

Algal harvesting in Clew Bay: pre-license survey, April – July 2016

A report for BioAtlantis Ltd. by Dr. [REDACTED] and Professor. [REDACTED]

Earth Institute & School of Biology and Environmental Science, University College Dublin.

Summary

A survey was conducted in Clew Bay as part of an assessment of *Ascophyllum nodosum* resources in the Clew Bay SAC. Its primary aim was to verify biomass estimates for *Ascophyllum nodosum* in the application originally submitted by BioAtlantis. Additional aims were to (a) characterising approximate patterns of distribution of that biomass across the Clew Bay complex (b) verify levels of existing harvesting for this species (c) estimate biomass of *Fucus vesiculosus* at sites in Clew Bay and (d) characterise substrata at each site sampled.

A stratified random sampling approach was used to select a subset of sites from among all potential harvest sites in the Clew Bay complex (including all Coastal and Island sites) identified in a preliminary survey undertaken by BioAtlantis Ltd. Out of a total of 191 sites identified by BioAtlantis, 44 were selected and sampled using transects and quadrats. The biomass of *A. nodosum* was recorded at all 44 sites. *A. nodosum* was not present at only two of the 44 sites. The mean biomass of *A. nodosum* at the other 42 sites ranged from 1.88 - 22.91 kg/m², with the highest biomass of 22.91 +/- 3.79 kg/m² recorded in the coastal site of Newfield and the lowest biomass of 1.88 +/- 0.55 kg/m² recorded on the island site of Island Moor.

Weighted stratified means were calculated for all four zones, which resulted in an estimated total biomass of *A. nodosum* of 55,606.7 tonnes for the whole of the Clew Bay complex. With an expected annual harvest estimate (calculated as 20% of total biomass) of *A. nodosum* of 11121 (+/- 658.7 CI 95%) tonnes per annum, which is approximately 14% lower than the original BioAtlantis mean estimate for annual harvest of 12,900 tonnes per annum (+/- 2370.8 CI 95%) and considerably more precise.

In terms of existing harvesting, this survey provides evidence that there was substantial existing harvesting occurring within the bay. Intensity of harvesting varied from site to site, but evidence of its occurrence arose at 26 of the 40 sites surveyed.

This report also provides estimates of the biomass (kg/m²) of *F. vesiculosus* at all sampled sites in the Clew Bay complex, which occurs at much lower values in comparison to that of *Ascophyllum nodosum*.

1. Introduction

In terms of the management framework within which harvesting needs to take place to satisfy licensing conditions, the percentage of total tonnage that is harvested is limited to 20%. In addition, the area of habitat subjected to continuous disturbance should not exceed an approximate area of 15% of the total area of Annex I habitat. For such limits to be set and adhered to, it is necessary to estimate the total biomass of *A. nodosum* in the bay.

Levels of the biomass of *A. nodosum* resources in Clew Bay were assessed by BioAtlantis from remote sensing outputs (use of GIS based maps and images) and by selecting a small subset of sites within Clew Bay to sample as part of its application for a licence to harvest. Using this approach, a total standing biomass of 64,758.4 tonnes was estimated, enabling an annual harvest of 12,900 tonnes per annum - based on 20% of the individual estimates of the brown algae (Table 3). The primary objective of the current study was to verify levels of intertidal biomass of *A. nodosum* using a rigorous programme of physical sampling.

Secondary objectives were to (a) characterise approximate patterns of distribution of that biomass across the Clew Bay complex so that harvesting can be appropriately targeted (b) assess levels of existing harvesting based on cut fronds and (c) estimate biomass for *Fucus vesiculosus* at each site and (d) characterise habitat characteristics at the sampled sites, in terms of substrata present.

2. Methods

Out of a total of 191 potentially harvestable sites identified by BioAtlantis, 44 representative sites were selected (Figure 1, Table 1) using a stratified random sampling approach, based on a number of factors. The bay was divided into four geographical zones within the Clew bay complex – NorthWest, North-Bay, Headland/Midzone and South-Bay. Within each zone, sites were classified as Coastal vs Island and Outer vs Inner – such that Inner sites were those expected to be more sheltered and Outer sites were those expected to be subjected to greater wave action (Figure 1, Table 1). As such, the bay was divided into 14 unique strata, each containing 1 - 6 sites with individual sites selected at random to be sampled from each stratum.

Areas of individual sample sites ranged in size from 4000 – 400,000 m², with 19 sites < 50,000 m², 18 sites ranging from 50,000 - 100,000 m² and 6 sites > 100,000 m² (See Table 2 for areas of all sampled sites).

Sampling took place in April- July 2016. Sites were accessed either by boat or, where possible, by road. In each site, a number (10 - 20) of 10 x 6 m transects (oriented perpendicular to the shoreline) were evenly spaced across the whole site. The distance between transects varied depending on the total size/area of each site, which was evaluated by a preliminary visual survey of the site (either by boat or by walking the site) and total

lengths of shoreline estimated from a scaled map. The number of transects and the density of quadrats placed in each site varied depending on the total area of each site (see Table 1). This was standardised by assigning sites based on total area into one of three categories (Small, Medium & Large; see Table 2). Ten transects/20 quadrats were sampled in sites in the Small category ($<50,000 \text{ m}^2$), 15 transects/30 quadrats were sampled at sites in the Medium category ($50,000 - 100,000 \text{ m}^2$) and 20 transects/40 quadrats were sampled at sites in the Large ($>100,000 \text{ m}^2$) category (Table 2). At each site, 1 x 1 m quadrats were randomly placed within transects using a random number table to generate coordinates.

In each quadrat, data collected included the wet weight biomass of both *A. nodosum* and *Fucus vesiculosus*, the type of substrate and the presence/absence of harvesting in each quadrat. In addition, areas outside of quadrats subjected to harvesting were visually assessed and levels of harvesting were noted at all sites.

Previous harvesting activity was estimated within quadrats based on visual identification of cut fronds within the quadrats and was recorded as presence/absence for each quadrat. The total number of quadrats with harvesting and the proportion of quadrats with harvesting was calculated for each site. None (0%), Light ($\leq 10\%$), Moderate ($>10\% \leq 35\%$) and Heavy ($>35\%$). At the site level, categories of harvesting were estimated based on field observations (notes) taken at each sampled site and the degree/extent of harvesting at each site were categorised broadly into the same four harvesting categories based on the following criteria: the type of evidence of harvesting noted, the number of instances of evidence observed (i.e. how many times areas of harvested algae were noted along the shoreline) and the extent of the harvested areas (quantified in meters in the field observations).

Substrates in each quadrat were evaluated and assigned to a series of eleven categories based on grain size and/or substrate mix, those being: Large boulders ($> 600\text{mm}$), medium boulders ($>300<600\text{mm}$), small boulders ($>150<300\text{mm}$), cobbles ($>75<150\text{mm}$), small cobbles ($>35<75\text{mm}$), pebbles ($>20<35\text{mm}$), Shingle ($>5\text{mm}<20\text{mm}$), sand, sand/pebble mix, mud/shingle mix and mud/sand mix. Multiple substrates within each quadrat were only marked as present when their area coverage was greater than 10 % of the total quadrat area.

Target species of macro-algae in all quadrats were cut using sharp blades on the stipes at 150 – 180 mm from the point of attachment. The wet weight biomass of each macro-algal species in each quadrat was assessed using a digital balance scales (to a maximum of 50 kg, accurate to within 10 g) and basket (values given were corrected for basket weight) after removing excess water using paper towels.

