulatum		1						1				1								
Notophycus fimbriatus		1		1		1														1
Pachymenia orbicularis		1																		1
Palmaria decipiens				1																
Pantoneura plocamiodes				1		1								1						
Phycodrys quercifolia									1											
Phyllophora antarctica							1													
Piconiella plumosa	1	1																		
Plocamium hookeri				1	1	1						1								
Plocamium secundatum				1																
Polysiphonia abscissa				1																1
Porphyra endiviifolia							1			1								1		
Porphyra plocamiestris							1								1					1
Porphyra umbilicalis														1						
Pseudophycodrys phyllophora						1														1
Pterothamnion simile		1											1							
Ptilonia magellanica		1																		1
Rhodymenia dichotoma						1														1
Schizoseris condensata										1					1					
Synarthrophyton patena		1																		
Trematocarpus antarcticus				1																
																			45	16
Total																			72	24

Discussion

The current survey has enabled an increased number of sites and habitats to be surveyed for benthic algae species within the intertidal and shallow sublittoral of South Georgia. Until this time many species of algae have only been documented from more southern or northern Antarctic and sub-Antarctic shores. It cannot be speculated at this time whether the change in species richness and composition is attributed to climatic changes and shifts in species geographic distribution patterns or through insufficient historical records due to the isolation of such areas and difficulty in conducting sublittoral surveys. It is perhaps a lack of opportunity that has lead to a number of species as yet being unidentified from South Georgia.

There are equally a few species endemic to the Antarctic such as *Antarctosaccion* that until this time have not been recorded from South Georgia. In this instance it is more likely that such species are not new to the island but a result of deficient data records. The presence of *Porphyra plocamiestris* within the intertidal is a new record for South Georgia yet has been recorded in the Antarctic Peninsula (Hommersand, 2009), Anvers Island, King George Island, Macquarie Island (Wiencke and Clayton, 2002) and the South Shetland Islands (Quartina et al., 2005). This further substantiates the theory of Wiencke and Clayton (2002) that knowledge of Antarctic seaweeds is highly incomplete. A number of Chlorophyta species were also new to South Georgia. Due to the wide geographic distribution of such species and their cosmopolitan nature it is possible that increased transportation has provided opportunity to increase their geographic limits to South Georgia.

It is well documented that intertidal communities are considered rare in the Antarctic due to severe ice scour, however, they may establish in sheltered areas but are often dominated by a few, primarily opportunist algae many of which are considered cosmopolitan (Wulff et al, 2009). The magnitude of ice abrasion varies according to the proximity to glaciers but may be documented by the increased dominance of crust forming algae and stunted forms of growth (Moe & DeLaca, 1976). Compared with species richness of temperate and tropical waters Antarctic algae are known to be relatively low in diversity. In general there is both lower diversity and lower biomass within the intertidal (Campana et al, 2009) and this was found to be the case when compared to the shallow subtidal between 5m and 18m.

It has been documented that many shallow subtidal areas, between 3-5m, are often devoid of fleshy macroalgae because of ice scour (Wulff et al, 2009). This may be more localised to the Antarctic Peninsula as there was seen to be a dense covering of foliose and filamentous red algae at such depths around South Georgia. This lack of intertidal and shallow subtidal algae diversity was evident but to a much lesser degree than previously described, with evident algal growth within the top 5m of the subtidal. Currently seaweed distribution is governed to a greater degree in the Antarctic by the presence of rocky habitats where ice scour is limited for at least 4 – 6 weeks during the polar summer (Luning, 1990). However the retreat of the Antarctic ice shelf is likely to provide new rocky habitats for macroalgae (Clarke et al, 2007) which may already be taking place in South Georgia. The Southern Ocean is also the only region in the world devoid of Kelps (Wulff et al, 2009) this was also evident at all sites. Instead these common stands of fucoids are replaced by *Desmarestia* commonly found on more stable bedrock or large boulders and *Himantothallus* which favours pebble substrate (Wulff et al, 2009, Wiencke, 1996, Kloser et al, 1996).

