I. INTRODUCTION

Submarine topographical relief that influences tidal currents are a recognised phenomena (Schneider & Hunt 1982, Haney & McGillivary 1985, Briggs *et al.* 1987 in Skov & Durinck 2000), and can influence the activity of prey and predator at a range of trophic levels (Brown 1980, Safina & Burger 1985, 1989, Decker 1995, Goss *et al.* 1997 in Swartzman & Hunt 2000), on different temporal (Currio 1976, Bell 1991 in Irons 1998) and spatial scales (Alldredge & Hamner 1980, Hamner & Hauri 1981, Omori & Hamner 1982, Zavodnik 1987 in St. John & Pond 1992).

The marine environment and its associated 'producers' are regarded as patchy in distribution, which means predators must forage for food. If a physical feature or interaction causes a concentration of the correct prey species, this will often catalyse an associated food chain at one spatial location or temporal scale. Fronts and upwellings are regarded as one type of physical process that can create these conditions (Mooers *et al.* 1978 in Owens 1981). Tidal upwellings and currents have been successfully studied (Alldredge & Hamner 1980, Hunt Jr. 1997, Irons 1998, Kinder *et al.* 1983, Mehlum 1998, 1999, Mendes *et al.* 2002, Uda & Ishino 1958, Webb *et al.* 1990) and the research of Zamon (2001, 2002, 2003) and Irons (1998) on the east coast of the Pacific show similarities to the potential conditions exhibited by the Gulf of Corryvreckan, Scotland.

The 'tidal-coupling hypothesis' suggested by Uda & Ishino 1958, Brown 1980, Johannes 1981, Wolanski & Hamner 1988, review in Hunt *et al.* 1999, Zamon 2001 in Zamon 2002 relates tidal phase to the interactions between currents, plankton and planktivorous fish, and can be used to describe the activity that is associated with the Gulf of Corryvreckan. The open sea region to the west of the Gulf toward Colonsay could exhibit the conditions required for phytoplankton production (Grantham 1983, Oatham 1983), and there are recognised frontal zones to the south (Barne *et al.*, 1997). Plankton at the periphery of a patch 'blooming' to the west of the Gulf could be drawn into the channel by the ebb (west-going) tide. Tidal fronts and up-wellings might then

create barriers that concentrate the plankton. The resultant effect draws in planktivorous fish, such as sandeels and herring. If the plankton are forced directly to the surface, planktivorous seabirds may be attracted. This increased biomass brings in piscivorous predators, like mackerel, porpoise and other seabirds. The speed of the currents could affect the level of concentration and distribution of the various prey, and therefore define the levels of attendance by the different species, as they are influenced by their own physiological limitations.

Studies of frontal systems and upwelling zones are worldwide and at varying scales. Upwellings and their influence on biological systems have been studied for many years (Uda & Ishino, 1958) and continue to be researched to this day (Hastie *et al.* 2004, Weichler *et al.* 2004). Research occurs worldwide from the tropical hemisphere (Wolanski *et al.*, 1988) to the polar regions (Baretta & Hunt Jr. 1994, Hunt Jr. 1997), and some closer to home (Hastie *et al.* 2003, 2004, Mendes *et al.*, 2002, Grantham 1983). The survey areas vary from hundreds of kilometres (Mehlum *et al.*, 1999) to tens of kilometres (Morgado *et al.* 2003, Mouny & Dauvin 2002, Parsons *et al.* 1981, Skov & Durinck 2000, St. John & Pond 1992, St. John *et al.* 1992, Zamon 2001, 2002, 2003) down to less than one kilometre (Hastie *et al.* 2004, Mendes *et al.* 2002)