Stratified means per sampling unit of biomass data for *A. nodosum* were calculated for each of the 14 strata in order to estimate an overall mean based on combining estimates of biomass for each area weighted by the total area in m^2 . The result is a more precise estimate of the overall mean (i.e. with smaller Confidence Intervals) than would be achieved just by sampling biomass per m^2 in quadrats/sites distributed randomly all over the bay. The overall mean was estimated using the following equations:

$$\bar{x}_{ST} = \sum_{h=1}^l \frac{N_h \bar{x}_h}{N}$$

Calculation of the stratified mean of data for each strata. Where \bar{x}_{ST} = Stratified population mean per sampling unit, N_h = size of stratum h , h = Stratum number, \bar{x}_h = observed mean for stratum h , N = Total number of sampling units.

Stratum weightings (W_h) were calculated by dividing the total area of the combined strata by the area of each stratum (Equation 2).

$$W_h = \frac{N_h}{N}$$

Calculation of the individual stratum weighting for each stratum, where W_h is the stratum weighting and N_h is the stratum size and N is the total area of combined strata

Total biomass of the whole bay (\hat{X}_{ST}) was calculated by multiplying the stratified mean per sample unit (\bar{x}_{ST}) by the total area (N) of the Clew Bay complex (Equation 3).

$$\hat{X}_{ST} = N\bar{x}_{ST}$$

The variance of the stratified mean was calculated using the following equation:

$$\text{Variance of } (\bar{x}_{ST}) = \sum_{h=1}^L \left[\frac{w_h^2 s_h^2}{n_h} (1 - f_h) \right]$$

Where w_h = Stratum weight, s_h^2 = Observed variance of stratum h , n_h = Sample size in stratum h and f_h = sampling fraction in sample $h = \frac{n_h}{N_h}$

The standard error of the stratified mean is the square root of its variance

$$\text{Standard error of } (\bar{x}_{ST}) = \sqrt{\text{Variance of } \bar{x}_{ST}}$$

The variance of the population total is given simply as

$$\text{Variance of } (\hat{X}_{ST}) = (N)^2 (\text{Variance of } \bar{x}_{ST})$$

The confidence intervals for the stratified mean and the stratified population total were obtained in the usual way:

$$\bar{x}_{ST} \pm t_{\alpha} (\text{Standard error of } \bar{x}_{ST})$$

$$\hat{X}_{ST} \pm t_{\alpha} (\text{Standard error of } \hat{X}_{ST})$$

The degrees of freedom for each stratum vary, so to calculate the appropriate degrees of freedom for the value of Student's t to use, one must calculate an effective number of the degrees of freedom from the following approximate equation:

$$d.f. \approx \frac{(\sum_h^L - 1) g_h s_h^2)^2}{\sum_h^L - 1 [g_h^2 s_h^4 / n_h - 1]}$$

Where d.f. is the effective number of degrees of freedom for the confidence limits, g_h is equal to $N_h(N_h - n_h)/n_h$, s_h is equal to the observed variance in stratum h , n_h is equal to the sample size in stratum h and N_h is equal to the size of stratum h .

Finally the total harvestable biomass per annum was calculated as 20% of the estimated total biomass and equally the associated standard errors and confidence intervals were expressed as 20% of each calculated value from the above equations.

Table 1 Complete list of all sites sampled in Clew Bay during the current survey with corresponding zones, type of site (Coastal or Island) and mean biomass +/- Standard error (kg/ m²) recorded at each individual site.

Site code	Site name	Zone	Site Type	Position
IS32	Inish Cannon	NorthWest	Island	Inner
IS6	Inis Quirk	NorthWest	Island	Inner
IS7	Inish Tubrid	NorthWest	Island	Inner
IS9	Inishdubinan	NorthWest	Island	Inner
IS19	Roeillaun	NorthWest	Island	Outer
IS18	Inishcoaa	NorthWest	Island	Outer
CZ5.15	Bunahowna	NorthWest	Coastal	Inner
CZ5.10	Newfield	NorthWest	Coastal	Inner
CZ5.13	Rosturk Strand	NorthWest	Coastal	Outer
CZ5.8	Roskell/Sandhill	NorthWest	Coastal	Outer
CZ5.17	Rosmurrevagh	NorthWest	Coastal	Outer
IS38	Inishchuill	North-Bay	Island	Inner
IS28	Fregallan Luggah	North-Bay	Island	Inner
IS25	Inishdaweel	North-Bay	Island	Inner
IS 1	Forilan	North-Bay	Island	Inner
IS4	Illannambraher	North-Bay	Island	Inner
IS48.1	Inishturk	North-Bay	Island	Inner
CZ 5.7	Baigh/Rostrunk	North-Bay	Coastal	Inner
CZ4.8	Rossanrubble	North-Bay	Coastal	Inner
CZ4.13	Knockeeragh	North-Bay	Coastal	Inner
CZ3.7	Ardkeen/Rassakeeran	North-Bay	Coastal	Inner
CZ4.3	Rosbeg	North-Bay	Coastal	Inner
IS58.1	Collanmore	Headland/Midzone	Island	Inner
IS61	Illanatagg	Headland/Midzone	Island	Inner
IS53	Inishbee	Headland/Midzone	Island	Outer
IS59	Inishgort	Headland/Midzone	Island	Outer
IS57.2	Island Moor	Headland/Midzone	Island	Outer
IS57.1	Rabbit	Headland/Midzone	Island	Outer
CZ3.2	Rosmoney	Headland/Midzone	Coastal	Inner
CZ3.3	Castleleaffy	Headland/Midzone	Coastal	Inner
CZ2.16	Moyour Channel	Headland/Midzone	Coastal	Inner
CZ2.10	Carrowcally	Headland/Midzone	Coastal	Inner
CZ3.6	Claggan Strand	Headland/Midzone	Coastal	Outer

Table 1
Continued

Site code	Site name	Zone	Site Type	Position
IS80	Illanroe	South-Bay	Island	Inner
IS67	Inishimell	South-Bay	Island	Outer
IS78	Monkellys	South-Bay	Island	Outer
IS79	Inishweela	South-Bay	Island	Outer
IS70	Inishraher	South-Bay	Island	Outer
IS68	Inishleague	South-Bay	Island	Outer
CZ2.6	Pigeon Point	South-Bay	Coastal	Inner
CZ1.13	Annaghaside middle	South-Bay	Coastal	Inner
CZ1.8	Annagh Island East	South-Bay	Coastal	Inner
CZ1.5	Murrisknaboll	South-Bay	Coastal	Inner
CZ1.2	White Strand	South-Bay	Coastal	Outer

Table 2 Total area and the number of transects and quadrats assigned for each sampled site as part of the UCD survey. Site codes are derived from the BioAtlantis application, where IS refers to island sites and CZ refers to coastal sites.