Comparisons with historic data

As previously described there are a number of historic studies that have documented the presence of benthic macroalgae species in South Georgia. Of these records the most comprehensive species list were compiled by Kylin and Skottsberg, which was also the earliest dating back to 1919, Papenfuss (1964) John et al (1994) and the most recent by Wiencke and Clayton (2002). A list of the marine benthic algae from South Georgia based on critical evaluations of published records and examinations of collected material was compiled by John et al (1994). A number of species records underwent nomenclatural revisions and re-examinations of material. Table 2 shows the total historic species records compared with the current study including those numbers of species thought to be new records to South Georgia. It is evident from Table 2 that there is yet to be a fully comprehensive species list compiled for South Georgia. The two most current species lists show the total number of species within each of the colour divisions varies considerably with a greater cumulative number of species, further inviting continued studies in this area.

Table 2: Species richness recorded for Chlorophyta, Phaeophyta, Rhodophyta and total from the current survey, historical records and a cumulative total.

	Chlorophyta	Phaeophyta	Rhodophyta	Total
Current survey	8	19	45	72

Historical records (John et al, 1994)	9	37	57	103
New species	4	4	16	24
Cumulative list	13	41	73	127

The number of previously undiscovered species from South Georgia is not surprising given the subtidal habitat preference of many of these species. It is also difficult to speculate as to which of these species are recently introduced and which are well established due to the cosmopolitan nature of many and their recognition as temperate species. Despite the high proportion of endemic species in the Antarctic more recent studies such as this are identifying those more widespread species (Clayton et al, 1997). Whether this is due to increased familiarity with such species or a genuine shift in distribution pattern remains to be investigated.

Table 2 also compares the varying levels of species diversity from the different taxonomic groups from the current survey results and historical data sets. This information highlights the lack of consistency in species composition and suggests much higher species richness than first anticipated. Despite a new total species richness of 127 there have been a number of species previously recorded that were not recorded in the current survey particularly with reference to the Phaeophyta species with a difference of 18 species. It is important that such species remain to be found within these locations to ensure that historic populations are still thriving.

Those species not previously recorded from South Georgia included, from the Chlorophyta: *Blidingia minima, Enteromorpha compressa, Monostroma hariotii, Ulothrix speciosa.* There have been very few Chlorophyta species recorded from this area over the last few centuries with a maximum diversity of 6 species recorded by John *et al* (1994)*,* although some consistent Genera were identified during the current survey the species varied. All the new records of Chlorophyta from the current survey, with the exception of *Monostroma hariotii,* are considered cosmopolitan. However, none of these previously unrecorded species appear to be new entities to the area with documentation of a broader distribution within the Antarctic (Wiencke & Clayton, 2002).

Of the Phaeophyta species a total of 4 new species were recorded from South Georgia which included the following: *Antarctosaccion applanatum, Hincksia granulosa, Microzonia vellutina and Scytosiphon lomentaria. Scytosiphon* has been recorded from other Antarctic locations but its infrequent documentation from such areas suggests it to be an adventive species. Despite its cosmopolitan status its increased presence in such locations may assist with the study of changes in distribution patterns of this and many other cosmopolitan species. *Hincksia* may also be referred to as a cosmopolitan species with records extending through Europe, Africa, Asia and the Americas with the southernmost records previously documented from New Zealand (Adams, 1994) and Chile (Ramirez & Santilices, 1991). In contrast *Antarctosaccion* is endemic to the Antarctic, documented from the Antarctic Peninsula and the South Shetland Islands but has remained unrecorded from South Georgia until the current survey. *Microzonia* although not a species endemic to the Antarctic does display a southern oceans distribution pattern with records from Australia and New Zealand (Adams, 1994) and the Antarctic and subantarctic islands such as Macquarie Island (Ricker, 1987).

