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Sensitivity of Intertidal Benthic Habitats to Impacts Caused by Access to Fishing Grounds

Dr Harvey Tyler- Walters & Chloe Arnold

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Mae'r astudiaeth hon yn rhan o brosiect mwy y mae Cyngor Cefn Gwlad Cymru yn ei weithredu ar hyn o bryd, i fapio sensitifrwydd cynefinoedd dyfnforol i weithgareddau pysgota ar hyd arfordir Cymru a dyfroedd y glannau. Mae yna bosibilrwydd y gall mynediad i bysgodfeydd penodol ddifrodi cynefinoedd, hyd yn oed pe nad ystyrid fod gweithgareddau'r bysgodfa ynddynt eu hunain yn effeithio ar y cynefinoedd ble maent yn digwydd. Mae mynediad yn cynnwys mynediad gan gerbydau neu ar droed, ac fe'i dosbarthwyd yn lefelau ysgafn, cymedrol a thrwm o ran dwysedd. Fe gynigiwyd diffiniadau mewn adroddiad drafft a gynhyrchwyd gan Brifysgol Lerpwl, ac a drafodwyd mewn gweithdy a gynhaliwyd yn Neganwy ar 21 - 22 Mehefin 2007. Fe gafodd y diffiniadau yma eu hystyried yn y lefelau dwysedd.

Nod yr astudiaeth hon oedd archwilio gwaith/ymchwil blaenorol ar effeithiau mynediad ar hyd y blaendraethau er mwyn cynnal adolygiad llenyddiaeth, penderfynu ar effeithiau mynediad ar y 'grwpiau o gynefinoedd' a nodwyd, a defnyddio'r wybodaeth i greu matrics sensitifrwydd o effeithiau'r gwahanol ffurfiau a lefelau mynediad.

Gwnaed adolygiad o dros 200 o gyfeiriadau at effeithiau troedio a mynediad gan gerbydau ar gynefinoedd rhynglanwol, wedi ei helaethu gan wybodaeth ar ecoleg hamdden cynefinoedd arfordirol daearol a gwybodaeth gan sefydliadau perthnasol. Amlygwyd y canlynol yn yr adolygiad.

- Astudiwyd effeithiau troedio ar y glannau rhynglanwol creigiog yn gymharol dda, ond astudiaeth gymharol wael a wnaed ar y glannau gwaddodol.
- Roedd yr astudiaethau ar y troedio a'u canlyniadau yn amrywiol iawn, ond yn dangos fod yr effeithiau'n dibynnu ar natur y cynefinoedd sydd yno, a grym y troedio. Mae mwy o droedio'n golygu llai o fioamrywiaeth, llai o gyflenwad neu fiomas o rywogaethau yr effeithir arnynt (yn enwedig macroalgâu), a mwy o fannau llwm ac, mewn rhai achosion, llwybrau clir.
- Canlyniad i gyffyrddiad corfforol a thraul oedd effeithiau'r troedio, gan ddibynnu ar rym, parhad, ac amlder y troedio, a hyd yn oed y math o esgidiau a wisgwyd.
- Roedd algâu sy'n ffurfio'r Canopi Deiliog (e.e. gwymon codog) yn arbennig o anoddefgar a sensitif i effeithiau troedio;
- Roedd troedio'n difetha tywyrch cwrel unionsyth, cregyn llong, ac o ganlyniad cafwyd cynnydd mewn mannau llwm; mewn rhai achosion roedd llwybrau ar draws y traeth yn weladwy;
- Ar y glannau lle roedd algâu brown amlycaf, gallai isdyfiant algâu ddioddef oherwydd cynnydd mewn dysychiant, ond fe allai niferoedd rhywogaethau tywyrch algâu, manteiswyr a phorwyr '*gastropod*' (e.e. llygaid meheryn) gynyddu'n fawr o ganlyniad anuniongyrchol i droedio.
- Dangoswyd fod troedio ar dywod lleidiog rhynglanwol a mwd yn lleihau niferoedd rhai isfilod, tra cynyddai niferoedd meioffawna a mwydod gwrychog isfilodaidd manteisgar. Yr un pryd, cafwyd effaith wael ar gregyn deuglawr.
- Ychydig iawn o astudiaethau sydd yna ar effeithiau cerbydau yn y rhynglanw; nid oedd yr un ohonynt yn uniongyrchol berthnasol i fynediad i bysgodfeydd.
- Yn gyffredinol fe ystyrir fod cerbydau'n gwneud mwy o ddifrod na cherdded (tua 30 i 5) oherwydd eu pwysau a'u pŵer, ond mae lefel y difrod yn amrywio o gerbyd i gerbyd, sut y cânt eu gyrru a natur y cynefinoedd sydd dan sylw.
- Difrodwyd gwelyau o forwellt gan effeithiau troedio, ond yn fwyfwy gan gerbydau, gan y gallent fod yn arbennig o sensitif iddynt.

Aseswyd sensitifrwydd 16 o wahanol gynefinoedd rhynglanwol i effeithiau tebygol mynediad ar droed a cherbydau i bysgodfeydd. Yn seiliedig ar waith Hall *et al.* (2008), cynigwyd graddio'r effeithiau mynediad ar droed a mynediad gan gerbydau, a’r ymatebion gan sefydliadau perthnasol. Er nad oedd sail y dystiolaeth yn caniatáu cymhariaeth uniongyrchol rhwng graddfeydd mynediad a lefelau grym yr effeithiau a adroddwyd, ni chaniataodd llenyddiaeth yr adolygiad i sensitifrwydd gael ei asesu ar sail barn arbenigol. O ganlyniad, mae’r sensitifrwydd yn yr adroddiad hwn o natur ragofalus. Fe argymhellir fod yr asesiadau sensitifrwydd a gyflwynir yma yn amodol ar esboniad pellach yn seiliedig ar wybodaeth leol ac ymgynghoriad. Yn ogystal â hyn, argymhellir rhagor o astudiaethau ar effeithiau troedio, ac yn arbennig mynediad gan gerbydau ar gymunedau rhynglanwol.

EXECUTIVE SUMMARY

This study is part of a larger project that Countryside Council for Wales (CCW) are currently undertaking to map the sensitivity of benthic habitats to fishing activities around the Welsh coast and coastal waters. There is the possibility that access to particular fisheries may damage habitats, even if the fishery activity itself is not deemed to have an impact on the habitat where it occurs. Access included both vehicle and foot access, and was grouped into light, moderate and heavy intensity. Intensity levels took into account the existing definitions that were put forward in the draft report produced by the University of Liverpool and discussed during a workshop held in Deganwy on 21st – 22nd June 2007.

This study aimed to examine previous research/work on the impacts of access across the foreshore in order to conduct a literature review, determine the effect of access on the identified ‘habitat groups’ and use the information to create a sensitivity matrix of the effects of the different forms and levels of access.

A review of over 200 references on the impacts of trampling and vehicular access on intertidal habitats was undertaken, augmented by information on the recreational ecology of terrestrial coastal habitats and information from relevant organizations. The review highlighted the following.

- Trampling has been relatively well studied on the intertidal rocky shores but relatively poorly studied on sedimentary shores.
- Trampling studies and their results were highly variable but demonstrate that the impacts depend on the nature of the receiving habitat and the intensity of trampling, with increasing trampling resulting in reduced biodiversity, reduced abundance or biomass of affected species (especially macroalgae) and increased bare space and, in some cases, clear paths.
- Trampling impacts resulted from physical contact and wear and were dependant on the intensity, duration, and frequency of trampling, and even the type of footwear used.
- Foliose canopy forming algae (e.g. fucoids) were particularly intolerant and sensitive to trampling impacts;
- Trampling damaged erect coralline turfs, barnacles, and resulted in an increase in bare space; in some cases paths across the shore were visible;
- On brown algae dominated shores, understorey algae could suffer due to increased desiccation but algal turf species, opportunists and gastropod grazers (e.g. limpets) could increase in abundance as an indirect effect of trampling,
- Trampling of intertidal muddy sands and muds was shown to reduce the abundance of some infauna while increasing the abundance of presumably opportunistic infaunal polychaetes and meiofauna, while bivalves were adversely affected.
- There are very few studies of the effects of vehicles in the intertidal; none of which were directly relevant to access to fishing grounds.
- Vehicles are generally considered to do more damage than walking (ca 5- 30 fold) due their greater weight and power but the level of damage varies with the vehicles used, how they are driven and the nature of the receiving habitat.
- Seagrass beds were damaged by trampling but more so by vehicular access to which they may be particularly sensitive.

The sensitivities of 16 separate intertidal habitats were assessed to the likely effects of foot and vehicular access to fishing grounds. Foot access and vehicular access intensity scales were

suggested based on the work of Hall *et al.* (2008) and the responses from relevant organizations. Although, the evidence base did not allow direct comparison between the access scales and the reported levels of impact intensities, the literature review did allow sensitivity to be assessed based on expert judgement. As a result, the sensitivities given in this report are precautionary in nature. It is recommended that the sensitivity assessments presented here are subject to further interpretation based on local knowledge and consultation. In addition, further studies on the effects of trampling and, especially, vehicular access on intertidal communities are recommended.

1 AIMS

There is the possibility that access to particular fisheries may damage habitats, even if the fishery activity itself is not deemed to have an impact on the habitat where it occurs. An example of this is intertidal hand gathering of cockles, where access may be gained through mudflats or *Zostera* beds. These habitats may be damaged by vehicle access, although there may be minimal or no damage to the habitat where the cockle gathering is actually occurring.

Access included both vehicle and foot access, and was grouped into light, moderate and heavy intensity. Intensity levels took into account the existing definitions that were put forward by the report produced by the University of Liverpool (Hall *et al.*, 2008) and discussed during a workshop held in Deganwy on 21st – 22nd June 2007.

The contract aimed to study previous research/work on the impacts of access across the foreshore in order to conduct a literature review, determine the effect of access on the identified 'habitat groups' and use the information to create a sensitivity matrix of the effects of the different forms and levels of access.

2 METHODOLOGY

This project was primarily a desk study and literature review. The literature review drew heavily on the Biology and Sensitivity Key Information programme[1] and database of MarLIN (Tyler-Walters *et al.*, 2001; Tyler-Walters and Hiscock, 2003) and a prior review of coasteering (Tyler-Walters, 2005a), with an additional literature review of recent publications, especially on the impacts of human and vehicular access in sedimentary habitats.

The literature review focused on the direct effects of access to fishing grounds over intertidal habitats. Therefore, the review focused on the physical impacts of trampling (walking or hiking) by humans across the intertidal, and various modes of transport that could be used by humans to access fishing grounds such as bicycles, motorcycles, off-road vehicles (ORVs) (including all-terrain vehicles (ATVs) and four-wheel drive 'sports utility vehicles (SUVs or 4x4's) and tractors.

The following definitions of access types are used in this report.

- Trampling – the effect of walking, hiking or trekking by humans on the environment, including soils, vegetation, seaweeds, epifauna and infauna. Trampling by grazing mammals (e.g. sheep, cows or horses) is not discussed save for horses as above.
- Mountain or All terrain bicycles – bicycles designed for off road use, e.g. on trails, tracks etc.
- Motorcycles or trail-bikes – motorized bicycles designed for off-road use.
- All-terrain vehicles (ATVs) – small motorized 3 or 4 wheeled vehicles designed for off – road use; also defined as a vehicle that travels on low pressure tyres, with a seat straddled by the operator with handlebars for steering control, e.g. quad bikes (Ouren *et al.*, 2007).
- Off-road vehicles (ORVs) – civilian off-road vehicles, including motorcycles, motorized dirt bikes, ATVs, snowmobiles, dune buggies, four wheel drive vehicles, and sports utility vehicles (SUVs)(adapted from Stokowski and LaPointe, 2000; Ouren *et al.*, 2007).
- Four by four's (4x4s) – four-wheeled, four wheel drive vehicles, includes SUVs, Jeeps and Land Rovers.

[1] see www.marlin.ac.uk

- Tractors – vehicles designed to deliver high traction effort at slow speeds, particularly for the haulage of agricultural and/or contraction trailers or machinery[2]; usually two or four wheeled drive, with one or both pairs of wheels bearing large tyres.

Due to the nature of access to the intertidal in the UK, snowmobiles were excluded from the study. Horses were included in the discussion but are unlikely to be used in the UK for access to fishing grounds. The disturbance of wildlife (seals and deer) and birds in particular by the presence of humans and/or noise from vehicles is not considered in this study, as considerable evidence of disturbance is readily available. Similarly, other impacts from access such as litter (discarded fishing lines, fishing weights, food waste and containers) or the water and air quality impacts of vehicles are not addressed.