Site code	Area of site (m²)	# of transects per site	# of quadrats per site	Size category
IS78	4222.28	10	20	Small
CZ2.16	6129.19	10	20	Small
CZ4.8	6827.77	10	20	Small
IS32	8656.469	10	20	Small
IS57.1	14757.09	10	20	Small
CZ5.10	17598.1	10	20	Small
IS31	20455.77	10	20	Small
IS79	24618.54	10	20	Small
IS6	25206.3	10	20	Small
IS80	28521.78	10	20	Small
CZ5.13	29666.28	10	20	Small
CZ5.15	30449.57	10	20	Small
CZ2.6	30578.55	10	20	Small
IS65	32313.65	10	20	Small
IS25	34023.52	10	20	Small
CZ3.2	40293.21	10	20	Small
IS1	40652.904	10	20	Small
IS9	42173.92	10	20	Small
IS7	45539.96	10	20	Small
IS68	54366.37	15	30	Medium

Continued

Site code	Area of site (m ²)	# of transects per site	# of quadrats per site	Size category
CZ5.17	55403.5	15	30	Medium
IS4	55475.14	15	30	Medium
IS48.1	56133.73	15	30	Medium
CZ1.5	59466.51	15	30	Medium
IS18	70929.48	15	30	Medium
CZ1.8	74406.4	15	30	Medium
IS59	74837.63	15	30	Medium
CZ3.6	78317.49	15	30	Medium
IS38	78713.6079	15	30	Medium
IS19	79878.14	15	30	Medium
CZ5.8	80757.81	15	30	Medium
IS70	81494.76	15	30	Medium
CZ1.2	83287.72	15	30	Medium
CZ1.13	90724.11	15	30	Medium
IS57.2	92902.642	15	30	Medium
CZ3.3	95816.95	15	30	Medium
CZ2.10	102718.79	20	40	Large
CZ4.3	103975.6	20	40	Large
CZ3.7	117114.4	20	40	Large
CZ5.7	143305.9	20	40	Large
IS53	213730.45	20	40	Large
CZ4.13	266418.905	20	40	Large
IS61	365624.876	20	40	Large
IS58.1	430527.54	20	40	Large
Total area	3489013.304			



Figure 1 Map of Clew Bay showing all 44 sites sampled in each of four geographical zones during UCD survey. Map source: Google Earth, data source for shapefiles: NPWS.

3. Results

3.1 Biomass estimates of *A. nodosum* in Clew Bay

The mean biomass per m² of *A. nodosum* varied between individual sites and types of site in each of the four zones in Clew Bay (Figure 2). Across the whole bay, *A. nodosum* was absent from only two sites surveyed: the coastal site Rossmurrevagh in the Northwest zone (Figure 2a) and the island of Inishgort in the Headland/Midzone (Figure 2c). *A. nodosum* was found in all other sites, with the highest biomass of 22.91 +/- 3.79 kg/m² recorded in the coastal site of Newfield in the NorthWest zone (Figure 2a) and the lowest biomass of 1.88 +/- 0.55 kg/m² recorded on the island site of Island Moor in the Headland/Midzone (Figure 2c).

In the NorthWest zone, where *A. nodosum* was present, the mean biomass in coastal sites ranged from 3.13 – 22.91 kg/m² with the lowest recorded on Rosturk Strand and the highest (as mentioned) on Newfield. For island sites, the mean biomass ranged from 0.6 – 6.25 kg/m² (Figure 2a).

In the North-Bay zone, the highest biomass per m² of *A. nodosum* in coastal sites was recorded at Ardkeen with 16.74 +/- 2.77 kg/m², all other coastal sites ranged from 6.25 – 7.5 kg/m² (Figure 2b). In islands sites, the mean biomass ranged from 4.94 – 19.34 kg/m², with the lowest biomass found on Inishdaweel and the highest biomass recorded on Forilan (Figure 2b).

For the Headland/Midzone, the biomass per m² of *A. nodosum* in coastal sites ranged from a low of 3.32 +/- 0.76 kg/m² on Claggan Strand to a high of 9.97 +/- 1.10 kg/m² recorded at Moyour Channel (Figure 2c). On islands in this zone, the biomass of *A. nodosum*, in sites where it was found, ranged from a low of 1.88 +/- 0.56 kg/m² on Island Moor to a high of 8.78 +/- 1.27 kg/m² recorded on Illanatagg (Figure 2c).

In the final zone, the South-Bay zone the biomass per m² ranged from 1.93 – 7.32 kg/m² of *A. nodosum* on coastal sites, with the lowest found at Annagh Island East and the highest recorded at Annaghside Middle (Figure 2d). On Island sites the lowest biomass of 1.93 +/- 0.45 kg/m² was recorded on Inishleague and the highest mean biomass of 8.01 +/- 1.52 kg/m² was recorded on Inishmell (Figure 2d).

In each of the fourteen individual strata sampled, results for unweighted means show that both the highest and lowest biomass of *A. nodosum* per unit area was found in strata in the NorthWest zone. The highest mean biomass of 15.01 +/- 2.31 kg/m² was in the Inner Coastal stratum and the lowest biomass of 0.79 +/- 0.21 kg/m² was recorded in the Outer Island strata (Figure 3a). There was little variation between the biomass of *A. nodosum* in strata in the North-Bay zone where each stratum had a mean biomass per unit area of ~ 9 +/- 0.7 kg/m². In the Headland zone, Inner strata had on average greater biomass (~ 7 +/- 0.75 kg/m²) than Outer strata (~ 3.25 +/- 0.6 kg/m²) with little variation within Inner/Outer strata (Figure 3a). In the South-Bay zone the Inner Islands strata had the highest average biomass of *A. nodosum* (7.03 +/- 1.14 kg/m²) in comparison to the other three strata which on average only had approximately 4.25 +/- 0.6 kg/m² of *A. nodosum* (Figure 3a). However when means were weighted and stratified according to the total area of each of the paired strata, in general it was found that Inner strata had higher stratified means of *A. nodosum* biomass than Outer strata in three out of the four zones with the reverse pattern observed in the South-Bay zone where Outer strata had higher stratified means of *A. nodosum* biomass than Inner strata (Figure 3b).

In the original Bioatlantis application, calculated means across the whole bay resulted in means estimates of *A. nodosum* biomass of 8.21 +/- 0.8 kg/m² (Table 3a), in comparison whole bay means calculated using the stratified random sampling approach resulted in a stratified mean estimate of 5.89 +/- 0.63 kg/m² (Table 3b). BioAtlantis mean estimates for Islands and Coastal sites were 12.5 +/- 1.58 kg/m² and 1.83 +/- 0.98 kg/m² respectively (Table 3a). Stratified means calculated as part of this study were 5.59 +/- 0.66 kg/m² for Islands sites and 6.99 +/- 0.76 kg/m² (Table 3b).

Overall, total biomass estimates as part of the BioAtlantis application were 64,758.4 +/- 11854 tonnes, enabling an annual harvest of 12,900 +/- 2370.8 tonnes per annum (Table 4a). Using the stratified sampling approach, this study estimated total standing biomass of *A. nodosum* to be 55606.7 +/- 3293.5 tonnes, with an estimated annual harvest of 11121.3 +/- 658 tonnes per annum for the whole of the Clew Bay complex (Table 4b). On a zone by zone basis, the highest proportion of total standing biomass was expected to occur in the North-Bay zone with estimates of 28620.8 +/- 1829.7 tonnes and an annual harvest of 5724.2 +/- 365.9 tonnes per annum and the lowest proportion of biomass occurring in the NorthWest zone with total biomass estimated to be 5068 +/- 1449.1 tonnes with an annual harvest of 1013.7 +/- 289.8

tonnes per annum (Table 4b). The estimated standing biomass of the Headland zone was 12963.2 +/- 2837.1 tonnes with an annual harvest of 2592.7 +/- 567.4 tonnes per annum and finally the South-Bay zone standing biomass was estimated to be 8954.1 +/- 1639.8 tonnes with an annual harvest of 1790.8 +/- 328 tonnes per annum (Table 4a).