Sixteen Rhodophyta species were new records for the area. Two of these are thought to be cosmopolitan species, Antithamnion pectinatum and Gelidium crinale, both of which have been recorded from a number of northern and southern hemisphere locations. Many of the new species records have also been identified from a number of other Antarctic and subantarctic locations as well as South America, New Zealand and Australia including *Delesseria lancifolia, Gigartina skottsbergii, Herposiphonia sullivaniae, Hymenena laciniata, Pachymenia orbicularis, Polysiphonia abscissa, Pseudophycodrys phyllophora, Ptilonia magellanica* and Rhodymenia dichotoma (Kylin and Skottsberg, 1919, Ramirez and Santelices, 1991, Papenfuss, 1964, Ricker, 1987, John et al, 1994). Although these species show no changes in their broad geographic distribution records their presence in South Georgia is still important for following future changes in localised distributions patterns. An additional four species identified in the current study are considered endemic to Antarctica; *Antarcticothamnion polysporum, Myriogramme mangini, Notophycus fimbriatus and Porphyra plocamiestris.* Until this now these endemic species have remained unrecorded from South Georgia and are an important addition to the species list. A final species *Erythroglossum undulatissimum*, has until now remained undescribed from the Antarctic with previously records only existing for New Zealand (Adams, 1994). Although the identification of this species remains tentative validation of this could prove to be an exciting find and possibly indicate an increased distribution limit for this species causing further speculation as to its form of transportation, natural or human induced.

For some species it was difficult to validate identification with many conflicting descriptions and general lack of species information from this geographic area. It is highly possible that a number of species have failed to be recorded due to unfamiliarisation with local species and may have been misidentified in situ. One such common species is the large endemic Phaeophyta species *Ascoseira mirabilis*, a large kelp like species that may have been mistaken for morphologically similar species, *Himantothallus,* due to poor diving conditions.

It is likely that there are a number of species yet to be identified and recorded from South Georgia. Despite the large geographic area covered within the current study the survey areas were considerably limited due to dive times and general conditions. The basic laboratory facilities and sheer scale of work undertaken in a short period of time prevented full examination of seaweed specimens prior to pressing for preservation. As a consequence it is expected that a number of microscopic algae have also been overlooked. Two epiphytic red species have been located in host species but as yet remain unidentified (Figures 17 and 18).

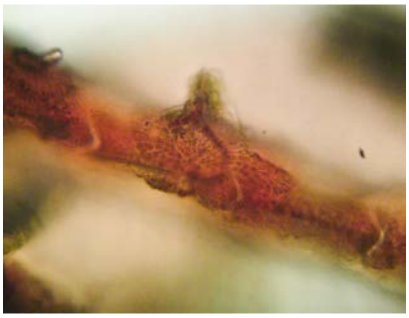

Figure 17 (left): Red algae species living epiphytically within a larger filamentous red algae.

Figure 18 (right): Small red algae species living epiphytically in Desmarestia viridis.

For some specimens it was also only possible to achieve identification to genus level with limited confidence, this was primarily due to lack of species descriptions however it is anticipated that clarification will be achieved in the near future. There are also a number of calcareous encrusting algae that have not been recorded within the current study for which identification is incredibly difficult particularly in the absence of specimen material and basic identification will only be achievable through photographs alone (Figure 19).

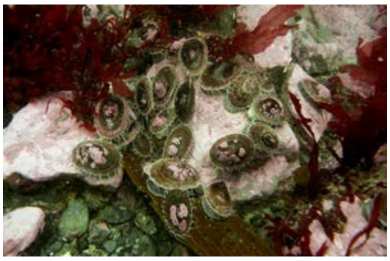

Figure 19: Red calcareous encrusting algae living on both the rock surface and epiphytically on local faunal species.

Studies of Antarctic seaweeds remain difficult due to severe lack of taxonomic and distributional information available (Clayton, 1994). This may be attributed to the remote location of South Georgia and inaccessibility of both intertidal and subtidal algal habitats resulting in infrequent studies with limited and sometimes inconsistent species descriptions. Despite some species identification remaining tentative this does not greatly affect the diversity of species recorded which has proved to be far greater than previously recorded. At this stage there are no new species to science but with some species remaining to be identified the possibility cannot be completed overlooked.