This report focuses on the major intertidal habitat types described by Hall *et al.* (2008) and listed below.

- Upper shore stable rock with lichens and algal crusts (Habitat 1).
- Wave exposed intertidal stable rock (Habitat 2).
- Moderately exposed intertidal rock (Habitat 3).
- Brown and red seaweeds and mussels on moderately exposed lower shore rock (Habitat 4).
- Mussels and boring bivalves (piddocks) on intertidal clay and pea (Habitat 5).
- Honeycomb worm reef (Habitat 6).
- Sheltered intertidal bedrock, boulders and cobbles (Habitat 7).
- Rockpools and overhangs on rocky shores (Habitat 8).
- Intertidal brown seaweeds, barnacles or ephemeral seaweeds on boulders, cobbles and pebbles (Habitat 9).
- Intertidal muddy sands – excluding biotopes supporting gaper clam (Habitat 10).
- Intertidal muds and sands supporting gaper clam (Habitat 11).
- Intertidal muds (Habitat 12).
- Saltmarsh (Habitat 13)
- Underboulder communities on lower shore and shallow subtidal boulders and cobbles (Habitat 26).
- Biogenic reef on sediment (Habitat 27).
- Seagrass beds (Habitat 30).

Habitat 29 'Unstable cobbles, pebbles, gravels and/or coarse sands supporting relatively robust communities' was not examined in this study, as the intertidal components of this habitat are characterized by relatively dynamic and mobile sediments that experience physical disturbance naturally, and are dominated by relatively robust and/or mobile fauna. Hence, their sensitivity is likely to be low. Habitat 29 also includes sublittoral habitats unlikely to be impacted by access.

2.1 Literature review

The following report was based on the best available scientific literature. The literature review was conducted using the resources of the National Marine Biological Library, Plymouth and the University of Plymouth Library, together with relevant abstracting services such as the Aquatic and Fisheries Sciences Abstracts (ASFA), Science Direct, the National Information Services

[2] Definition adapted from Wikipedia (www.wikipedia.org)

Corporation (NISC) Biblioline, and the British Library. However, only abstracts were available for some of the more obscure and low circulation reports. Web-based resources such as Google Scholar were also consulted. Additionally, scientific reports produced by organizations such as English Nature and Scottish Natural Heritage were consulted where relevant. All references consulted are listed.

Representatives of relevant organizations and key individuals were also contacted. The organizations contacted included the Countryside Council for Wales (CCW), Scottish Natural Heritage (SNH), Natural England (NE), the Environment Agency (EA), South Wales and North Western and North Wales Sea Fisheries Committees (SWSFC & NWNWSFC), and the Alfred Wegener Institute for Polar and Marine Research (AWI) (regarding the Wadden Sea).

2.2 Sensitivity assessment

The sensitivity assessment follows the methodology developed by Hall *et al.*(2008), in that the results of the literature review were interpreted using expert judgement to assess the likely sensitivity of each habitat type to damage against a series of intensity scales for each fishing 'gear type'. The literature review and information gleaned from representatives of relevant organizations was used to inform 'intensity scales' used to assess sensitivity to access. While information on recovery rates is included in the literature review, recoverability was not taken into account in the sensitivity assessment (sensu Hall *et al.*, 2008).

Sensitivity was assessed against the following scale (from Hall *et al.*, 2008).

--	High sensitivity
	Medium sensitivity
	Low sensitivity
(white)	The gear type is unlikely to occur in this habitat type and scientific studies are unlikely to have been undertaken for this gear and habitat combination. However, if for instance technology were to advance to allow this gear and habitat combination to occur than an assessment / scientific study would be required to assess the impact and potential effects to aid in conservation and management.

It was assumed that many rocky shores would limit access for vehicles. The nature of rocky out crops and near vertical fissures, gullies, and mixture of slopes characteristic of many rocky shores will severely limit vehicular access to the surrounding terrain rather than the rocky shore itself. Therefore, steep rocky shores are likely to be more vulnerable to trampling due to access by foot but less vulnerable to vehicular access. Where the shore takes the form of a rocky platform or gentle incline then vehicular access is more possible. Similarly, mixed sediment, cobble, and small boulder fields may also be accessible to vehicles, depending on the size and agility of the vehicle in question, especially where mussels fill gaps between rocks and boulders.

3 RESULTS OF THE LITERATURE REVIEW

The ecological impacts of outdoor recreation have been studied in detail under the theme of ‘recreational ecology’ (Liddle, 1997). The effects of trampling on terrestrial plant communities and sand dunes communities are relatively well studied (Liddle, 1991, 1997). Recent reviews by Davenport and Switalski (2006) and Davenport and Davenport (2006)examined the impacts of tourism and leisure based transportation on terrestrial and coastal environments. Nevertheless, there are relatively few studies of the effects of trampling on intertidal communities and even fewer on the effects of vehicles in the intertidal.

The majority of intertidal studies of trampling were conducted overseas and the affected species do not occur in UK waters. Study techniques also varied, from comparative studies of sites with visitors to those without, to careful experimental studies with varying degrees of trampling intensity (summarized in Table 3.1). The rocky shores examined tended to be shores that were subject to or threatened by recreational use, and therefore tended to be shores that were easily accessible. Sedimentary shores were poorly represented in the studies reviewed and, with the exception of a few studies of the impacts of trampling from bait diggers or collectors on the shore, few studies were directly relevant to access to fishery grounds.

The majority of studies of the impacts of vehicles on habitats were terrestrial (Yorks *et al.*, 1997; Stokowski and LaPointe, 2000; Yorks, 2000; Buckley, 2004; Davenport and Davenport, 2006; Davenport and Switalski, 2006; Ouren *et al.*, 2007), although their effects on sand-dunes were documented (Liddle, 1973, 1997; Kutiel *et al.*, 2001). None of the studies that addressed vehicular access were directly relevant to this study i.e. the studies did not examine the use of vehicles to access fishing grounds.

3.1 Results of contacting relevant organizations

Detrimental impacts on saltmarsh habitats as a result of vehicles accessing intertidal fisheries were widely reported by those contacted. Morecambe Bay and several other sites along the North West coast suffered rutting of salt marshes, although the damage was superficial with the habitat recovering relatively quickly over a period of 1-2 years. Damage from vehicle access on salt marshes in the Burry Inlet reportedly resulted in erosion and a subsequent ditch up to 8ft deep in places. This created access problems and the route was therefore abandoned, and another established. The use of vehicles and quad bikes again resulted in rutting of salt marsh in the Three Rivers Estuary. In North Lincolnshire, the use of quad bikes, tractors and 4x4’s in accessing fishing grounds over salt marshes was reported. This resulted in severe rutting of the saltmarsh that was still visible several years later.

There were few examples of access to fishing sites over the habitat types considered in this report. Tracks created by vehicles witnessed on the mudflats of Angle Bay, Wales were still visible 6 months later, with three vehicles being sited on the shore at one time (pers comm.). Horse wagons and tractors are reportedly used on the tidal flats of the Wadden Sea. However, the aerial extent of the trampling relative to the size of seagrass beds was reported as <1% (pers comm.).

Table 3.1 Summary of characteristics of studies cited. The type of habitat and degree of wave exposure are expressed as described in the papers cited (* = wave exposure was not indicated and has been inferred from the communities present; ? = unknown).

Study	Location	Habitat type	Shore type (wave exposure)	Community type examined	Type of study	Trampling intensity (period/duration)	Trampling intensity (weight/footwear)
Bally and Griffiths (1989).	Dalebrook, Cape Town, South Africa	Gently sloping sandstone	Moderately exposed to exposed*	Littorinid zone, Barnacles (balanoid zone)	Experimental: 4x 31 m transects plus one single trampling point experiment.	0,10,100, and 500 times /month (3 months)	Average weight 82kg, wearing neoprene thongs (flip flops).
Beauchamp and Gowing (1982).	Santa Cruz, California	Rock platforms	Moderately exposed to exposed*	Mussels beds Barnacles, Brown algal mats	Comparative: 20x 0.1 m^2 quadrats at 3 sites of low, intermediate and high visitor use.	0, 1 and 7 people/day depending on site (autumn and spring).	Not recorded.
Boalch *et al.* (1974); Boalch and Jephson (1981).	Wembury, Devon, UK	'Slatey' undulating rocky shore	Moderately exposed	Brown algal mats	Resurvey: Resurvey of Colman's 1931 transects.	Unknown	None
Brosnan (1993); Brosnan and Crumrine (1994).	Newport, Oregon, USA	Flat basaltic benches	Moderately exposed*	Brown algal mats Algal turf Barnacles Mussel bed	Experimental: Trampling – 0.2x0.2 m (algae) or 0.2x0.3 m (mussels) blocks. Human exclusion.	Blocks trampled 250/month (12 months).	Not noted.
Brown and Taylor (1999).	Cape Rodney to Okakari Point Marine Reserve, New Zealand	Intertidal reef flat	Moderate to exposed*	Coralline algal turf	Experimental: 4 x 0.09 m^2 quadrats.	0, 2, 5, 30 footsteps/day (5 days).	Not recorded.
Chandrasekara and Frid (1996).	Lindisfarne National Nature Reserve, UK.	Soft mud tidal flat	?	Intertidal mud*	Comparative; Transect with 5 quadrats, perpendicular to path through tidalflat. Sampled summer (intense usage) and winter (low usage).	Not recorded.	Not recorded.
Cook *et al.* (2002).	Moel y Don, Anglesey, Wales.	Shallow sloping sand flat	?	Intertidal muddy sands (not supporting gaper clams).	Experimental; Square of 15m sides, divided into 9 5mx5m plots, treatment applied to central $9m^2$	Twice a week for almost 5 months.	Not recorded.

Study	Location	Habitat type	Shore type (wave exposure)	Community type examined	Type of study	Trampling intensity (period/duration)	Trampling intensity (weight/footwear)
Cunningham *et al* (1984).	Llwyngwril, mid-Wales, UK.	Sabellaria reef	Moderate to exposed*.	Honeycomb worm reefs.	Comparative; Comparison of the effects of different trampling intensities on colonies.	Single trampling event, intensities; light (porches crushed), medium (causes indentations and scuffing), and heavy (jumping on or kicking colony).	Not recorded.
Denis and Murray (2001).	South California	?	Moderately exposed*	Brown algal mats.	Experimental: 15 0.5 x 0.7 m blocks.	0, 150, or 300 foot steps / month (16 months).	Not noted.
Eckrich and Holmquist (2000).	La Parguera, Puerto Rico.	Seagrass bed		Seagrass bed	Experimental; 3 experimental trampling lanes (5m x 2.5m) at 10 sites.	20 and 50 passes (to end of lane and back), applied once a month for 4 months.	57kg individual wearing rubber-soled shoes.
Erickson *et al.* (2004).	Olympic National Park, Washington	?	Moderately exposed*	Brown algal mats, Mussel beds, Barnacles.	Comparative: Sites accessible to visitors vs. inaccessible sites.	Not specified.	Not recorded.
Fletcher and Frid (1996a).	Cullercoats Bay & St. Mary's Island, Newcastle upon Tyne, UK	Flat sandstone shore	Moderately exposed	Brown algal mats.	Experimental: 2 sites, 4 x 1 m^2 blocks.	0, 20, 80, 160, footsteps/ m^2 per spring tide (9 months).	Not noted.
Fletcher and Frid (1996b).	Cullercoats Bay & St. Mary's Island, Newcastle upon Tyne, UK	Flat sandstone shore	Moderately exposed	Brown algal mats.	Experimental: 2 sites, 4 x 1 m^2 blocks.	0, 20, 80, 160, footsteps /m^2 per spring tide (16 months).	Not noted.
Ghazanshahi *et al.* (1983).	Palos Verdes Peninsula, S California, USA	Gentle rocky slopes and low reef	Moderate to exposed*	Barnacles, Algal turf, Coralline algae, Sabellariid worms.	Comparative: Survey of 20 m transects at 13 sites of different visitor intensity.	High = >1.7 persons/10 m/day Low- <1.3 persons/100 m/day	Not recorded.
Jenkins *et al.* (2002) (abstract only).	San Juan Country Park, Washington, USA	?	Sheltered to moderately exposed*	Brown algal mats.	Experimental: 6 x 3-5m transects.	250 steps/transect, 3 times /week for 6 weeks.	Not noted.