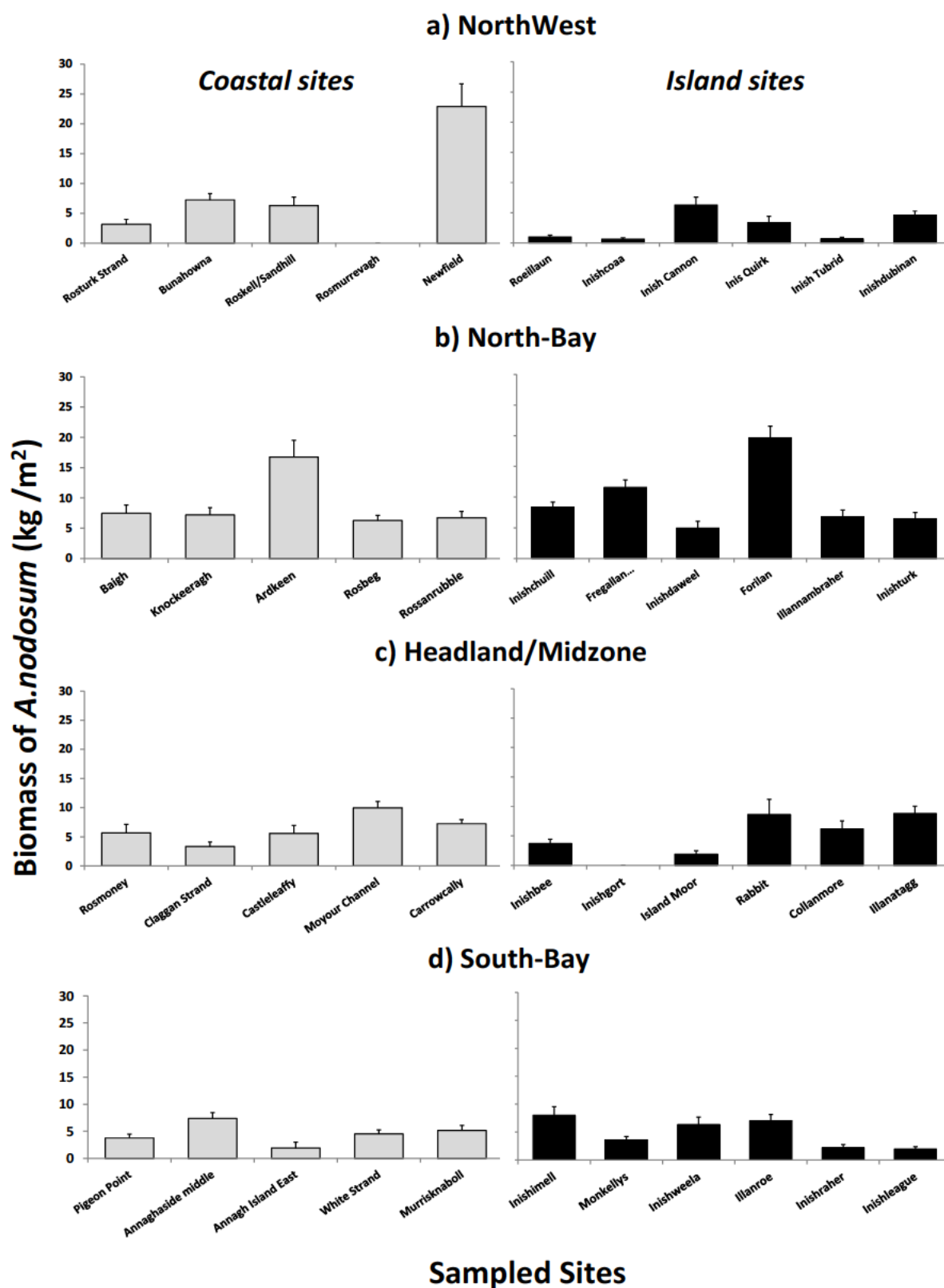


Figure 2 Mean biomass per m² of *A. nodosum* (kg/m²) recorded at individual sites sampled in each of 4 zones (a – d) across the whole of Clew Bay. Coastal sites are indicated by grey columns and islands sites are indicated by black columns.