Seaweed Migration

It is commonly known that seaweed species can be carried expansive distances by both ocean currents and transferred between locations via human transportation. Although South Georgia remains largely inaccessible to most, tourism is enabling increased human activity within localised areas. This can prove beneficial in terms of disseminating important information as to the hostile and somewhat fragile nature of the Antarctic and aid with future preservation and conservation projects. But with this also comes the risk of introducing new species. Particularly detrimental are those of an opportunist nature able to inhabit and tolerate a variety of habitats and environmental conditions causing potential interference and competition with native species. The introduction of so called alien species may also obstruct the detection of long term changes from global warming.

Such migration of species along coastlines during periods of temperature change has already been documented over long time scales the most recent example taken from Hiscock et al (2004) where seaweeds were seen to migrate within the North Sea and English Channel after a short warm period in the early 20th century. However, it has been predicted that for South Georgia the sea surface temperature will not change significantly during the 21st century, this is not the case for other locations where changes are predicted to be more considerable (Muller et al, 2009). Despite this, South Georgia has been regarded as a prominent stepping stone in the southern migration route from the Patagonian Coastline to the Antarctic Peninsula with evidence already provided from the expanded distribution limits of animals and possibly the seaweed *Chordaria linearis* (Luning, 1990). It is also thought that the identification of *Blidingia minima* and *Petalonia fascia* in the current study may be the initial signs of migrational shifts (Muller, 2009). Therefore comparing current and historic species records and community characteristics are key to identifying distribution shifts.

Most studies to date have focused around basic research with little consideration as to the impacts of global climate changes on marine benthic algae and how the knowledge of these communities can assist with monitoring such changes. It has already been argued that the existing Antarctic algal flora has been influenced by climate change over geological time as well as changes in ocean currents (Wiencke & Clayton, 2009a). It is also the Polar Regions that are under most threat from global climate change. More specifically, the melting of glaciers will reduce salinity, increase sedimentation and decrease light penetration affecting algal succession and ultimately lead to changes in benthic community structure and function (Wiencke & Clayton, 2009a). An increase in water temperatures would allow such temperate species as *Scytosiphon, Petalonia, Enteromorpha* and *Ulothrix* to increase their population size within Antarctic waters. Equally the presence of Blidingia recorded during the current study is considered to be related to climate warming (Campana et al, 2009, Muller et al, 2009).

Unfortunately, due to the nature of this study it was not possible to determine distribution patterns of the macroalgae with regards to habitat, geographical location or depth. This is something that requires further investigation in the future.

Conclusion

Comparisons of current data with historical species lists provide evidence that to date this is singly the most comprehensive record of species richness from the shallow sublittoral of the north coast of South Georgia. It may be speculated that subsequent surveys are likely to result in further records of benthic macroalgae particularly if the survey is to be extended to the southern coastline of South Georgia. However, it is fair to say that at this stage the species list for South Georgia is not exhaustive, advances in molecular phylogeny is likely to cause such lists to be continually refined and this account of seaweed presence in South Georgia is only representative of the selected number of sites surveyed and specimens collected within the short time period.

This study has highlighted the uncertainty that still lies around the taxonomy of many Antarctic species and conflicting species descriptions. Of equal concern is the evident gap in biodiversity studies that still exist for the Antarctic (Wulff et al, 2009, Hommersand et al, 2009, Wiencke and Clayton, 2009a, Muller et al, 2009) and the importance surrounding the need to rectify this as a foundation from which to follow future changes (Muller et al, 2009). It is the changes in composition and diversity levels of seaweed that will assist in monitoring such environmental transformations. All these factors prompt the need for more intensive studies on the benthic marine algae of the Antarctic.

References

Adams, N.M. (1994). *Seaweeds of New Zealand*. An Illustrated Guide. pp. [1-7], 8-360, 116 pls. Christchurch: Canterbury University Press.