Study	**Location**	**Habitat type**	**Shore type (wave exposure)**	**Community type examined**	**Type of study**	**Trampling intensity (period/duration)**	**Trampling intensity (weight/footwear)**
Johnson *et al.* (2007).	Yealm Estuary, Devon, UK.	Mudflat		Intertidal mud meiofauna	Experimental; 2 grids (10m x 10m), divided into 16 x 1m^2 plots, randomly allocated control or trampling treatment.	Trampled 6 times over a 2 week period.	Not reported.
Keough and Quinn (1991).	Review article	N/A	N/A	N/A	Review: Discussed past and present work by authors and others.	See Povey and Keough (1991).	See Povey and Keough (1991).
Keough and Quinn (1998).	Mornington Peninsula National Park, SE Australia	Flat limestone platforms	Moderate exposed to sheltered	Brown algal mats, Coralline algal mats.	Experimental: 0.5 x 2m transects.	0, 2 & 25 passes /day, (6-8 days /summer for 6 years).	Average size person wearing rubber soled athletic shoes.
Major *et al.* (2004).	Willapa Bay, Washington, USA.	Site 1= deep soft muddy substrate. Site 2= hard packed sand substrate.	?	Seagrass bed.	Experimental; Single footprints applied at set points along a 10m transect.	Placement of single footprints at the centre of sample points along 10m transects. Transects established in June, July and August.	Treatments applied by one individual, of 68kg, shoe size, men's US 9, using 3 types of footwear; rubber boots, Mudders and Mudlocks.
Murray *et al.* (2001).	Orange & Los Angeles counties, California	?	?	Macroalgae.	Resurvey: Comparison of recent survey results to surveys in the 1950s, 60s, 70s, and 80s.	Not identified.	Not identified.
Pinn and Rodgers (2005).	Kimmeridge Bay, Dorset, UK	Rocky ledge	Moderate*	Macroalgae, limpets, barnacles.	Comparative; Sites accessible to visitors vs. less accessible sites.	Not identified.	Not identified.
Povey and Keough (1991).	Mornington Peninsula National Park, SE Australia	Flat limestone platforms	Moderate exposed to sheltered	Brown algal mats, Coralline algal mats, Bare rock, Mussel beds.	Experimental; Single steps, gastropod dislodgement, kicking/stepping on limpets, and 0.5 x 2 m transects (every daytime low tide from July-October)	Transects: 0, 2 & 25 passes/day. Small scale effects: 1, 10 50 or 75 steps (single tide)	Rubber soled shoes worn.
Rossi *et al* (2007).	Paulina Polder, Westerschelde, The Netherlands.	Intertidal mudflat		Intertidal muddy sands (not supporting gaper clams).	Comparative; 3 sites 4m x 4m within an area that had been trampled during a previous experiment.	Visited twice a month for 5 months, for 3-5hrs per visit.	5 people per visit, average weight of 70kg.

Study	Location	Habitat type	Shore type (wave exposure)	Community type examined	Type of study	Trampling intensity (period/duration)	Trampling intensity (weight/footwear)
Schiel and Taylor (1999).	Wairepo flats, South Island, New Zealand	Gently sloping siltstone platforms	Sheltered to moderately exposed*	Brown algal mats.	Experimental: 7 x 0.3mx2 m transects. Trampling initiated in spring and autumn.	0, 10, 25, 50, 100, 150 & 200 tramples	Not recorded.
Sheehan (2007).	Yealm, Erme and Avon Estuaries, south-west England.	Mid-shore mudflats or sandy mudflats		Intertidal muds and sands.	Experimental; 3 sites per estuary. At each site, 10m x 10m plot divided into 16 plots. 4 replicates of trampling treatment.	3 times a week for 1 month.	Not noted.
Smith and Murray (2005).	Monarch Bay, California, USA.	Extensive, flat rock platforms	Exposed*	Mussel beds.	Experimental; 24 x 0.35 m^2 plots arranged in 4 blocks.	0, 150, 300 steps per month for 12 months (equivalent to 0, 429 or 857 steps m^{-2} respectively).	60 to 75kg individuals wearing soft-soled shoes.
van de Werfhorst and Pearse (2007).	Santa Cruz, California	Mudstone platforms	Moderately exposed to exposed*	Mussels beds Barnacles, Brown algal mats	Resurvey: Resurvey of sites used in Beauchamp and Gowing (1982). NB. 2007 study applied stratified sampling design.	Not noted.	Not noted.
Wynberg and Branch (1997).	Klein Oesterwal, Langebaan Lagoon, South Africa.	Intertidal muddy sands.	?	Intertidal muddy sands not supporting gaper clams.	Experimental; 3 areas of 3m x 4m. Trampled at different intensities.	No of footsteps dependent on the number taken in prawn collection treatment to collect varying no’s of prawns (25, 50, 100).	Not noted.

3.2 Nature of the impact

The effects of trampling by humans and animals, different modes of transport (e.g. trail-bikes, cars, and four-wheel-drive vehicles), camping and boating are reviewed by Liddle (1997), Yorks *et al.* (1997), Buckley (2004), Davenport and Davenport (2006) and Davenport and Switalski (2006).

3.2.1 Trampling

In terrestrial and coastal environments, trampling has been shown to cause the decline in the height, cover and biomass of plants with an increasing trampling intensity. Intensity is usually expressed as the number of tramples, footsteps per square metre or number of passes along a prescribed path or route. Some species are more resistant or tolerant than others, and the disturbance may cause an initial increase in the cover of some species (Liddle, 1991). However, intensive trampling eventually results in bare space or bare paths, and can cause cumulative erosion and soil compaction (Liddle, 1997).

Sand dune vegetation is particularly vulnerable due to the low soil penetration resistance of sand (Liddle 1975, cited in Davenport and Davenport, 2006). Dunes are eroded by tracks that deepen and widen with use and are exaggerated by wind, while trampling decreases plant and associated insect population biodiversity. In Brittany, fixed dunes were more resilient to damage from trampling than mobile or semi-fixed dunes but much less resilient once damage had occurred (Davenport and Davenport, 2006).

In plants, small size, folded leaves, rosette habit (a growth form that protects the meristem from damage), and small cell size have been identified as resistant features (Liddle, 1991, 1997). Plants can also be grouped into susceptibility categories dependant on the likelihood of damage and their rates of recovery, in a similar manner to sensitivity (*sensu* Hiscock and Tyler-Walters, 2006). Similarly, the degree of impact depends on the plant community and habitat, with the number of passes required to reduce biomass or cover by 50% ranging from 12 passes (for Eucalyptus woodland ground flora, Brisbane) to 1412 passes (for subtropical grassland, Brisbane) (Liddle, 1997).

The growth form of tropical corals was also found to influence the level of damage inflicted by visitors walking across coral reefs in the Great Barrier Reef. Digitate, wedge or blade like, encrusting and massive forms were tolerant of trampling, while plate, foliaceous and open arborescent forms were intolerant (Liddle, 1997). Again, the species could be categorized by their resistance to damage and ability to recover. For example, resilient forms were defined as species with a low resistance to damage but with high recovery rates (Liddle, 1997).

In the intertidal, trampling has been shown to be an additional type of physical disturbance on rocky shore habitats, and the pre-adaptation of macroalgae and sessile organisms to wave action does not necessarily provide protection or tolerance of the effects of trampling. Brosnan and Cumrine (1994) noted that storms and wave driven logs resulted in localized and seasonal (winter) disturbances often resulting in patches of bare space. Trampling also resulted in bare space in some communities but was likely to be chronic in nature and more frequent in spring and summer (less so in winter). They noted that many species are adapted to take advantage of bare space left by winter storms, and peak recruitment for many species (e.g. algae and barnacles) occurs in spring and summer, which coincides with peak periods for visitation of shores, and hence trampling (Brosnan and Cumrine, 1994). Pinn and Rodgers (2005) noted that conservation areas encounter the worst damage as they attract the most visitors. For example, Pinn and Rodgers (2005) noted that trampling and visitor pressure impacted limpets and large branched seaweeds at Purbeck Marine Wildlife Reserve. Similarly, Boalch (1974) and Boalch and Jephson (1981) suggested that visitor pressure was responsible for a reduction in the cover of brown algal shrubs at Wembury VMCA, Devon. In addition, trampling has been reported to leave visible paths (bare space) across the rocky shore (Fletcher and Frid, 1996a, 1996b) and through *Sabellaria alveolata* reefs (Holt *et al.*, 1998).

3.2.2 Vehicles

The majority of observed and studied impacts of vehicles have been made in the terrestrial environment, and are summarised below.

- Mountain bikes may have similar effects to those of walkers but can cover much more ground (5-10 times) in a given time when compared to walkers, especially downhill. However, they cause more damage than walkers when skidding downhill or due to wheel-spin uphill and are probably a significant cause of damage when mountain bikers build illicit tracks or ramps (Thurston and Reader, 2001; Cessford, 1995; cited in Davenport and Switalski, 2006).
- Horse riding was reported to cause more damage than hikers in forest and alpine habitats, create deeper paths than walkers and also cause other effects due to manuring, browsing and the transmission of weeds (Liddle, 1997; Davenport and Switalski, 2006).
- Off road vehicles were reported to have caused damage to heritage coasts, especially cliff-tops, quarries, sand dunes and woodlands (Edwards, 1987).
- ATVs use results in significant soil compaction, collapses burrows and can lead severe soil erosion. ATVs cut paths and severe rutting can cause widening of paths as subsequent drivers avoid ruts (Davenport and Switalski, 2006). Ruts themselves cause canalization of water, and pooling that can lead to increased erosion.
- Repeated ATV driving results in a reduction in vegetative cover, with shrub communities generally replaced by forb and grass communities. In addition, the tyres and undercarriage of ATVs can also transport the seeds of non-native species into wild land habitats (Davenport and Switalski, 2006).
- ATVs and ORVs have been reported to damage dune and beach systems. ATVs damage dune vegetation cover. ORV tracks in beaches were reported to be deep enough to stop turtle hatchlings reaching the sea. ORVs were reported to decimate ghost crab populations by collapsing their burrows, and by crushing the crabs during night driving as the crabs are disorientated by head-lights (Davenport and Davenport, 2006).
- Gilbertson (1981, cited in Davenport and Davenport, 2006) reported that ORVs and ATVs increased soil erosion, destabilised dunes, damaged sand-binding grasses and scrub, and increased dune mobility. Gilbertson (1981) concluded that ATV use had done more damage to coastal barrier system near Adelaide, Australia in a few years than previous centuries of pastoralism.
- On the KwaZulu-Natal coast of South Africa, Celliers *et al.* (2004) noted that ORVs caused physical damage to beaches in the form of changes in the density of soil bulk and erosion, where erosion could be substantial on beach slopes as vehicles force the sand downhill. Celliers *et al.* (2004) also noted that ORVs disturbed flora and fauna by inhibiting new growth of plants, disturbing nesting and resting birds, and crushing ghost crabs. As a result South Africa had set up strategic plan to restrict ORVs to certain recreational use areas.

Buckley (2004) noted that damage by ORVs was highly variable, with the number of passes required to reduce vegetation cover by 50% varying by 100 fold between ecosystems. Damage was also dependant on how the vehicle was driven, so that more damage occurs on turns and slopes than on straight level ground, and skilled drivers do less damage than unskilled (Buckley, 2004).

3.2.3 Relative impacts of different access types

Liddle (1997) compared the relative impact of various recreational activities using their different ground pressures, i.e. the weight of the human, animal or vehicle divided by its area in contact with the ground and expressed as g/cm^2. For example, bare feet on hard ground produce a ground pressure of 297 g/cm^2, while shoes produce 180 g/cm^2, and Vibram-soled boots (on hard ground) produce a pressure of 416 g/cm^2. Mechanical transport generally has a high ground pressure (with the exception of snowmobiles and hovercraft) (Liddle, 1997) (see Table 3.2). The use of an animal or vehicle for transport increases the ground pressure to about 5-10 times that of a walker (Liddle, 1997).

Table 3.2 Examples of calculated ground pressures of outdoor recreational vehicles, animals and humans (from Liddle, 1997).