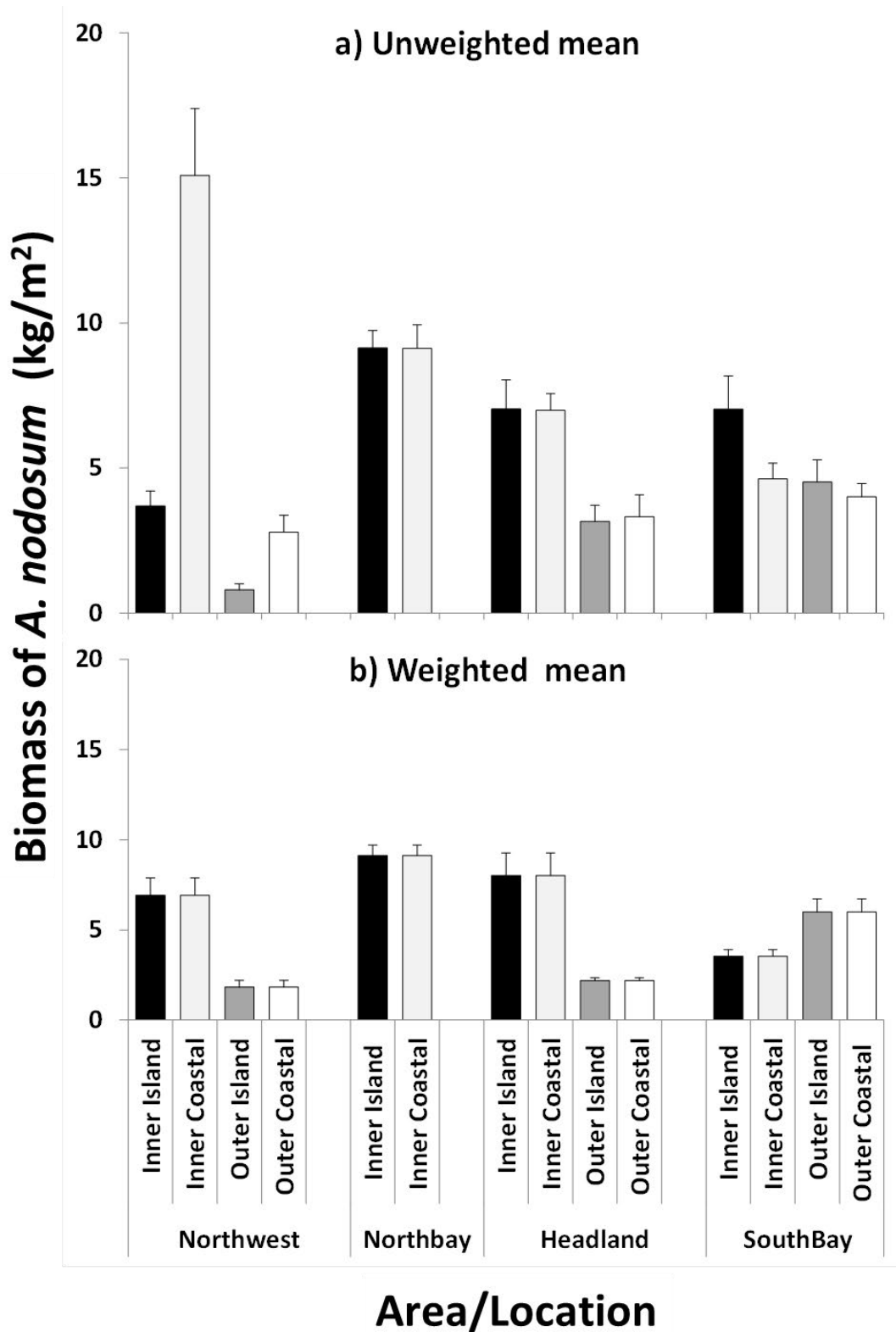


Figure 3 Means estimates of the biomass (kg/m²) of brown algae *A. nodosum* in the Clew Bay complex. Shown are estimates for a) unweighted means and b) weighted stratified means for the 14 strata sampled in the four zones. Errors bars are indicative of the calculated confidence intervals (+/- 95% CI) for each value.

Table 3 Estimates of biomass per unit area (kg/m²) of *A. nodosum* at potentially harvestable sites in the whole of Clew Bay, island sites only and coastal sites only. Shown are a) Bio-Atlantis estimates and b) estimates from the current stratified sampling programme.

Estimates	No of sites/replicates	Mean	Std. Error	Lower 95% CI	Upper 95% CI
<u>a) Bio-Atlantis</u>					
Whole bay	191 [*]	8.21	0.55	6.86	9.01
Islands	117 [*]	12.5	0.65	10.93	14.08
Coastal sites	74 [*]	1.83	0.26	1.21	2.81
<u>b) Stratified sampling</u>					
Whole bay	1191 [#]	5.89	0.38	5.27	6.52
Islands	572 [#]	5.59	0.40	4.92	6.25
Coastal sites	619 [#]	6.99	0.46	6.22	7.75

* Refers to the number of sites in BioAtlantis licence application, [#] Refers to the number of replicate quadrats sampled across 44 sites (24 Island sites & 20 Coastal sites)

Table 4 Estimates of total biomass (*tonnes*) of *A. nodosum* at sites in Clew Bay. Shown are a) BioAtlantis estimates for the whole of Clew Bay and b) estimates from stratified sampling approach for the whole of Clew Bay and for the four individual zones (+/- 95% CI). Also shown are calculated Maximum annual harvest (*tonnes per annum*) calculated as 20% of the mean estimates of total biomass (+/- 95% CI).

Estimates	Biomass of <i>A. Nodosum</i> (t)	+/- 95% CI	Max. annual harvest (t/Year)	+/- 95% CI
<u>a) Bio-Atlantis</u>				
Whole Bay	64758.4	11854	12900	2370.8
<u>b) Stratified sampling</u>				
Whole Bay	55606.7	3293.5	11121.3	658.7
NorthWest	5068.6	1449.1	1013.7	289.8
North-Bay	28620.8	1829.7	5724.2	365.9
Headland/Midzone	12963.2	2837.1	2592.7	567.4
South-Bay	8954.1	1639.8	1790.8	328.0

3.2 Biomass estimates of *F. vesiculosus* in Clew Bay

The biomass of *F. vesiculosus*, for the most part, was consistent throughout the bay with little variability between coastal and island sites (Figure 4). In particular, the biomass ranged from 0.9 (+/- 0.21) – 6.6 (+/- 0.81) kg per m² with the lowest biomass observed on the island site of Inishcoaa in the Northwest zone and the highest biomass that occurred on the coastal site of Ardkeen in the North-bay zone (Figure 4).

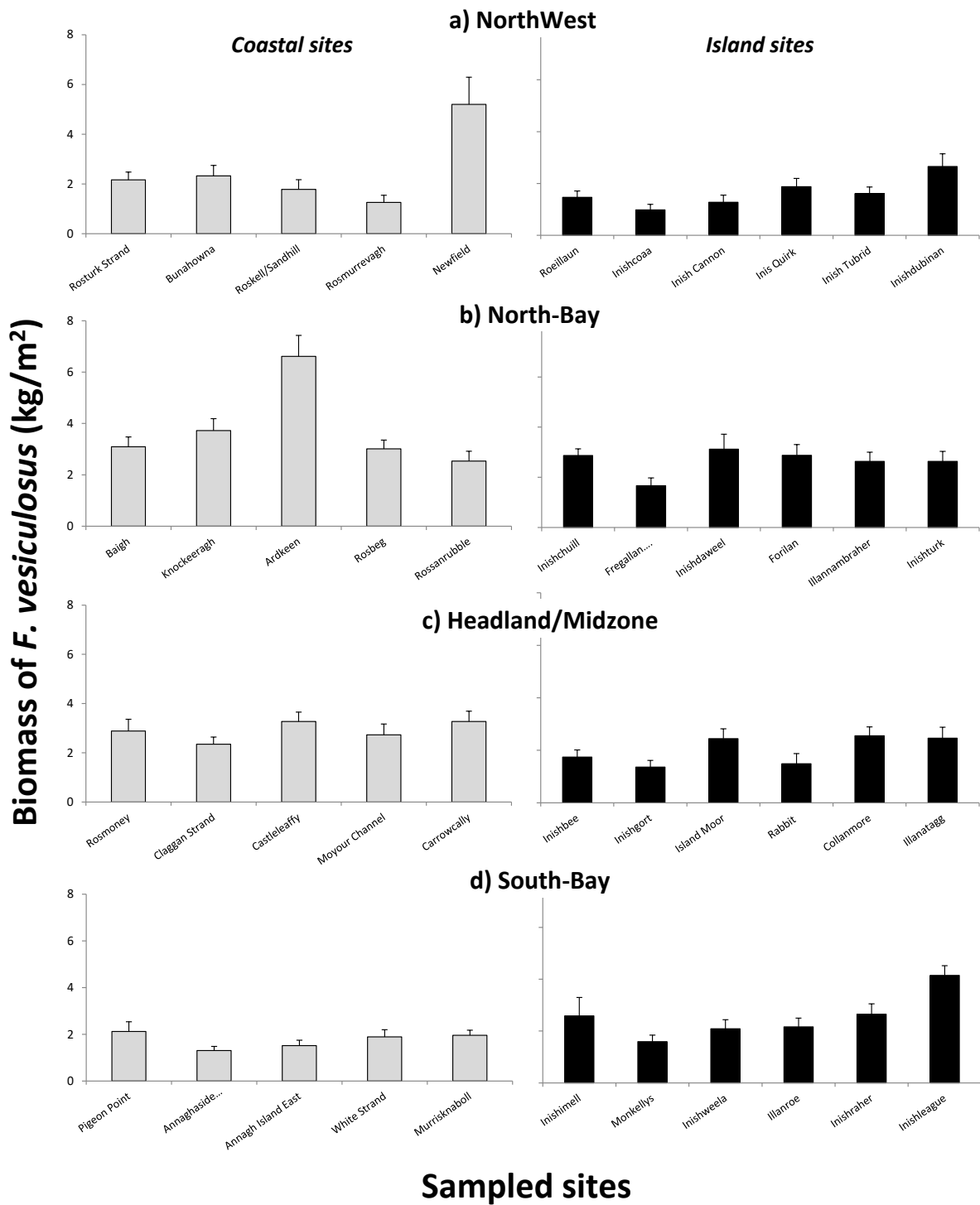


Figure 4 Mean biomass per m² of *Fucus vesiculosus* (kg/m²) recorded at individual sites sampled in each of 4 zones (a – d) across the whole of Clew Bay. Coastal sites are indicated by grey columns and islands sites are indicated by black columns.