Boraso, A and Zaixso, J.M. 2008. Atlas de Sensibilidad Ambiental de la Costa y el Mar Argentino. Algas marinas bentónicas. http://atlas.ambiente.gov.ar/tematicas/mt_02/macroalgas.htm

Campana, G.L., Zacher, K., Fricke, A., Molis, M., Wulff, A., Quartino, M.L. and Wiencke, C. 2009. Drivers of colonization and succession in polar benthic macro- and microalgal communities. *Botanica Marina*. 52: 655 – 667.

Clarke, A., Murphy, J., Meredith, M.P., King, J.C., Peck, L.S., Barnes, D.K.A and Smith, R.C. 2007. Climate change and the marine ecosystem of the western Antarctic Peninsula. *Phil. Trans. R. Soc. B.* 362: 149 – 166.

Clayton, M.N., Wiencke, C. and Kloser, H. 1997. New records of temperate and sub Antarctic marine benthic macroalgae from Antarctica. *Polar Biology*. 17: 141 – 149.

Cotton, A.D. 1915. Cryptograms from the Falkland Islands collected by Mrs Vallentin and described by A.D. Cotton. *Journal Linnean Society, Botany*. 43: 137 – 231.

Delepine, R., Lamb, J.M. and Zimmerman, M.H. 1996. Preliminary report on the vegetation of the Antarctic peninsula. *Proceedings International Seaweed Symposium*. 5:107 – 116.

Dhargalkar, V. K and Verlecar, X.N. 2009. Southern Oceans seaweeds: A resource for exploration in food and drugs. Aquaculture. 287: 229 – 242.

Gain, L. 1912. La Flore algologique des regions antarctiques et subantarctiques. In: Charcot, J.: Deuxieme expedition Antarctique francaise (1908 – 1910). Sciences naturelles: Documents scientifiques, tome 8, Masson et Companie, Paris p 1 – 218.

Gaudichaud, C. 1826. Botanique. In: Freycinet, L. (ed.) Voyage autour du monde, entrepons par ordre du Roi, ...execute sur le corvette de S. M. 'I 'Uranie' et la 'Physicienne', Pendant les annees 1817, 1818, 1819 et 1820, Pillet Aine, Paris, 522.

Guiry, M.D. & Guiry, G.M. 2011. *AlgaeBase*. World-wide electronic publication, National University of Ireland, Galway. http://www.algaebase.org; searched on 26 July 2011.

Hiscock, K., Southward, A., Tittley, I. And Hawkins, S. 2004. Effects of changing temperature on benthic marine life in Britain and Ireland. *Aquatic Conservation: Marine and Freshwater Ecosystems.* 14: 333 – 362.

Hooker, J.D. 1847. The botany of the Antarctic voyage of H.M. discovery ships, Erebus and Terror. Vol. I Flora Antarctica. Part II. Botany of Fuegia, the Falklands, Kerguelens Land, etc. Reeve Brothers, London p 209 – 574.

Kloser, H., Ferreyra, G., Schloss, I., Mercuri, G., Laturnus, F. and Curtosi, A. 1993. Seasonal variation of algal growth conditions in sheltered Antarctic bays: The example of Potte Cove (King George Island, South Shetlands). Journal of Marine Systems. 4: 289 – 301.

Kloser, H., Quartino, M.L. and Wiencke, C. 1996. Distribution of macroalgae and macroalgal communities in gradients of physical conditions in Potter Cover, King George Island, Antarctica. Hydrobiologia. 333: 1 – 17.

Kylin, H. & Skottsberg, C. (1919). Zur Kenntnis der subantarktischen und antarktischen Meeresalgen. II. Rhodophyceen. In: *Wissenschaftliche Ergebnisse der Schwedischen Südpolar-Expedition 1901-1903*. (Nordenskjöld, O. Eds) Vol.4, fasc. 15, pp. 1-88. Stockholm: Litographisches Institut des Generalstabs.