Activity / access type	Calculated ground pressure (g/cm$^{2)}$
Small, personal, three-wheeler, ATV	100
Four-wheel, ATV	100
Human (shoes)	180
Human (bare footed, hard ground)	297
Human (Vibram-soled boots, hard ground)	416
Horse with rider (whole foot)	1,282
Saloon car and driver, hard ground	1,500
Four wheel drive Toyota, empty, hard ground	1,550
Four wheel drive Toyota, loaded with four people and gear, hard ground	1,686
Trail -bike	2,008
Jeep	2,240
Horse with rider (shoes only)	4,360

Nevertheless, several factors vary the ground force applied. Soft ground, grass and clumps of vegetation spread the load reducing ground pressure. Different footwear also changes the ground pressure exerted by walkers (Table 3.2). In the intertidal studies above (Table 3.1), footwear used in experimental trampling studies varied. For example, Povey and Keough (1991) used rubber-soled athletic shoes or sandals; Brosnan and Crumrine (1994) used rubber-soled shoes; and Schiel and Taylor (1999) used gumboots, while other studies did not specify.

Similarly, the foot and hoof exert different pressures at different parts of the step. In the case of the foot, most pressure is exerted as the heal touches the ground. The pressure is increased by changes in motion, such as accelerating, decelerating or turning, together with travelling up or down slopes.

Liddle (1997) notes that the tangential forces exerted by a vehicle are much higher than those exerted by horses or persons, as even though the ground pressures exerted by tyres may be lower than exerted by horse’s foot, vehicles have the power to disrupt vegetation (and presumably soil) to a greater degree.

Yorks (2000) provided another method to compare the effects of vehicular impact on vegetation, using the following model.

$$\text{Land impact} = (\text{weight} + \text{output acceleration}) \times \text{swath}$$

‘Output acceleration’ is vehicle horsepower (power/mass) and ‘swath’ is the product of width (of the vehicles tyre, foot or track) and distance travelled. Yorks (2000) compared walkers, horses, motorcycles, ATVs, and SUVs using this model, which he used to demonstrate their relative impact (Table 3.3).

Table 3.3 Relative 'land impact' of different access types (walkers and vehicles) summarised from Yorks (2000).

	Mass (kg)	Power (kw)	Output acceleration (relative)	Daily range (km/day)	Daily range (relative)	Width (m)	Net swath (relative)	Net land impact (relative)
Walker	75	0.1	1	8	1	1	1	1
Bicyclist	88	0.1	1	25	3	1	3	3
Horse	500	1	1	25	3	1	5	18
ATV	330	15	37	83	10	1	20	410
Pickup truck	1,800	110	50	210	25	2	100	3,700
Large SUV	2,700	150	44	210	25	2	110	4,300
Semi-Truck	36,000	300	7	670	80	2	390	97,000

Yorks' calculations suggest that a SUV could create approximately 10 times the relative impact of an ATV and 4000 times the relative impact of a walker. While an ATV could create ca 400 times the relative impact of a walker and ca 20 times that of a horse rider. Application of Yorks model to a utility tractor[3] produces a 'relative land impact' of ca '2033', comparable to the values provided for a Pick-up or SUV (Yorks, 2000).

However, Yorks' model does not take into account the habitat type, soil hardness, slope, or the fact that horses and motorcycles widen tracks differently depending on slope (see below) nor the ground pressures exerted by different types of footwear, tyres and tracks. In addition, the potential distance a vehicle could travel in a day may skew the 'net land impact' values so that long range vehicles have the greatest impact. While distance travelled is highly relevant in wilderness habitats it may not be so relevant over the relatively short distances involved in access to fishing grounds.

Few studies examined the relative impacts of different access types directly. Leney (1974, cited in Liddle, 1997) demonstrated that walkers in bare feet did less damage to beach grass (*Ammophila breviligutata*) on sand dunes, and took more passes the achieve the same level of reduction in bulk biomass that walkers in shoes. Curiously in South Africa, Bally and Griffiths (1989) found little difference in experimental trampling experiments, in which 'neoprene thongs' (flip-flops) were worn. Bally and Griffiths (1999) noted that 85% of visitors in their study area walked across the shore in bare feet, which forced the visitor to proceed with caution to prevent personal injury, and hence minimized damage.

Weaver and Dale (1978) (cited in Liddle, 1997) compared the effects of walkers, horses and motorcycles on forest and grassland habitats, depending on slope. A slope of just 15% was enough to increase the effect of trampling. On level ground, 1000 passes were required to reduce cover by 50%, while to only 700 passes caused the same effect on sloping ground. Forest floor vegetation, was six times more vulnerable on sloping ground. Horses reduced grassland cover twice a fast as walkers on level ground, three times as fast on sloping ground. On forest floor understorey vegetation, horses reduced cover three times as fast but showed similar rates to walkers on sloped ground. Walkers also created more damage going downhill than uphill, with a 95% and 35% reduction in cover respectively after 1000 passes (Weaver and Dale, 1978; cited in Liddle, 1997). Motorcycles (trail-bikes) reduced level grassland cover twice a fast as walkers after only 500 passes but were about equivalent in damage after 1000 passes. However, on sloped ground the motorcycles destroyed all cover within only 400 passes while 35% remained on the horse trail and 65% on the walkers trail. In addition, the motorcycle trail was 1.5 times the width of the horse trail and 1.75 times the width of the hiker trail on sloping ground. This

[3] Massy Fergusson, utility tractor MF2435 (76hp, 56kw power, 3050 kg, width 2m) (data from Massey Fergusson UK (2008) (http://www.masseyferguson.com/agco/mf/uk/home.htm)) assuming a potential range 100 km a day.

demonstrated the potential damage that could be caused by powerful machines, and the effect of torque when applied as a lateral force to vegetation (Liddle, 1997).

In another comparative study, Liddle (1973; cited in Liddle, 1997) examined the relative impact of a 760 kg light van and walkers on sand dune pasture over a period of 20 weeks in summer and winter. In summer, the van resulted in nine times the level of damage, having reduced the cover to 50% after 203 passes while walkers required 1828 passes to achieve the same impact.

In summary comparison of ground pressure or York's 'land impact' provides a guide to the relative impact of walkers and different types of vehicles, while direct comparative studies are few. No comparative studies were found in the intertidal. Vehicles are generally considered to have a markedly greater potential impact than walkers due to their power and torque effects. Nevertheless, the level of impact is directly related to the intensity of trampling or number of passes. Liddle (1997) noted that the relationship between reduction in vegetation biomass and cover is generally curvilinear, loss increasing with increasing intensity, that is, the number of passes.

3.3 Intensity scales for access types

Hall *et al.* (2008) identified a series of intensity scales for a variety of fishing activities and gear types, based on local expertise. These intensities were based on direct observation of the fishing activities in practice within Wales.

No such information was available in this study and few of the studies discussed in the literature review provide information on levels of intensity relevant to access to fishing grounds as, where recorded intensities are given, the intensities cited refer to visitor pressure. In addition, few of the studies reviewed (see Table 3.1) are directly comparable. Even experimental studies vary in their experimental design (quadrats vs. transects), intensities used (no. tramples, no. passes, footsteps per transect, footsteps per quadrat, or footsteps/m^2), habitats examined and, where habitats were similar, the species examined.

Therefore, the intensity scale for human access to fishing grounds across intertidal habitats was based on the existing scale for 'hand gathering' (Hall *et al.*, 2008). The suggested scale is shown in Table 3.4.

Table 3.4 Gear intensity definitions for access to fishing grounds on foot (walking) (gear type 15a). Adapted from Hall *et al.* (2008).

Intensity	Definition
Heavy	Access by >10 people per hectare per day. Large numbers of individuals mainly concentrated in one area
Moderate	Access by 3-9 people per hectare per day
Light	Access by 1-2 people per hectare per day
Single	Access on a single occasion

If we presume that individuals use the same path or take the same route across the intertidal to access the fishing area, then the intensity scale is directly comparable to number of passes. For example, two individuals accessing a fishing area will result in four passes across the intertidal (there and back) and 10 individuals will result in 20 passes. However, this estimate does not take into account differences in individuals' weights or if they are laden, especially on the return trip.

Information on the comparative impact of different vehicle types was mixed. Although Yorks' (2000) model is imperfect, it still probably represents the best comparative study available. However, it is likely that Yorks estimate that an SUV could have 4000 times the impact of a walker is an exaggeration, certainly in the relatively short distances involved in access to fishing grounds. Therefore, the general estimate that ORVs could create 5-30 times the damage of a walker (Liddle, 1997; Buckley, 2004) seems more sensible. Nevertheless, based on Yorks' comparison and other studies the potential relative impact of different vehicles types can be ranked as follows:

- Semi-truck
- > 4x4 (SUV, Pick up) and tractors
- > ATV and/or trail-bike
- > Walker.

The 'gear intensity' scale suggested in Table 3.5 was based on the levels of activity reported by organization representatives (pers. comm.) and the potential relative impact of vehicles discussed above.

Table 3.5 Gear intensity definitions for access to fishing areas assisted by vehicle(s) (gear type 15b).

Intensity	Definition
Heavy	Access by more than two 4x4s (or SUVs) or a mixture of SUV and ATVs per hectare per day. Several vehicles access the area as a group.
Moderate	Access by a single 4x4 (or SUV) or several ATVs per hectare per day
Light	Access by one – two trail bikes or ATVs per hectare per day
Single	Access on a single occasion

The gear intensity scale (Table 3.5) does not take into account differences in weight of vehicles caused by loading and/or the pulling of trailers.

4 THE EFFECTS OF ACCESS ON INTERTIDAL COMMUNITIES AND SENSITIVITY ASSESSMENT

While the species examined in many of the studies reviewed may not occur in the UK, the communities examined have counterparts on UK shores. The effects of access (trampling and vehicle use) on the all the habitat types reviewed in this study (1-13, 26, 27,30) were either reported in the literature or were inferred from the effects on similar habitats or communities. In each case, the sensitivity of each habitat type has been assessed against each of the intensities given for 'gear type' 15a (walkers) and 15b (vehicles).

The available evidence is presented below, together with a summary explanation of the suggested sensitivities given in Table 5.1 following.

4.1 Upper shore stable rock with lichens and algal crusts

The yellow and grey lichen zone may be particularly vulnerable to trampling. Fletcher (1980) noted that large specimens of lichens, e.g. *Ramalina siliquosa*, were only found on vertical rocks inaccessible to animals, including man. Trampling damage was greatest when the thallus was wet, causing it to peel from the surface, while when dry, some fragments were likely to remain to propagate the lichen (Fletcher, 1980). Physical disturbance of the lichen flora or substratum may reduce species richness and favour more rapid growing, disturbance tolerant species, e.g. *Lecanora dispersa*, *Candelariella vitellina* and *Rinodina gennerii* (Fletcher, 1980). However, growth rates are low (rarely more than 0.5-1 mm/year in crustose species while foliose species may grow up to 2-5 mm/year) and, although ubiquitous, colonization is slow. Crump and Moore (1997) observed that lichens had not colonized experimentally cleared substrata within 12 months. Brown (1974) reported that recolonization of substrata within Caerthillian Cove, Cornwall, which was heavily affected by oil and dispersants after the *Torrey Canyon* oil spill, took 7 years to begin. Therefore, recoverability is likely to be low, and lichens may be highly sensitive of physical disturbance at the top of the shore.

In summary lichens were considered to be intolerant of trampling (Tyler-Walters, 2005a). Physical disturbance (such as trampling) may reduce species richness and while growth rates are variable between growth forms, colonization is slow. Vehicular access is unlikely.

4.2 Wave exposed intertidal stable rock

4.2.1 Mussels

Large declines of mussels *(Mytilus californianus)* from mussel beds due to trampling have been reported (Brosnan, 1993; Brosnan and Crumrine, 1994; Smith and Murray, 2005). Brosnan and Crumrine (1994) recorded the loss of 54% of mussels from a single experimental plot on one day. Mussels continued to be lost throughout the experimental period, forming empty patches larger than the experimental plots. The empty patches continued to expand after trampling had ceased, due to wave action. At another site, the mussel bed was composed of two layers, so that while mussels were lost, cover remained. Brosnan (1993) also reported a 40% loss of mussels from mussel beds after three months of trampling, and a 50% loss within a year. Van de Werfhorst and Pearse (2007) examined *M. californianus* abundance at sites with differing levels of trampling disturbance. The highest percentage of mussel cover was found at the undisturbed site while the severely disturbed site showed low mussel cover. Smith and Murray (2005) reported that in experimental plots exposed to trampling, mussel loss was 20-40% greater than in untreated plots. However, only 15% of mussel loss was as a direct result of trampling, with the remaining loss occurring during intervals between treatment applications.