3.3 Evidence of existing harvesting of *A. nodosum* in Clew Bay

There was extensive evidence of existing harvesting found throughout the sampled sites with 323 quadrats out of a total of 1192 found to have evidence of harvesting within them (Table 5). However, the amount of harvesting did vary from site to site and from zone to zone (Table 5 & Figure 5). For example, in the Northwest zone evidence of harvesting was only found within quadrats for one coastal site (Rosmurrevagh) (Table 5 & Figure 5). However at the Newfield site, although there was no evidence of harvesting within quadrats, there was strong evidence of harvesting onsite with multiple areas (~ 10 x 30m) noted throughout the site (Table 5 & Figure 5). In contrast, for the island sites in the Northwest zone, harvesting was recorded within quadrats at all sites, with the exception of the Inish Tubrid site. On these island sites there was no systematic (strip-cutting) evidence of harvesting outside of quadrats, instead harvesting occurred in unstructured patches throughout the sites (Table 5 & Figure 5). In the North-bay zone, harvesting was recorded inside quadrats at all coastal sites with the exception of the Ardkeen site and at four of the six island sites (Table 5 & Figure 5). For sites where harvesting did occur; the proportion of quadrats with harvesting ranged from 10-45 % at the coastal sites and from 30-53% at island sites (Table 5 & Figure 5). In the Headland zone, harvesting was recorded at all but one coastal site (Rosmoney) and the proportion of quadrats with harvesting within these sites ranged from 10-45% (Table 5 & Figure 5). For the island sites again there was only one site (Inishgort) where harvesting was not recorded within quadrats but at all other sites the proportion of quadrats with harvesting ranged from 20-80% (Table 5 & Figure 5). In the South-bay zone harvesting within quadrats was recorded at all sites and ranged from 12.5 - 55% at coastal sites and from 10 – 65 % at island sites respectively (Table 5 & Figure 5).

Overall, in terms of observations of harvesting at the site level, across the whole of Clew Bay, there was evidence of harvesting at 26/40 sampled sites but the intensity of harvesting varied across these sites. In particular, there were six sites with evidence of ‘light’ harvesting, eight sites with ‘moderate’ levels of harvesting and twelve sites with evidence of ‘heavy’ harvesting (see Table 5). At only 18/40 sites sampled was there no evidence of harvesting at the site level (Table 5).

Table 5 Instances of existing harvesting of *A. nodosum* recorded within quadrats and across each individual sampled site across the Clew Bay complex.

Site	Code	Zone	Shore type	Quadrats per site	Quadrats with harvesting	Harvesting at site (observations)
Rosturk Strand	CZ5.13	NorthWest	Coastal	20	0	None
Bunahowna	CZ5.15	NorthWest	Coastal	20	0	None
Roskell/Sandhill	CZ5.8	NorthWest	Coastal	22	0	None
Rosmurrevagh	CZ5.17	NorthWest	Coastal	30	10	Light
Newfield	CZ5.10	NorthWest	Coastal	20	0	Heavy
Roeillaun	IS19	NorthWest	Island	32	2	None
Inishcoaa	IS18	NorthWest	Island	30	3	None
Inish Cannon	IS32	NorthWest	Island	20	13	None
Inis Quirk	IS6	NorthWest	Island	24	7	None
Inish Tubrid	IS7	NorthWest	Island	20	0	None
Inishdubinan	IS9	NorthWest	Island	20	10	None
Baigh	CZ 5.7	North-Bay	Coastal	40	16	Heavy
Knockeeragh	CZ4.13	North-Bay	Coastal	40	4	None
Ardkeen	CZ3.7	North-Bay	Coastal	40	0	Light
Rosbeg	CZ4.3	North-Bay	Coastal	40	18	Heavy
Rossanrubble	CZ4.8	North-Bay	Coastal	20	8	Moderate
Inishchuill	IS38	North-Bay	Island	30	16	Heavy
Fregallan Luggah	IS28	North-Bay	Island	20	0	None
Inishdaweel	IS25	North-Bay	Island	20	6	None
Forilan	IS 1	North-Bay	Island	20	0	None
Illannambragher	IS4	North-Bay	Island	30	16	Heavy
Inishturk	IS48.1	North-Bay	Island	30	14	Heavy
Rosmoney	CZ3.2	Headland/Midzone	Coastal	20	0	None
Claggan Strand	CZ3.6	Headland/Midzone	Coastal	30	10	Moderate
Castleleaffy	CZ3.3	Headland/Midzone	Coastal	30	6	Light
Moyour Channel	CZ2.16	Headland/Midzone	Coastal	20	2	Light
Carrowcally	CZ2.10	Headland/Midzone	Coastal	40	9	Moderate
Inishbee	IS53	Headland/Midzone	Island	44	22	Light
Inishgort	IS59	Headland/Midzone	Island	30	0	None
Island Moor	IS57.2	Headland/Midzone	Island	30	9	Heavy
Rabbit	IS57.1	Headland/Midzone	Island	20	4	Moderate
Collanmore	IS58.1	Headland/Midzone	Island	40	22	Heavy
Illanatagg	IS61	Headland/Midzone	Island	20	16	None
Pigeon Point	CZ2.6	South-Bay	Coastal	20	11	None
Annaghaside middle	CZ1.13	South-Bay	Coastal	30	4	Heavy
Annagh Island East	CZ1.8	South-Bay	Coastal	30	5	Heavy
White Strand	CZ1.2	South-Bay	Coastal	30	5	Moderate
Murrisknaboll	CZ1.5	South-Bay	Coastal	30	5	Light
Inishimell	IS67	South-Bay	Island	20	9	Moderate
Monkellys	IS78	South-Bay	Island	20	5	None
Inishweela	IS79	South-Bay	Island	20	7	Moderate
Illanroe	IS80	South-Bay	Island	20	13	Heavy
Inishraher	IS70	South-Bay	Island	30	13	Heavy
Inishleague	IS68	South-Bay	Island	30	3	Moderate
Total Quadrats				1192		
Total with harvesting				323		