There has been little research into the primary production and its associated consumers in the Firth of Lorn. In the early 1980's, the Scottish Association of Marine Science (SAMS, then SMBA) based at Dunstaffnage in Argyll compiled data on the hydrography, nutrients and chlorophyll levels of the Firth of Lorn (Grantham, 1983a, 1983b Grantham *et al.* 1983, Oatham 1983). There was some evidence to suggest the area to the west of the Gulf of Corryvreckan exhibited estuarine characteristics, with a 'salt-wedge' intrusion from the south, and studies in July 1983 (Grantham *et al.* 1983) showed evidence of thermal stratification in the mid depth waters. These conditions are widely accepted as ideal for primary production, by phytoplankton, to occur. There are many studies that examine the relationship between primary production and the associated food chain (Alldredge & Hamner 1980, Hamner & Hauri 1977, Vermeer *et al.* 1987, Wolanski & Hamner 1988 in Irons 1998, Mehlum *et al.* 1998, Mendes *et al.* 2002,

Owens 1981, Skov & Durinck 2000, St. John *et al.* 1992, St. John & Pond 1992, Webb *et al.* 1990, Zamon 2002).

Research into associations between marine organisms and physical processes is well developed (Hastie *et al.* 2003, 2004, Zamon 2001,2002, 2003) and regarded by some as essential to fisheries policy (Furness 2002, Camphuysen & Garthe 1997). These studies focus from the primary production (Uda & Ishino 1958, Parsons *et al.* 1981) through planktonic associations (St. John *et al.* 1992, Vermeer *et al.* 1987, Zamon 2002) and planktivorous fish (Suryan *et al.* 2002, Weichler *et al.* 2004) to piscivorous predators (Zamon 2001, 2003, Hastie *et al.* 2003b, 2004, Irons 1998, Barrett *et al.* 2002, DeNardo *et al.* 2001, Mehlum *et al.* 1998, Raum-Suryan *et al.* 1998)

The Gulf of Corryvreckan (or *coire bhreacain*, Gaelic for 'speckled cauldron') is internationally renowned for producing the third largest whirlpools in the world. To many sailing folk, its name conjures images of six metre 'standing' waves and deep 'sucking' whorls. Ferocious currents and an unpredictable nature make the Corryvreckan an area to be respected by all boat users. However, this fearsome reputation belies its importance to a variety of wildlife. It is well regarded by many as a haven for feeding seabirds and marine mammals, and is the centre of a thriving eco-tourism network, approximately 100 in the Oban area alone. The difficulties and dangers of studying such an environment have meant little research has been structured about this area. Nevertheless, the cliffs of Jura and Scarba are steep and high, making a land-based study extremely feasible.

It is the tidal nature of the Gulf, which potentially drives a food web associated with the area. The whole of the west coast of Scotland is renowned for cetacean (Barne *et al.* 1997, Weir *et al.* 2001) and seabird activity (Webb *et al.*, 1990). This is due to its varied habitat structure (Barne *et al.* 1997, Davies 1999, Grantham 1983a) and proximity to the deep waters of the NE Atlantic. With the productive inshore waters (Grantham *et al.*, 1983) and the unique hydrographic features (Barne *et al.* 1997, Haswell-Smith 1996), the Gulf of Corryvreckan could support a well-developed tidal-driven ecosystem.

But little research has been centred about this area; Davies (1999) mapped the habitat structure and associated biota of the Firth of Lorn including the Gulf of Corryvreckan, while others (Grantham 1983, Oatham 1983) have studied the productivity of waters to the north and west of the Gulf. Some have collected incidental data on cetacean activity (Seafari Appendix C, HWDT *pers. comm.*) within the channel. But, the tidal currents and unpredictable nature make the Gulf a difficult study site (Elliott, *pers. obs.*).

A land-based survey from one of the islands is the safest, most cost-effective and least intrusive method for studying the area (Denardo *et al.* 2001, Evans & Hammond, 2004). This method of research is well regarded (Hastie *et al.*, Evans & Wang 2002, Zamon) and a developed technique (Gordon 2001, HWDT *pers. comm.*).

The aim of this study was to assess whether distribution of seabirds and cetaceans changed with the tidal activity within the Gulf of Corryvreckan.

The objectives of this study were:

1. To determine whether there were significant differences in seabird and/or cetacean abundance on an ebb or flood tide.
2. To investigate whether the tidal phase and/or strength had any effect on the species observed.
3. To assess any differences in small-scale distribution of seabirds or cetaceans.