Brosnan and Crumrine (1994) suggested that trampling destabilizes the mussel bed, making it more susceptible to wave action, especially in winter. Smith and Murray (2005) proposed that an indirect effect of trampling was weakening of byssal threads, which increases mussel susceptibility to wave disturbance (Denny, 1987). Brosnan and Crumrine (1994) observed recruitment within experimental plots did not occur until after trampling had ceased, and no recovery had occurred within 2 years

Brosnan and Crumrine (1994) noted that mussels that occupied hard substrata but did not form beds were adversely affected. Although only at low abundance (2.5% cover), all mussels were removed by trampling within 4 months. Brosnan and Crumrine (1994) noted that in earlier experiments mussels were not common and confined to crevices in heavily trampled sites. Similarly, the mussel beds infauna (e.g. barnacles) was adversely affected, and were crushed or lost with the mussels to which they were attached. However, Beauchamp and Gowing (1982) did not observe any differences in mussel density between sites that differed in visitor use.

In summary trampling is likely to destabilize mussel beds by loosening byssal attachment resulting in loss of mussels due to wave action. Once a gap has been made in the bed, wave action, especially in winter, can enlarge the gap further. Similar effects have been reported to occur as a result of wave driven debris (e.g. logs) (see Seed and Suchanek, 1992). However, trampling adds an additional physical disturbance. Recovery in mussel beds is unpredictable, and may take several years and often longer in some environments (Seed and Suchanek, 1992).

4.2.2 Barnacles

Jenkins *et al.* (2002) did not observe any effects on barnacle cover as a result of trampling. Similarly, Beauchmap and Gowing (1982) did not observe any difference in barnacle density between sites with different levels of visitor use. However, levels of visitor use (trampling intensity) were low in comparison with other studies. Bally and Griffiths (1989) listed the removal of dead barnacles as one of the immediate effects of trampling but did not observe any longer term effects in any fauna. Their study was unique in the respect that 85% of visitors in their study area walked across the shore in bare feet, which forced the visitor to proceed with caution to prevent personal injury, and hence minimized damage.

Ghazanshahi *et al.* (1983) reported that *Balanus glandula* exhibited reduced cover at all shore heights with increasing public use, and suggested that trampling rather than collecting was the likely cause. However, cover in this species varied between ca 0.1% and 1.5%. Keough and Quinn (1991) and Ghazanshahi *et al.* (1983) cited a study by Zedler (1978) which suggested that barnacles and polychaetes decreased in abundance with increased public use. Pinn and Rodgers (2005) also reported reduced abundances of *Chthamalus montagui* at a heavily visited site. Erickson *et al.* (2004) found that visitor accessible areas of Olympic National Park coast had a greater percentage cover of bare space in five of seven sites examined. They observed significantly greater numbers of *Balanus glandula* barnacle scars (remains of bases when a barnacle is removed or dies) in accessible areas, and noted that barnacles were consistently smaller in more accessible areas. However, they did not detect any significant differences between treatment and reference sites in their pilot study.

Brosnan and Crumrine (1994) reported that trampling significantly reduced barnacle cover at both of their study sites, falling from 66.6% to 7.2% in 4 months at one site and from 21.3 to 5.1% within 6 months at the other. Cover remained low until recruitment in the following spring. Similarly, barnacle cover as epibionts on mussels was reduced significantly in the first month following trampling. Overall, trampling crushed barnacles on rocky or mussel substrata. In single step experiments, *Chthamalus antennatus* were the most easily crushed species, and about 15% of individuals were crushed by a single step, while less than 5% of littorinids and mussels were crushed (Povey and Keough, 1991). Nevertheless, Brosnan and Crumrine (1994) noted that decreased algal cover due to trampling could increase bare space for settlement by barnacles.

In summary the effects of trampling on barnacles seem to be variable, with some studies not detecting significant differences between trampled areas and controls. However, in the case of Beauchamp and Gowing (1982) trampling intensity was low, while Ghazanshahi *et al.* (1983)

examined low abundance populations. The worst case incidence was reported in the algal-barnacle assemblage studied by Brosnan and Crumrine (1994), which may be more representative of barnacle dominated shores. Overall, barnacles are probably relatively easily damaged and crushed by trampling, and are regularly heard to 'crunch' under foot while walking on the shore.

4.2.3 Macroalgae

Erect coralline algae (e.g. *Corallina* spp.) can form extensive turfs in wave exposed conditions, or in shallow rocky pools, that harbour a diverse array of amphipods and meiofauna, and support a variety of red algae. The effect of trampling on erect coralline algal turf in New Zealand was studied by Brown and Taylor (1999). For example, moderate trampling (50 steps per 0.09 m^2) or more reduced turf height by up to 50%, and the weight of sand trapped within the turf to about one third of controls. This resulted in declines in the densities of the meiofaunal community of gastropods, ostracods, and polychaetes within two days of trampling. The community returned to normal levels (except polychaetes) within 3 months of trampling events (Brown and Taylor, 1999). However, their experiment only subjected the turf to five days of trampling.

Zedler (1976; 1978; cited in Ghazanshahi *et al.*, 1983), reported a reduction in coralline algae abundance in areas of Cabrillo National Monument, San Diego, subject to heavy visitor use, and further noted that coralline algae decreased when visitor use increased. Povey and Keough (1991) noted that erect coralline turf was damaged by intensive trampling and was reduced in height by 50% compared to other treatments (low intensity and control). In addition, while the overall cover of coralline turf increased by 11% in other treatments, it only rose by 3% in transects trampled at high intensity but no significant effect on cover was seen at the end of the trampling experiment (Povey and Keough, 1991).

Fletcher and Frid (1996b; 1996a) noted a decrease in the understorey algal community of encrusting coralline algae and red algae, which was probably an indirect effect due to increased desiccation after removal of the normally protective fucoid canopy (Hawkins and Harkin, 1985) by trampling. Similarly, Schiel and Taylor (1999) noted that trampling had a direct detrimental effect on coralline turf species on the New Zealand rocky shore. At one site, coralline bases were seen to peel from the rocks (Schiel and Taylor, 1999), although this was probably due to increased desiccation caused by loss of the algal canopy. Keough and Quinn (1998) also noted a slight (8%) decrease in erect coralline turf cover in their most intensive trampling, at one site only. However, again this may have been due to increased desiccation.

Beauchamp and Gowing (1982) compared rocky shore communities between sites that varied in visitor use on the California coast. They noted a general pattern of higher diversity and density of species at the less trampled sites. Most noticeable was the absence of the brown alga *Pelvetiopsis limitata* at the most trampled site. Van de Werfhorst and Pearse (2007) applied a stratified sampling technique (with respect to tidal height) to resurvey the study area used by Beauchamp and Gowing (1982). At the heavily trampled site, as tidal height increased, bare rock cover also increased. The results obtained by van de Werfhorst and Pearse (2007) showed that increased visitor numbers resulted in decreased intertidal biota diversity and density. In quadrats $\leq$2 m tidal height, species diversity in the untrampled area was significantly greater than in the severely trampled area. In a comparative survey of low and high use sites in southern California, Ghazanshahi *et al.* (1983) noted that the overall algal abundance 'rank' was lower where public use was higher. However, their abundance rank combined foliose and turf forming algal species.

On the coast of Oregon, Brosnan (1993) reported a significant reduction in brown foliose algae (the fucoids *Pelvetiopsis limitata* and *Fucus distichus*, and foliose red alga *Iridaea cornucopiae*) as a result of trampling (250 tramples per plot for one day per month for 12 months). Their abundance were reduced from 80% to 35% within a month of the start of trampling, and remained so for the rest of the experiment. In a visitor exclusion experiment, foliose algae increased from 62% to 94.5% cover in six months. When visitor access was returned foliose algae declined rapidly.

Brosnan and Crumrine (1994) noted that trampling significantly reduced algal cover within 1 month of trampling. Foliose algae were particularly affected and decreased in cover from 75% to 9.1% in trampled plots. *Mastocarpus papillat*us decreased in abundance from 9% to 1% in trampled plots but increased in control plots. *Fucus distichus* decreased in the summer months only to recover in winter but in trampled plots remained in low abundance (between 1 and 3% cover). Trampling resulted in a decrease in cover of *Pelvetiopsis limitata* from 16% to 1.5%. *Iridaea cornucopiae* decreased from 38 to 14% cover within a month and continued to decline to 4-8% cover. However, after trampling ceased, recovery of algal cover including *Iridaea cornucopiae* and *Mastocarpus papillat*us was rapid (ca 12 months) (Brosnan and Crumrine, 1994).

Fletcher and Frid (1996a) noted that the species composition of the algal community was changed by as little as 20 steps per m^2 per spring tide of continuous trampling since recolonization could not occur. A trampling intensity of 20 steps per m^2 per spring tide could be exceeded by only five visitors taking the same route out and back again (10 passes) across the rocky shore in each spring tide. Both of the sites studied receive hundreds of visitors per year and damage was generally visible as existing pathways, which were sustained by continuous use (Fletcher and Frid, 1996a, 1996b). However, the impact was greatest at the site with the lower original abundance of fucoids.

In summary erect coralline turf is probably of intolerant of trampling, demonstrating a reduction in turf height and reduced cover in the highest trampling intensities studied. Brown and Taylor (1999) noted that a reduction in turf height was due to tissue loss. The resident meiofaunal community is intolerant but recovers quickly. Foliose (e.g. *Mastocarpus papillat*us) and brown algae on exposed shores are also probably intolerant of trampling. Brown algae characterized by fucoids (*Fucus* spp. in the UK) are particularly intolerant of trampling, depending on intensity. Associated infauna also responds deleteriously to trampling, showing reduced diversity in more heavily trampled areas.

Overall, the communities' characteristic of this habitat (i.e. coralline turfs, mixed mussels and barnacles and barnacle dominated shores) are likely to be intolerant of trampling, depending on intensity and time of year. Barnacles are likely to be most sensitive in the spring settlement period. High intensities of trampling (foot access) may result in bare space. Vehicular access is unlikely.

4.3 Moderately wave exposed intertidal rock

In the UK, Boalch *et al.* (1974) and Boalch and Jephson (1981) noted a reduction in the cover of fucoids at Wembury, south Devon, when compared to surveys conducted by Colman (1933). The size ranges of *Ascophyllum nodosum*, *Fucus vesiculosus* and *Fucus serratus* were skewed to smaller length, and the abundance of *A. nodosum* in particular was reduced (Boalch and Jephson, 1981). It was suggested that visitor pressure, especially after the construction of a car park, was responsible for the reduced cover of fucoids (Boalch *et al.*, 1974). They suggested that the raised edges of the slatey rock severed fronds when the rocks were walked over. However, no quantitative data was provided.

Pinn and Rodgers (2005) compared a heavily visited ledge with a less visited ledge at Kimmeridge Bay, Dorset. Although the mean species richness was similar at both sites, the total number of species was greater at the less utilized site. Comparatively, the heavily utilized ledge displayed a reduction in larger, branching algal species (e.g. *Fucus serratus*) and increased abundances of ephemeral and crustose species (e.g. *Enteromorpha linza* and *Lithothamnia* spp. respectively).

Fletcher and Frid (1996a; 1996b) examined the effects of persistent trampling on two sites on the north east coast of England. The trampling treatments used were 0, 20, 80, and 160 steps per m^2 per spring tide for 8 months between March and November. Using multivariate analysis, they noted that changes in the community dominated by fucoids (*Fucus vesiculosus, F. spiralis* and *F. serratus*) could be detected within 1 to 4 months of trampling, depending on intensity. Intensive trampling (160 steps/m^2/spring tide) resulted in a decrease in species richness at one site. The area of bare substratum also increased within the first two months of trampling but declined afterwards, although bare space was consistently most abundant in plots subject to the greatest trampling (Fletcher and Frid, 1996a, 1996b). The abundance of fucoids was consistently lower in trampled plots than in untrampled plots. Fletcher and Frid (1996a) noted that the species composition of the algal community was changed by as little as 20 steps per m^2 per spring tide of continuous trampling since recolonization could not occur. A trampling intensity of 20 steps per m^2 per spring tide could be exceeded by only five visitors taking the same route out and back again across the rocky shore in each spring tide. Both of the sites studied receive hundreds of visitors per year and damage is generally visible as existing pathways, which are sustained by continuous use (Fletcher and Frid, 1996a, 1996b). However, the impact was greatest at the site with the lower original abundance of fucoids.