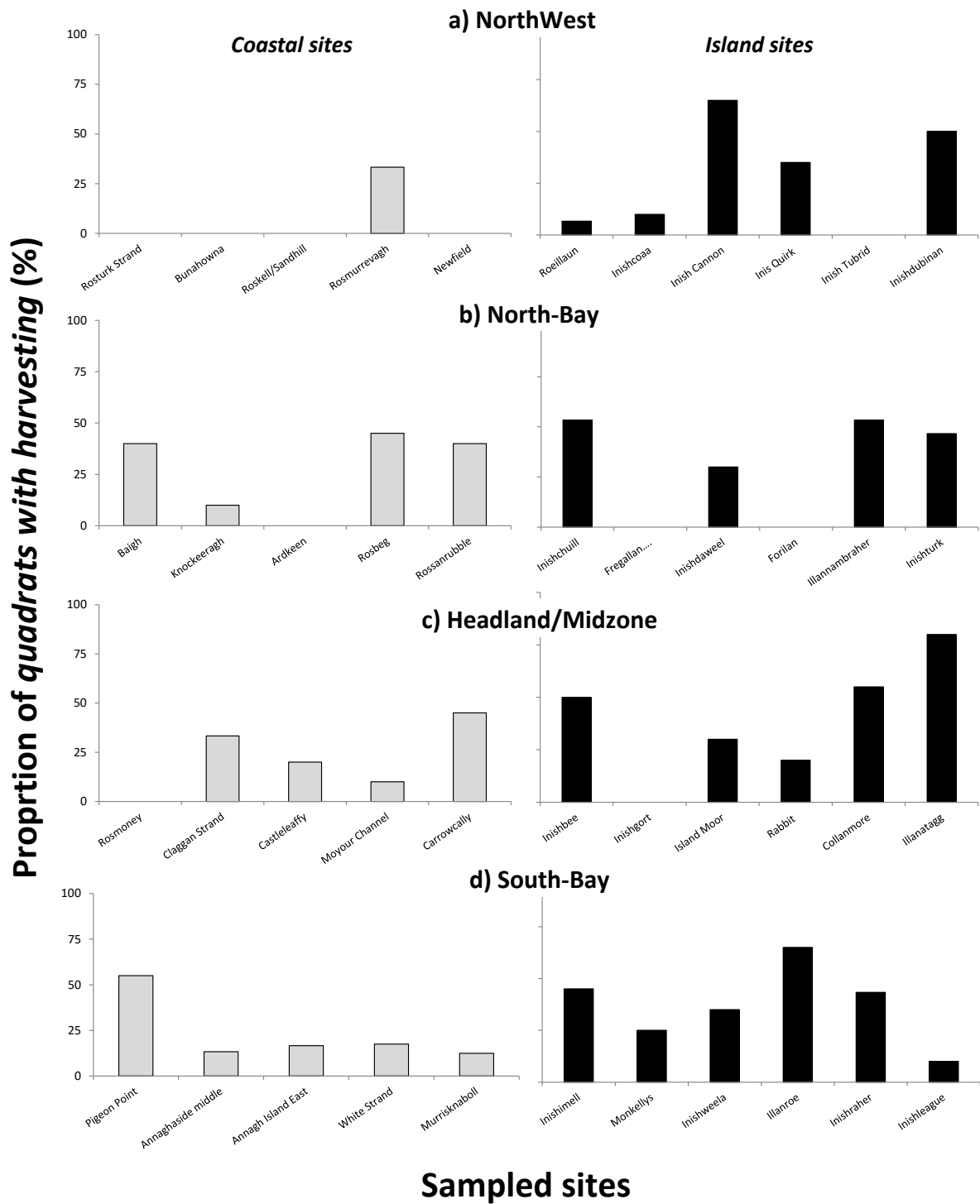


Figure 5 Proportion of quadrats with harvesting recorded at individual sites sampled in each of 4 zones (a – d) across the whole of Clew Bay. Coastal sites are indicated by grey columns and islands sites are indicated by black columns.

3.4 Substrate description for all sampled sites in Clew Bay

The type of substrate recorded in quadrats at sites across the whole of Clew Bay varied considerably from site to site (see Tables 6 & 7). That said, across the whole of the bay, for both coastal and island sites in each of the four zones, the majority of quadrats had 1- 3 substrate types associated with them with a total of 194 quadrats having one substrate only, 620 quadrats having two substrates and 313 quadrats having a three substrate mix (Figure 7 & 8). Of those totals, across the bay cobbles and shingle were the predominant substrate within quadrats and accounted for a total of 671 and 554 quadrats respectively (Figure 9). In addition boulders (combined across size categories) were recorded in 654 quadrats, which consisted of 52 quadrats for large boulders, 222 quadrats for medium boulders and 380 quadrats for small boulders (Figure 9).

Table 6 Number of quadrats for each substrate type recorded at individual sites sampled in each of 4 zones (a – d) across the whole of Clew Bay.

a) North West

Site	Code	Shore type	Quadrats per site	Large boulders	Medium boulders	Small boulders	Cobbles	Small cobbles	Pebble	Shingle	Sand	Sand/pebble mix	Mud/shingle mix	Mud/sand mix
Rosturk Strand	CZ5.13	Coastal	20	2	14	5	7	0	2	0	11	0	0	0
Bunahowna	CZ5.15	Coastal	20	0	7	7	8	0	2	0	1	1	0	11
Roskelll	CZ5.8	Coastal	22	2	3	8	10	1	3	5	3	0	3	2
Rosmurrevagh	CZ5.17	Coastal	30	4	20	24	25	6	0	5	10	0	0	0
Newfield	CZ5.10	Coastal	20	0	3	9	11	0	0	2	0	0	0	14
Roeillaun	IS19	Island	32	7	15	13	16	6	6	7	4	0	0	0
Inishcoaa	IS18	Island	30	1	14	11	15	3	10	11	5	0	0	0
Inish Cannon	IS32	Island	20	5	15	10	6	1	4	1	0	0	0	0
Inis Quirk	IS6	Island	24	0	2	15	15	7	2	13	8	0	0	0
Inish Tubrid	IS7	Island	20	0	3	6	12	0	0	16	7	0	0	0
Inishdubinan	IS9	Island	20	5	15	10	6	5	4	1	0	0	0	0

b) North-Bay

Baigh	CZ 5.7	Coastal	40	0	4	8	18	10	5	16	19	2	0	10
Knockeeragh	CZ4.13	Coastal	40	0	4	6	25	14	0	25	3	5	0	8
Ardkeen	CZ3.7	Coastal	40	2	5	9	27	0	1	8	0	14	0	24
Rosbeg	CZ4.3	Coastal	40	6	9	10	17	3	8	27	15	0	0	0
Rossanrubble	CZ4.8	Coastal	20	0	0	6	17	5	0	14	1	4	0	0
Inishchuill	IS38	Island	30	1	11	18	14	2	4	6	3	0	0	3
Fregallan Luggah	IS28	Island	20	2	11	12	9	0	1	2	2	0	0	1
Inishdaweel	IS25	Island	20	0	6	9	11	1	6	11	7	0	0	0
Forilan	IS 1	Island	20	0	3	6	15	1	0	15	1	0	0	9
Illannambraher	IS4	Island	30	0	3	8	11	17	0	22	6	0	0	0
Inishturk	IS48.1	Island	30	0	4	8	14	11	1	24	1	0	0	4

c) Headland/Midzone

Site	Code	Shore type	Quadrats per site	Large boulders	Med boulders	Small boulders	Cobbles	Small cobbles	Pebble	Shingle	Sand	Sand/pebble mix	Mud/shingle mix	Mud/sand mix
Rosmoney	CZ3.2	Coastal	20	0	1	3	12	3	8	6	6	3	2	8
Claggan Strand	CZ3.6	Coastal	30	0	2	4	15	10	0	22	5	2	0	3
Castleleaffy	CZ3.3	Coastal	30	0	0	4	19	6	0	14	2	13	0	7
Moyour Channel	CZ2.16	Coastal	20	0	0	5	15	7	0	15	0	2	0	3
Carrowcally	CZ2.10	Coastal	40	5	9	14	24	7	6	22	15	0	0	10
Inishbee	IS53	Island	44	0	3	13	19	3	9	30	18	0	0	0
Inishgort	IS59	Island	30	0	0	6	24	2	0	13	0	0	0	1
Island Moor	IS57.2	Island	30	0	2	6	13	5	0	20	5	8	0	1
Rabbit	IS57.1	Island	20	0	0	0	10	0	0	12	1	2	0	3
Collanmore	IS58.1	Island	40	0	3	17	29	6	0	19	0	8	4	0
Illanatagg	IS61	Island	20	5	15	10	6	5	4	1	0	0	0	0