Lamb, I.M. and Zimmermann, M.H. 1977. Benthic marine algae of the Antarctic Peninsula. Antarctic Research Series 23, Biology of the Antarctic Sea V, paper 4: 129 – 229.

Luning, K. 1990. *Seaweeds: their environment, biogeography and ecophysiology*. Wiley& Sons, New York.

Moe, R.L. and DeLaca, T.E. 1976. Occurrence of macroscopic algae along the Antarctic Peninsula, *Antarctic Journal US*. 11:20 – 24.

Muller, R., Laepple, T., Bartsch, I. And Wienck, C. 2009. Impact of oceanic warming on the distribution of seaweeds in polar and cold-temperate waters. *Botanica Marina*. 52: 617 – 638.

Nueshul, M. 1966. Diving observations of subtidal Antarctic marine vegetation. *Botanica Marina.* 8: 234 – 243.

Papenfuss, G.F. (1964). Catalogue and bibliography of Antarctic and Sub-Antarctic benthic marine algae. In: *Bibliography of the Antarctic Seas*. (Lee, M.O. Eds) Vol.1, pp. 1-76. Washington D.C.: American Geophysical Union.

Ramírez, M.E. & Santelices, B. (1991). Catálogo de las algas marinas bentónicas de la costa temperada del Pacífico de Sudamérica. *Monografías Biológicas* 5: 1-437.

Ricker, R.W. (1987). *Taxonomy and Biogeography of Macquarie Island Seaweeds*. pp. vi + (2) + 344. London: British Museum (Natural History).

Skottsberg C. 1923. Botanische Ergebnisse der schwedischen Expedition nach Patagonien und dem Feuerlande 1907 – 1909, IX. Marine Algae, 2. Rhodophyceae. Kungliga Svenska Vetenskapsakademiens Handlingar 63 (8): 70.

Skottsberg, C. 1907. Zur Kenntnis der subantarktischen und antarktischen meersalgen, I. Phaeophyceen. In: Nordenskjold, O (ed.): Wissenschaftliche Ergebnisse der Schwedischen Sudpolarexpedition 1901 – 1903, Band IV, Lieferung 6, Lithographisches Institut des Generalstabs, Stockholm, A. Asher & Co., Berlin W, Haar & Steinert, A. Eichler, Succir, Paris, Dulau & Co, London, W., 172.

Skottsberg, C. 1921. Botanische Ergebnisse der schwedischen Expedition nach Patagonien und dem Feuerlande 1907 – 1909, Viii Marine Algen 1. Phaeophyceae. Kungliga Svenska Vetenskapsakademiens Handlingar 63 (11): 56.

Wiencke, C and Clayton, M. 2009. Biology of polar benthic algae. *Botanica Marina*. 52: 479 - 481

Wiencke, C. 1996. Recent advances in the investigation of Antarctic macroalgae. *Polar Biology*. 16: 231 – 240.

Wiencke, C. and Clayton, M. 2002. *Antarctic seaweeds. Synopsis of the Antarctic benthos 9*. ARG Gantner Verlag KG, Ruggell, Lichtenstein.

Wiencke, C. and Clayton, M. 2009. Future perspectives on the investigation of polar benthic algae. *Botanica Marina*. 52: 669 – 671.

Wienkce, C, Gomez, I. And Dunton, K. 2009. Phenology and seasonal physiological performance of polar seaweeds. *Botanica Marina*. 52: 585 – 592.

Wulff, A. Iken, K., Quartino, M.L., Al-Handal, A., Wiencke, C. And Clayton, M. 2009. Biodiversity, biogeography and zonation of marine benthic micro- and macroalgae in the Arctic and Antarctic. *Botanica Marina*. 52: 491 – 507.

Zaneveld, J.S. 1966. Vertical zonation of Antarctic and subantarctic benthic marine algae. Antarctic Journal of the United States. 1: 211 – 213.

Zaneveld, J.S. 1968. Benthic marine algae, Ross Island to Balleny Islands. Antarctic Map Folio Series. American Geographical Society New York, Folio. 10: 1 – 12.