In Australia, the articulated brown algae *Hormosira banksii* was reported to be severely affected by trampling (Povey and Keough, 1991; Keough and Quinn, 1998; Schiel and Taylor, 1999). Povey and Keough (1991) observed a 50% reduction in *H. banksii* cover within 12 days of high intensity trampling (25 passes/tramples per day), and paths became visible in the brown algal mats within four days of trampling. After ca 6 weeks (includes 12 days of trampling), transects were clear of *H. banksii*. Low intensity trampling (two passes/tramples per day) reduced *H. banksii* cover and paths were visible after ca 6 weeks trampling, although considerable cover of *H. banksii* remained. After 270 days, the low intensity treatments recovered by growth from existing holdfasts, while *H. banksii* cover was still <50% of controls in high intensity treatments. After a further 150 days, the high intensity treatments reached 50% cover, which was markedly less than controls (Povey and Keough, 1991). The fronds of *H. banksii* are composed of rows of articulated vesicles, which may make it particularly susceptible to trampling damage. Povey and Keough (1991) noted that a single step could remove up to 34% of the frond, as pieces are easily broken off. Fletcher and Frid (1996a) noted that the low trampling intensity used above is equivalent to as few as two visitors per day walking across the transect.

Keough and Quinn (1998) examined the effects of different trampling intensities on rocky shore communities over a six year period. The experiment involved 6-8 days trampling per transect at 0, 5, 10 or 25 passages per trampling, every summer for 6 years. The effects of trampling varied with site. At one site, trampling resulted in a reduction in cover, proportional to the trampling intensity. Recovery occurred by the following summer but an even greater decline was seen in the next summer, with little subsequent recovery and the intermediate treatments remained at 60-70% cover. High intensity trampling, however, caused a severe decline, with little recovery and after four years cover remained <10%. At another two sites, trampling resulted in an initial decline and recovery (within 8-9 months) and subsequent greater decline as above. But all plots recovered completely and no trampling effects were observed over the next 3 years. Keough and Quinn (1998) suggested that there was greater variation in trampling effects between sites than within treatments but did not determine the cause of the variation.

Murray *et al.* (2001) resurveyed southern California shores previously surveyed in the 1950s, 60s, 70s, and 80s. They reported a decrease in fleshy macrophyte cover and diversity, with increases in crustose and articulated (erect) coralline algae and small turf-forming algal species. They suggested that the rocky shore community changes were due to an increase in coastal development and the resident human population, although they did not distinguish between recreational use and pollution effects.

Brosnan (1993) noted that algal turf species (*Endocladia muricata* and *Gelidium* spp.) increased by 38% in trampled plots as foliose algae declined, and algal turf dominated trampled areas. Exclusion of visitors, and hence reduced trampling, reduced relative algal turf abundance by 31%, while foliose algae increased in abundance. Brosnan and Crumrine (1994) noted that the algal turf forming species *Endocladia muricata* showed the least change in cover as a result of trampling, from 5% to between 3 and 5%. *Endocladia muricata* recovered quickly after trampling ceased and increased its cover to 5.6%, slightly higher than before trampling. Similarly, Jenkins *et al*. (2002) noted that *Endocladia muricata* did not decline significantly in response to trampling.

Brosnan and Crumrine (1994) noted that trampling significantly reduced algal cover within 1 month of trampling. Foliose algae were particularly affected and decreased in cover from 75% to 9.1% in trampled plots. *Mastocarpus papillat*us decreased in abundance from 9% to 1% in trampled plots but increased in control plots. *Fucus distichus* decreased in the summer months only to recover in winter but in trampled plots remained in low abundance (between 1 and 3% cover). Trampling resulted in a decrease in cover of *Pelvetiopsis limitata* from 16% to 1.5%. *Iridaea cornucopiae* decreased from 38 to 14% cover within a month and continued to decline to 4-8% cover. However, after trampling ceased, recovery of algal cover including *Iridaea cornucopiae* and *Mastocarpus papillat*us was rapid (ca 12 months) (Brosnan and Crumrine, 1994).

Fletcher and Frid (1996a; 1996b) reported a decrease in the understorey algal community of encrusting coralline algae and red algae, which was probably an indirect effect due to increased desiccation after removal of the normally protective fucoid canopy (see Hawkins and Harkin, 1985) by trampling. They also noted that opportunistic algae (e.g. *Ulva* sp.) increased in abundance. Schiel and Taylor (1999) also observed a decrease in understorey algae (erect and encrusting corallines) after 25 or more tramples, probably due to an indirect effect of increased desiccation as above. However, Schiel & Taylor (1999) did not detect any variation in other algal species due to trampling effects. Similarly, Keough & Quinn (1998) did not detect any effect of trampling on algal turf species.

In summary algal turfs seem to be relatively tolerant of the direct effects of trampling (based on the available evidence) and some species may benefit from removal of canopy forming algae (Tyler-Walters, 2005). Their tolerance may result from their growth form as has been shown for vascular plants and corals (Liddle, 1997). Brosnan (1993) suggested that algal turf dominated areas (on shores usually dominated by fucoids) were indicative of trampling on the rocky shores of Oregon. However, tolerance is likely to vary with species and their growth form and little species specific data was found. Furthermore, algal turf may suffer negative indirect effects where they form an understorey below canopy forming species.

Conversely, fucoid algae are particularly intolerant of trampling, depending on intensity. Fucoid algae demonstrate a rapid (days to months) detrimental response to the effects of trampling, depending on species, which has been attributed to either the breakage of their fronds across rock surfaces (Boalch *et al.*, 1974) or their possession of small discoid holdfasts that offer little resistance to repeated impacts (Brosnan and Crumrine, 1992; Fletcher and Frid, 1996b). Foliose species such a *Mastocarpus papillat*us, *Pelvetiopsis limitata* and *Iridaea cornucopiae* are also likely to be intolerant of trampling (Brosnan and Crumrine, 1994). Brosnan (1993) suggested that the presence or absence of foliose algae (e.g. fucoids) could be used to indicate the level of trampling on the rocky shores of Oregon.

This habitat (no. 3) is characterized by fucoid (*Fucus vesiculosus, F. serratus*), dominated communities, foliose red algae (e.g. *Mastocarpus, Osmundea* and *Palmaria*), *Pelvetia* and barnacle, and ephemeral green algae (e.g. *Ulva*) dominated communities. Ephemeral dominated communities, by nature, are likely to be damaged by trampling but recover quickly enough to be of little concern. However, fucoid dominated shores and, to a lesser extent, foliose red algae dominated shores are likely to be adversely affected by trampling.

As little as five visitors per spring tide were shown to affect the algal community and reduce fucoid abundance (Fletcher & Frid, 1996a). Keogh & Quinn (1998) noted a decrease in macroalgal cover with increasing trampling intensity, with high intensity trampling (25 passes over six to eight days) resulting in severe declines, although the communities studied included the particularly sensitive articulated brown algae *Hormosira.* Therefore, daily access by individuals is likely to be of concern in areas dominated by brown algal mats and foliose algae. Vehicular access is unlikely.

4.4 Brown and red seaweeds and mussels on moderately exposed lower shore rock

The effects of trampling on brown and red algae and mussels are summarized in section 4.2 and 4.3. This habitat is characterized by the scattered mussels and fucoids with barnacles and red seaweeds on bare rock and the mussel themselves. It is likely to exhibit similar sensitivity to that of Habitat 3 (see section 4.3). This habitat occurs on rock surfaces that can vary in height and slope. Where the habitat occurs on gentle slopes, it could be potentially exposed to vehicular access. Given the increased weight and torque exerted by vehicles (see section 3.2), vehicles are likely to remove fucoids in particular. In the absence of evidence, a precautionary sensitivity assessment has been given.

4.5 Mussels and boring bivalves (piddocks) on intertidal clay and peat

The effect of trampling on mussel beds on rocky shores in discussed above (see section 4.2). To the authors' knowledge, no studies have been conducted on the impacts of trampling on mussels and piddocks on intertidal clay and peat habitats. However, it is suggested that the species in this habitat may be susceptible to death from crushing or asphyxia as a result of burial, as has been shown in bivalves in intertidal muds and sands (see section 4.10).

Of higher concern, is the potential damage to the substratum itself due to trampling, where trampling could crush and dislodge parts of the clay or peat bed. Potentially, vehicles might be expected to damage the peat or clay bed itself, causing rutting, breakage and increasing its erosion, although no evidence of this impact was found. Brodhead & Godfrey (1979) reported that ORV traffic destroyed natural vegetation and the peat substratum, slowing subsequent recovery of low marsh. The fossilized peat and clay beds themselves are unusual and rare habitats, so that damage to the substratum itself is likely to be of concern.

4.6 Honey comb worm reefs

Sabellariid worms build tubes of concreted sand and large colonies can form raised biogenic reefs in the littoral zone (Holt *et al.*, 1998). Ghazanshahi *et al.*(1983) cited a study by Zedler (1978) that reported a decrease in abundance of the sabellariid worm *Phragmatophoma californica* in areas of heavy visitor use in California.

In the UK, littoral biogenic reefs are formed by *Sabellaria alveolata.* Cunningham *et al.* (1984) examined the effects of trampling on *Sabellaria alveolata* reefs. The reef recovered from the effects of trampling, (i.e. treading, walking, kicking or jumping on the reef structures) within 23 days. Recovery was achieved by repair of minor damage to the worm tube porches. Severe damage from kicking and jumping on the reef structure, resulted in large cracks between the tubes, and removal of sections (ca 15x15x10 cm) of the structure. Subsequent wave action enlarged the holes or cracks. However, after 23 days at one site, one side of the hole had begun to repair, and tubes had begun to extend into the eroded area. At another site, a smaller section (10x10x10 cm) was lost but after 23 days the space was already smaller due to rapid growth.

Cunningham *et al.* (1984) reported that *Sabellaria alveolata* reefs were more tolerant of trampling than expected but noted that cracks could leave the reef susceptible to erosion and lead to large sections of the reef being washed away. But eroded sections can survive and may lead to colonization of previously unsettled areas. The strange sculpturing of colonies in some areas is probably due to a combination of erosion and recovery (Cunningham *et al.*, 1984).

Continuous trampling may be more detrimental and Holt *et al.* (1998) reported that, in Brittany, damage to reefs on popular beaches was limited to gaps created by trampling through the reef. Once gaps are formed, they may be enlarged by wave action as seen above.

In summary *Sabellaria alveolata* reefs are probably of intermediate intolerance to trampling (Tyler-Walters, 2005a) and although worms can repair and stabilize the reefs relatively quickly, complete recovery will probably take several years once trampling has ceased. However, if a gap is formed, continuous trampling through the gap would probably remove any growing 'crust' of worms and the gap could not be repaired. No evidence of the effects of different trampling intensities on *S. alveolata* reefs was found. However, the information from Brittany suggests that continued, regular access across the reef is likely to result in paths through the reef structure.

No evidence on the effects of vehicles was found and the reefs are unlikely to encounter vehicles on rocky shores. But where reefs form on rocky outcrops on beaches they may be impacted by passing, parking or reversing vehicles. The increased weight and torque exerted by vehicles is probably at least equivalent to the experimental kicking and jumping impacts carried out by Cunningham *et al* (1984), which could potentially crack the colonies and remove sections of the reef. Regular impacts by vehicle might be expected to wear away the edges of the reef over time.

4.7 Sheltered intertidal bedrock, boulders and cobbles

This habitat is characterized by a mixture of fucoid (and especially *Ascophyllum nodosum*) dominated sheltered shores.

Fucus dominated communities have been discussed in above sections. However, sheltered shores dominated by the fucoid *Ascophyllum nodosum* were suggested to be particularly sensitive to trampling due to its slow recruitment (Holt *et al.* 1997). Knight & Parke (1950) noted that *A. nodosum* had not recolonized a cleared area after 8 years, despite sporadic development of short-lived juveniles. Boalch *et al.* (1974) proposed that *A. nodosum* at Wembury, Devon suffered from the effects of trampling, although no quantitative comparative data were available. However, Boalch & Jepson (1981) noted that the size range of fucoids, including *A. nodosum* were skewed to smaller length individuals, and that the abundance of *A. nodosum* in particular was reduced.

The brown algae *H. banksii* is particularly susceptible to trampling damage due to its frond composition of rows of articulated vesicles. Although quantitative examples of the effects of trampling on *A. nodosum* are lacking, it was suggested that this species which also has fronds with multiple vesicles, is intolerant of trampling (Tyler-Walters, 2005a). Its length makes it particularly vulnerable to being severed when trapped across the edges of rock, while its slow growth and poor recruitment will slow recovery.

The above evidence suggests that *A. nodosum* dominated shores are at least as sensitive to trampling damage as fucoid dominated shores. Their slow growth suggests that they may be more sensitive but no quantitative information was available to guide an assessment. Vehicles would be expected to damage *A. nodosum* but it is unlikely that vehicles would attempt to access fishing grounds across rocks covered by *A. nodosum*.

4.8 Rockpools and overhangs on rocky shores

To the authors knowledge no studies have been conducted on the impacts of trampling in rockpools. While Pinn & Rogers (2005) examined rockpools from sites with different visitor pressures at Kimmeridge Bay, no difference between rockpools due to visitor pressure at the two sites were given.

Trampling may occur if individuals accessing the shore are equipped with wellingtons and indifferent about rockpools. Deep rockpools probably act as a deterrent or impedance to access but shallow rockpools may be trampled on route. It is assumed that algal communities in rockpools have similar trampling sensitivities to their exposed rock surface counterparts (Tyler-Walters, 2005b). Therefore, rockpools dominated by fucoids and foliose red algae are likely to be sensitive, while coralline dominated communities may be more resistant.

In hydroid dominated pools (LR.Rkp.H), the community is dependent on the influence of physical disturbance such as sand scour and dominated by ephemeral hydroids and seaweeds, which thrive due to the disturbed nature of the habitat that prevents their competitive exclusion by late successional species. Abrasion could potentially destroy parts of the biotope, depending on the size of the pool and on the intensity of the impact. The delicate filamentous fronds of *Ulva intestinalis* will easily be scraped off the surface of the rock. Parts of the delicate *Obelia longissima* colonies are also likely to be removed. However, the surface covering of hydrorhizae may remain largely intact, from which new uprights are likely to grow. In addition, the resultant fragments of colonies may be able to develop into new colonies. If the shells of littorinids or mussels are damaged, individuals may be lost. Overall, the community may experience damage but will recover quickly (Marshall, 2005).

Overhang and crevice biotopes are likely to be protected from the effects of trampling due to the nature of the habitat, i.e. near vertical or overhanging and hence avoided during access.

In areas subject to visitor pressure, rockpools are probably impacted by trampling by rock poolers and their biodiversity is probably lower than in areas not accessed by visitors. However, access across the shore will probably have little impact on deep pools or overhangs, while shallow pools may be trampling through on route. Trampling may damage shallow pools dominated by coralline turfs, foliose red algae and fucoids but further study would be required to ascertain the level of impact at different levels of trampling intensity. Therefore, a precautionary sensitivity has been given. Vehicles are unlikely to drive across areas of the rocky shore with pot-marked with rock pools and overhangs are unlikely to be assessable to vehicles.

4.9 Intertidal brown seaweeds, barnacles or ephemeral seaweeds on boulders, cobbles and pebbles

This habitat is characterized by sheltered and very sheltered mixed substrata of pebbles and cobbles lying on muddy sand and gravel (Connor *et al.*, 1997). This gives rise to a variety of biotopes depending on the stability of the hard substrata. For example, in unstable cases the hard substrata is colonized by barnacles with dense aggregations of littorinids while in more stable examples the hard substrata supports fucoids such as *F. ceranoides, F. serratus* and *F. vesiculosus*. The mixed substratum supports infauna such as the blow lug *Arenicola marina*, ragworms *Hediste diversicolor*, the sand mason *Lanice conchilega*, occasional cockles *Cerastoderma edule* and clumps of mussels.

No specific examples of the impacts of access on this habitat were found. Unstable examples of this habitat are inherently dynamic and the community may be resistant to physical disturbance from trampling and vehicular access. However, where fucoids dominate the community is likely to be sensitive. This habitat is general flat and potentially exposed to vehicular access. Given the increased weight and torque exerted by vehicles (see section 3.2), vehicles are likely to remove fucoids in particular, and potentially move or turn boulders. In the absence of evidence a precautionary sensitivity assessment has been given.

4.10 Intertidal muddy sands – excluding biotopes supporting gaper clams

Johnson *et al.* (2007) examined the effects of trampling on the nematode component of the meiofauna in mudflats. Trampling simulated movements made by operators collecting crabs from under tiles (crab-tiling). Plots were trampled 6 times over a 2 week period. The effect of trampling significantly reduced nematode abundance, although Johnson *et al.* (2007) suggested that this might have been caused by meiofauna burrowing deeper into the sediment. However, 12-36 hours after crab-tiling activity ceased, species numbers had returned to control levels. Johnson *et al.* (2007) attributed the fast recovery to the dynamic nature of intertidal mudflats, which frequently experience natural disturbance.

Sheehan (2007) also investigated the effects of trampling associated with crab-tiling but looked at the effect on macrofauna. Trampling was conducted 3 times a week for 1 month. The abundance and diversity of infauna was found to be lower as a result of trampling. Wynberg and Branch (1997) simulated the trampling intensities associated with the collection of sand prawns *Callianassa kraussi* for bait. Six weeks after the single disturbance event, prawn densities in the trampled sites were 80% lower than control densities. However, after 32 weeks densities had returned to control levels. Total meiofaunal numbers increased significantly in trampled plots. However, total macrofaunal numbers were depressed in two of three trampled areas. This was attributed to the collapsing of burrows, compaction of sediment and reduction of oxygen levels. Similarly, Sheehan (2007) attributed the reduced abundance of infauna to the physical disturbance created by trampling, noting that trampling reduced sediment penetrability and sediment stability, creating a harsher environment. Sheehan (2007) also proposed that after trampling occurred, organisms avoided trampled sediment resulting in reduced immigration, or increased emigration.

Cook *et al.* (2002) examined the effects of trampling, using plots trampled in a manner comparable to the level of disturbance experienced in their tiled plots. The plots were visited twice a week for almost 5 months. Trampling had an effect on infaunal abundance but this was less than experienced under crab-tiles. This finding contrasts the results of Sheehan (2007), who reported that the ‘presence of tiles did not influence species assemblages’. Cook *et al.* (2002) noted that the number of taxa was not significantly affected by trampling. Also, trampling did not affect species richness, species diversity nor the sediment characteristics. The authors attribute this to an absence of fragile burrow systems in the study site.

Cook *et al.* (2002) and Rossi *et al.* (2007) reported average trampling depths of up to 5 cm, while Sheehan (2007) reported depths of 30-50cm. The variation in trampling depth may explain the variation in findings. However, Wynberg and Branch (1997) noted that the effects of trampling are variable due to sediment nature and the associated infauna.

Chandrasekara and Frid (1996) investigated the impacts of trampling on the benthic infauna of Lindisfarne tidal flats. During the five months in summer, about 10,000 pilgrims typically walk along a traditional path through the mudflat to access the holy site of Lindisfarne (approximately equivalent to ca 50 individual a day). A transect was positioned perpendicular to the footpath. Five quadrats were sampled, the third being positioned on the path centre. Chandrasekara and Frid (1996) found that repeated trampling on the path during the summer had a significant impact on the benthic community. The abundance of several species reduced on the path, while several of the dominant taxa significantly increased in abundance. During winter the benthic community of the path was not significantly different from other samples. The authors suggest that the observed increases in abundance may have been due to several factors: (1) rapid recruitment of adult stages, (2) trampling stimulating bacterial growth on organic matter, thereby providing food for deposit-feeding infauna, and (3) an additional food source from animals killed/injured by trampling.

Rossi *et al.* (2007) noted the effects of trampling on a mudflat. The experiment involved trampling by an average of five people for 3-5 hours, twice a month between March and

September 2005. Rossi *et al.* (2007) noted that mobile fauna were not affected by trampling, with abundances in trampled treatments being within the range of natural variability of the mudflat. However, trampling did alter the distribution of bivalves, the effect depending on their size-class. *Macoma balthica* exhibited increased recruitment in trampled plots but decreased abundances of juveniles and one year old individuals. Size class I (<12 mm) *Cerastoderma edule* showed no response to trampling. Conversely, size class II individuals (>12 mm) decreased in response to trampling. Rossi *et al.* (2007) suggested that because the study was conducted during the reproductive periods for both *M. balthica* and *C. edule*, there were juveniles present in the water column to replace individuals displaced by trampling. *C. edule* inhabits the top 2-3 cm of sediment. Therefore, size class II individuals were probably killed directly by crushing or asphyxia due to burial. The authors proposed that *M. balthica* were killed because trampling severed their connection to the surface.

Limited information on the effect of vehicles on intertidal mudflats is available. Lyndon *et al.* (2004) reported evidence of quad bikes accessing mud-flats in Kentra Bay, Scotland. Lancaster (2004) noted that tracks created by dry tractor dredging would be exposed over low water period, impeding and delaying recovery. Davenport and Davenport (2006) noted that ruts left by ORVs on tropical beaches were deep enough to trap turtle hatching on route to the sea, suggesting that ORVs could leave cause rutting of muddy sands and sands.

In summary meiofauna appear to be relatively unaffected by trampling, which was attributed to the dynamic nature of intertidal mud (Johnson *et al.*, 2007), rapid recruitment and increased food supplies (Chandrasekara and Frid, 1996). However, the remaining evidence (with the exception of Cook, 2002) suggests that trampling has an adverse impact on macrofauna. Recovery from impact is relatively fast as shown by Chandrasekara and Frid (1996), where no difference was reported between samples in winter following summer trampling. Wynberg and Branch (1997) suggest that trampling effects are most severe in sediments dominated by animals with stable burrows, as these collapse and the sediment becomes compacted. In Rossi *et al.* (2007) experiments, trampling as low as passes by five individuals twice a month reduced the abundance of adult *M. baltica* and size II *C. edule,* although small (size I) *C. edule* showed no effects and juvenile *M. baltica* increased in abundance.

Sensitivity is likely to vary with the relative proportion of mud to sand (sediment porosity), the dominant infauna (nematodes and polychaetes vs. bivalves) and the presence of burrows. However, daily access by walkers is likely to be of concern. Given their increased weight, ground pressure and torque, vehicles would be expected to affect the sediment to a greater degree and greater depth than foot access alone.

4.11 Intertidal muds and sands supporting gaper clam

Emerson *et al.* (1990) examined smothering and burrowing of *Mya arenaria* as indirect effects of after clam harvesting. Significant mortality (2 - 60%) in small and large clams occurred only at burial depths of 50 cm or more in sandy substrates. However, they suggested that gaper clams buried under 25 cm of sediment would almost certainly die. Trampling is unlikely to disturb enough of the sediment surface to smother individuals but individual burrows may be collapsed along the access path used, potentially resulting in the death of deeply buried individuals as *M. arenaria* can burrow to depth of 50 cm.

Limited information on the effect of vehicles on intertidal mudflats and muddy sands was available. Godfrey *et al.* (1978; cited in Liddle, 1997) reported the use of off-road vehicles (ORV) on sediments suitable for the clam *Mya arenaria*. ORVs killed clams by compacting sediments, crushing burrows and preventing siphon extension to the surface or by directly crushing individuals. Presumably, the smallest and hence least deeply buried individuals were most likely crushed.

In summary the evidence suggests that the effects of trampling on *Mya arenaria* are dependent upon size class. However, vehicle use appears to have a potentially severe impact on gaper clams. Large clams establish a permanent burrow (Tyler-Walters, 2003) and are therefore susceptible to burrow collapse and sediment compaction through trampling and especially vehicle use. The sensitivity of the surrounding habitat is probably similar to that of Habitat 10 (above) but the presence of *M. arenaria* probably increases its sensitivity to vehicular access.

4.12 Intertidal muds

The studies of Johnson *et al.* (2007), Rossi *et al.* (2007), Cook *et al.* (2002), and Chandrasekara and Frid (1996) examined the effects of trampling in intertidal mudflats. As above, trampling was reported to affect the benthic infauna. Chandrasekara and Frid (1996) noted that some species reduced in abundance on the pilgrim's path (*Capitella capitata* and *Scoloplos armiger*) while others increased in abundance in the face of high levels of trampling probably due to rapid recruitment and growth of more opportunistic species, even though their population experienced mortality. Cook *et al.* (2002) found that trampling associated with bait digging had little effect of infaunal species composition. While, Sheehan (2007) found that trampling associated with bait digging reduced the infaunal abundance and diversity, and increased the penetrability of the sediment.

In summary the intertidal muds probably exhibit similar sensitivity characteristics to the intertidal muddy sands (see above)

4.13 Saltmarsh

Saltmarsh communities were the most impacted communities reported by the organizations contacted. In a study of Danish coastal habitats, Anderson (1995) noted that saltmarsh vegetation was the most resistant to trampling, when compared to sand dune and coastal grassland habitats. Anderson (1995) noted that the communities examined received ca 1815-3630 passes per year (ca 5-10 passes per day) which was light, whereas that 7500 passes per year was enough to cause complete loss of vegetation (Burdon and Randerson, 1975; cited in Andersen, 1995). Chandrasekara and Frid (1996) also noted that continual trampling on the 'old track', Lindisfarne, reduced vegetation cover and increased the area of bare mud, so that the 'old path' is 'clearly distinguishable on the vegetated marsh' (Chandrasekara and Frid, 1996).

Vehicles have been reported to damage saltmarsh. Packham and Willis (1997) noted that the longevity of ruts caused by vehicles result in abrupt changes in the vegetation, so that ruts favour damp tolerant plants such as *Salicornia* and *Puccinellia maritima*. Brodhead and Godfrey (1979) noted that only a few passes of ORVs were sufficient to severely damage salt marsh plants. In the low marsh ORV traffic destroyed natural vegetation and the peat substratum, slowing subsequent recovery.

In summary, while saltmarsh communities are relatively resistant to trampling (foot access) they are likely to be more sensitive to vehicular access.

4.14 Underboulder communities on lower shore and shallow subtidal boulders and cobbles (Habitat 26)

No specific examples of the effect of access on this habitat were found. Davenport & Davenport (2006) note that boulder turning during collecting and gathering adversely affects intertidal boulder habitats. However, foot access is unlikely to involve deliberate boulder turning and pedestrians are likely to walk between boulders and over large rather than small boulders. Where fucoids are present, they may suffer trampling impacts as above (section 4.3). No information on the effects of trampling on Laminarians was found (e.g. *Laminaria digitata*, *Saccharina latissima* (syn. *L. saccharina*). Laminarians are robust and tough species but trampling on prostrate blades at low tide could potentially damage the blade or the growing meristem.

Boulder communities are noted for the diversity of species under the boulders themselves. Accidental movement of the boulder is likely to disturb the under-boulder communities. Stable boulders are fused together by algal growth (especially corallines) and breaking this matrix would be very harmful (Foster-Smith, pers. comm. cited in Hiscock, 2005). Furthermore, this disturbance and habitat degradation could change a stable boulder field to an unstable field on a long-term basis. Movement of the boulder surface against other hard surfaces (for instance, other boulders) is likely to cause significant damage to encrusting fauna that is characteristic of the community (Foster-Smith, pers. comm.; cited in Hiscock, 2005).

Vehicular access could potentially disturb small and large boulders and crush delicate species within the underboulder community by driving over them or pushing out of the way as they pass.

4.15 Biogenic reef on sediment and mixed substrata (Habitat 27)

In the intertidal, this habitat is characterized by mussel beds. As noted previously in section 4.2, trampling has a deleterious effect on mussel beds resulting in increased losses of mussels due to destabilization of the bed due to damage to byssal threads that bind the individuals within the bed together. On sediment, there is the added possibility that weight on the surface of the bed (from walkers and especially from vehicles) may push the bottom layer of mussels into the sediment resulting in mortality of individuals. The use of vehicle to cross mussel beds would undoubtedly be far more damaging than foot access alone.

4.16 Seagrass beds (Habitat 30)

Seagrass beds are not physically robust. Their root systems are located within the top 20 cm of sediment and are therefore easily dislodged (Fonseca, 1992). Eckrich and Holmquist (2000) examined the effects of trampling on a bed of *Thalassia testudinum* in Puerto Rico. Experimental trampling of three ‘lanes’ was conducted at 0, 20 and 50 passes. Treatments were applied once a month for 4 months at 10 sites. Sand cover increased in the heavily trampled treatments. With exceptions at one site, heavy trampling (50 passes per month for four months) resulted in reduced rhizome biomass of up to 72% and loss of standing crop up to 81%. Seagrass recovery was incomplete seven months after trampling ceased and reduced cover was still visually distinguishable at several study sites after 14 months. Eckrich and Holmquist (2000) reported that rhizome biomass loss was greatest at sites with softer substrates.

Major *et al.* (2004) compared the impact of three types of footwear on eelgrass *(Zostera japonica)* beds at two sites in Washington State. One site had a deep soft muddy substrate, the second a hard packed sand substrate. The treatments were a single footprint, placed at the centre of sampling points positioned at set locations along a 10 m transect. Transects were established in June, July and August. A significant decrease in shoot density was seen at only one mud site in July. However, Major *et al.* (2004) noted that eelgrass incurred more physical damage in the soft muddy substrate than in the sand substrate.

Holt *et al.* (1997) cited the work of Thom (1993), who reported trampling damage to *Zostera marina* beds during mitigation work performed in response to crab mortalities in Washington State. Cockle collectors accessing fishing grounds in Yaquina Bay, Oregon, were reported to wade through seagrass beds into 1 m of water at low tide, potentially creating disturbance to a depth of 2 m (Boese, 2002). Eckrich and Holmquist (2000) highlighted that trampling or wading depth may influence trampling disturbance. Less force is exerted by an individual at greater depths due to the effects of buoyancy, while wading intensities are greatest in shallowest areas. Eckrich and Holmquist (2000) suggested that the effect of trampling may be more pronounced in temperate areas, where seagrasses experience a shorter growing season.

Hodges and Howe (1997) documented the impact of vehicular access on *Zostera angustifolia* beds in Angle Bay, Wales after the Sea Empress oil spill. Vehicle use, required for the initial clean up, resulted in patchy beds, criss-crossed with wheel ruts up to 1 m deep. Unauthorized activities before the spill, including vehicles associated with bait digging and the use of motorbikes, created ruts that were still visible over a year later.

In summary seagrass beds exhibit a detrimental response to the effects of trampling and vehicle use. The effects of trampling are more pronounced in soft mud habitats (Eckrich and Holmquist, 2000; Major *et al.*, 2004). Repeated heavy trampling results in large losses of seagrass biomass and standing crop, compounded by a slow recovery rate (Eckrich and Holmquist, 2000).

5 SENSITIVITY MATRIX.

The likely sensitivity of habitats to access to fishing grounds by foot (‘gear type’ 15a) and by vehicle (‘gear type’ 15b) are shown in Table 5.1. The likely sensitivities shown are based on the evidence collated above and expert judgement. Where evidence is scant, a precautionary approach has been taken. Further investigation of the effects of access on intertidal habitats is required to test the sensitivity assessments suggested.

In particular, little direct evidence is available to assess the sensitivities of intertidal communities to vehicular access. Therefore, in the absence of evidence, precautionary sensitivity assessments (to vehicular access) have been given, based on the premise that vehicles were considered to do 5-30 times the level of damage as walkers in terrestrial and coastal habitats.

Table 5.1 Sensitivity matrix. Gear type and intensities are allotted scores depending on the likely effects on marine intertidal habitat types.

Habitat Type	1. Upper shore stable rock with lichens & algal crusts				2. Wave exposed stable rock				3. Moderately wave exposed rock				4. Brown & red seaweeds & mussels on moderately exposed lower shore rock			
Gear Intensity	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**
Gear Type																
15a. Foot Access	--	--			--				--	--			--	--		
15b. Vehicular Access													--	--		

Habitat Type	5. Mussels & boring bivalves (piddocks) on clay and peat				6. Honey comb worm reefs				7. Sheltered bedrock, boulders + cobbles				8. Rockpools & overhangs on rocky shores			
Gear Intensity	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**
Gear Type																
15a. Foot Access					--											
15b. Vehicular Access	--	--			--	--										

Habitat Type	9. Brown seaweeds, barnacles or ephemeral seaweeds on boulders, cobbles & pebbles				10. Muddy sands, excluding *Mya arenaria*				11. Muds & sands supporting *Mya arenaria*				12. Intertidal muds			
Gear Intensity	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**
Gear Type																
15a. Foot Access					--				--				--			
15b. Vehicular Access	--				--	--			--	--			--	--		

Habitat Type	13. Saltmarsh				26. Underboulder communities on lower shore & shallow sublittoral boulders + cobbles				27. Biogenic reef on sediment				30. Seagrass beds			
Gear Intensity	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**	**H**	**M**	**L**	**S**
Gear Type																
15a. Foot Access													--			
15b. Vehicular Access	--	--	--		--	--			--	--			--	--	--	

Legend

-- High sensitivity | Medium sensitivity | Low sensitivity | Gear unlikely to occur in this habitat

6 CONCLUSIONS

The effects of trampling (walking and hiking) on terrestrial and some coastal habitats (e.g. sand dunes) is well documented. The effects of vehicles on terrestrial habitats and, to a lesser extent coastal habitats, is also documented.

Trampling causes reduced cover and/or biomass of vegetation, and alters plant communities and their associated animal communities, depending on the intensity of trampling (usually expressed as number of passes) and the nature of the receiving habitat, i.e. the resistance of plant communities to trampling damage, slope and substratum type. High intensities of regular trampling leads to the bare space and clear paths so typical of frequently visited natural habitats. Vehicles are generally considered to do more damage than walking (ca 5- 30 fold) due their greater weight and power. However, the level of damage varies with the vehicles used, how they are driven and the nature of the receiving habitat.

Trampling has been relatively well studied on the intertidal rocky shores but relatively poorly studied on sedimentary shores. The studies and their results are highly variable but again demonstrate that the impacts depend on the nature of the receiving habitat and the intensity of trampling, with increasing trampling resulting in reduced biodiversity, reduced abundance or biomass of affected species (especially macroalgae) and increased bare space and, in some cases, clear paths. However, there are very few studies of the effects of vehicles in the intertidal, none of which were relevant directly to access to fishing grounds.

In this study, the scales of intensity used for foot access (gear type 15a) and vehicular access (gear type 15b) to fishing grounds was based on expert judgement and local knowledge supplied by representatives of relevant organizations. The 'foot access' scale was based on expertise collected by Hall *et al.* (2008). The 'vehicular access' scale was based on expert judgement and the responses of contacted organizations. Although, ground pressure (Liddle, 1997) and 'land impact' (Yorks, 2000) compared the relative potential impact of vehicle types, there are too many variables influencing how vehicles actually affect the environment to do more than rank vehicle types in order of increasing potential damage. Direct comparative studies are few and none were found in the intertidal. However, the 'vehicular access' scale suggested in this report is precautionary and requires further testing and adjustment through consultation.

There was not enough evidence to compare directly the reported effects of trampling and vehicular access to the access scales used, especially for vehicles. The trampling studies reviewed were varied, and even experimental studies were not directly comparable. In addition, few studies considered daily access as represented by the access scales suggested but the studies often reported the results of many more visitors (hundreds to thousands) than the number of individuals likely to access fishing grounds via the intertidal.

There was enough evidence in the literature to support expert judgement and allow the likely sensitivity of the habitat types to different intensities of foot and vehicular access to be assessed. Nevertheless, in many cases the sensitivity assessments given are precautionary in nature and would benefit from further local expertise and consultation, together with additional studies to test the sensitivities suggested.

It is clear that further study is required to examine the effects of different intensities of trampling on different habitats within Wales and the rest of the United Kingdom. Evidence on the effects of vehicular access on intertidal rock and sedimentary habitats is lacking and studies are required urgently if vehicular access continues to be a concern. Also, it is clear that un-managed access to the intertidal can have detrimental effects on intertidal communities.

7 RECOMMENDATIONS

The above report and conclusions give rise to the following recommendations.

- Further studies are required to provide evidence on the effects of trampling and especially vehicular access on intertidal habitats in Wales and the rest of the United Kingdom.
- Such experimental studies should ensure that their methodologies are compatible with other studies in the field of recreational ecology, so that different studies in terrestrial, coastal and marine habitats are directly comparable.
- Experimental studies should be augmented by direct observation of the effects of access, especially where vehicles are used.
- The provision of designated access points and tracks may be one method to avoid or mitigate impacts to sensitive habitats.

Although our knowledge is incomplete, un-managed access has the potential to damage intertidal habitats. Management should be put in place to minimize current impacts while further studies continue to improve our understanding and help to adapt management measures in the future.

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