d) South-Bay

Pigeon Point	CZ2.6	Coastal	20	0	8	5	7	2	0	12	0	0	0	0
Annaghaside middle	CZ1.13	Coastal	30	0	1	6	21	11	3	6	15	0	0	8
Annagh Island East	CZ1.8	Coastal	30	0	3	2	15	5	0	23	0	11	0	2
White Strand	CZ1.2	Coastal	30	0	0	1	20	3	0	20	0	7	0	4
Murrisknaboll	CZ1.5	Coastal	30	0	0	2	20	8	0	21	0	7	0	1
Inishimell	IS67	Island	20	0	0	9	14	1	0	9	0	5	2	0
Monkellys	IS78	Island	20	2	1	14	11	0	0	1	0	0	0	0
Inishweela	IS79	Island	20	0	0	8	13	0	0	15	0	1	4	0
Illanroe	IS80	Island	20	3	2	6	15	5	0	14	0	1	0	4
Inishraher	IS70	Island	30	0	1	11	20	10	0	22	0	7	0	1
Inishleague	IS68	Island	30	0	0	16	20	0	0	6	1	10	0	3

Table 7 Proportion of quadrats at individual sites for each substrate type sampled in each of 4 zones (a – d) across the whole of Clew Bay.***a) North West***

Site	Code	Shore type	Quadrats per site	Large boulders	Med boulders	Small boulders	Cobbles	Small cobbles	Pebbles	Shingle	Sand	Sand/pebble mix	Mud/shingle mix	Mud/sand mix
Rosturk Strand	CZ5.13	Coastal	20	10	70	25	35	0	10	0	55	0	0	0
Bunahowna	CZ5.15	Coastal	20	0	35	35	40	0	10	0	5	5	0	55
Roskell	CZ5.8	Coastal	22	9.1	13.64	36.37	45.45	4.55	13.64	22.73	13.64	0	13.64	9.1
Rosmurrevagh	CZ5.17	Coastal	30	13.33	66.67	80	83.33	20	0	16.67	33.33	0	0	0
Newfield	CZ5.10	Coastal	20	0	15	45	55	0	0	10	0	0	0	70
Roeillaun	IS19	Island	32	21.89	46.88	40.63	50	18.75	18.75	21.88	12.5	0	0	0
Inishcoaa	IS18	Island	30	3.33	46.67	36.67	50	10	33.33	36.67	16.67	0	0	0
Inish Cannon	IS32	Island	20	16.67	50	33.33	20	3.33	13.33	3.33	0	0	0	0
Inis Quirk	IS6	Island	24	0	6.67	50	50	23.33	6.67	43.33	26.67	0	0	0
Inish Tubrid	IS7	Island	20	0	10	20	40	0	0	53.33	23.33	0	0	0
Inishdubinan	IS9	Island	20	25	75	50	30	25	20	5	0	0	0	0

b) North-Bay

Baigh	CZ 5.7	Coastal	40	0	10	20	45	25	12.5	40	47.5	5	0	25
Knockeeragh	CZ4.13	Coastal	40	0	10	15	62.5	35	0	62.5	7.5	12.5	0	20
Ardkeen	CZ3.7	Coastal	40	5	12.5	22.5	67.5	0	2.5	20	0	35	0	60
Rosbeg	CZ4.3	Coastal	40	15	22.5	25	42.5	7.5	20	67.5	37.5	0	0	0
Rossanrubble	CZ4.8	Coastal	20	0	0	30	85	25	0	70	5	20	0	0
Inishchuill	IS38	Island	30	3.33	36.67	60	46.67	6.67	13.33	20	10	0	0	10
Fregallan luggah	IS28	Island	20	10	55	60	45	0	5	10	10	0	0	5
Inishdaweel	IS25	Island	20	0	30	45	55	5	30	55	35	0	0	0
Forilan	IS 1	Island	20	0	15	30	75	5	0	75	5	0	0	45
Illannambraher	IS4	Island	30	0	10	26.67	36.67	56.67	0	73.33	20	0	0	0
Inishturk	IS48.1	Island	30	0	13.33	26.67	46.67	36.67	3.33	80	3.33	0	0	13.33

c) Headland/Midzone

Site	Code	Shore type	Quadrats per site	Large boulders	Med boulders	Small boulders	Cobbles	Small cobbles	Pebble	Shingle	Sand	Sand/pebble mix	Mud/shingle mix	Mud/sand mix
Rosmoney	CZ3.2	Coastal	20	0	5	15	60	15	40	30	30	15	10	40
Claggan Strand	CZ3.6	Coastal	30	0	6.67	13.33	50	33.33	0	73.33	16.67	6.67	0	10
Castleleaffy	CZ3.3	Coastal	30	0	0	13.33	63.33	20	0	46.67	6.67	43.33	0	23.33
Moyour Channel	CZ2.16	Coastal	20	0	0	25	75	35	0	75	0	10	0	15
Carrowcally	CZ2.10	Coastal	40	12.5	22.5	35	60	17.5	15	55	37.5	0	0	25
Inishbee	IS53	Island	44	0	7.5	32.5	47.5	7.5	22.5	75	45	0	0	0
Inishgort	IS59	Island	30	0	0	20	80	6.67	0	43.33	0	0	0	3.33
Island Moor	IS57.2	Island	30	0	6.67	20	43.33	16.67	0	66.67	16.67	26.67	0	3.33
Rabbit	IS57.1	Island	20	0	0	0	50	0	0	60	5	10	0	15
Collanmore	IS58.1	Island	40	0	7.5	42.5	72.5	15	0	47.5	0	20	10	0
Illanatagg	IS61	Island	20	25	75	50	30	25	20	5	0	0	0	0

d) South-Bay

Pigeon Point	CZ2.6	Coastal	20	0	40	25	35	10	0	60	0	0	0	0
Annaghaside	CZ1.13	Coastal	30	0	3.33	20	70	36.67	10	20	50	0	0	26.67
Annagh Island	CZ1.8	Coastal	30	0	10	6.67	50	16.67	0	76.67	0	36.67	0	6.67
White Strand	CZ1.2	Coastal	30	0	0	3.33	66.67	10	0	66.67	0	23.33	0	13.33
Murrisknaboll	CZ1.5	Coastal	30	0	0	6.67	66.67	26.67	0	70	0	23.33	0	3.33
Inishimell	IS67	Island	20	0	0	45	70	5	0	45	0	25	10	0
Monkellys	IS78	Island	20	10	5	70	55	0	0	5	0	0	0	0
Inishweela	IS79	Island	20	0	0	40	65	0	0	75	0	5	20	0
Illanroe	IS80	Island	20	15	10	30	75	25	0	70	0	5	0	20
Inishraher	IS70	Island	30	0	3.33	36.67	66.67	33.33	0	73.33	0	23.33	0	3.33
Inishleague	IS68	Island	30	0	0	53.33	66.67	0	0	20	3.33	33.33	0	10

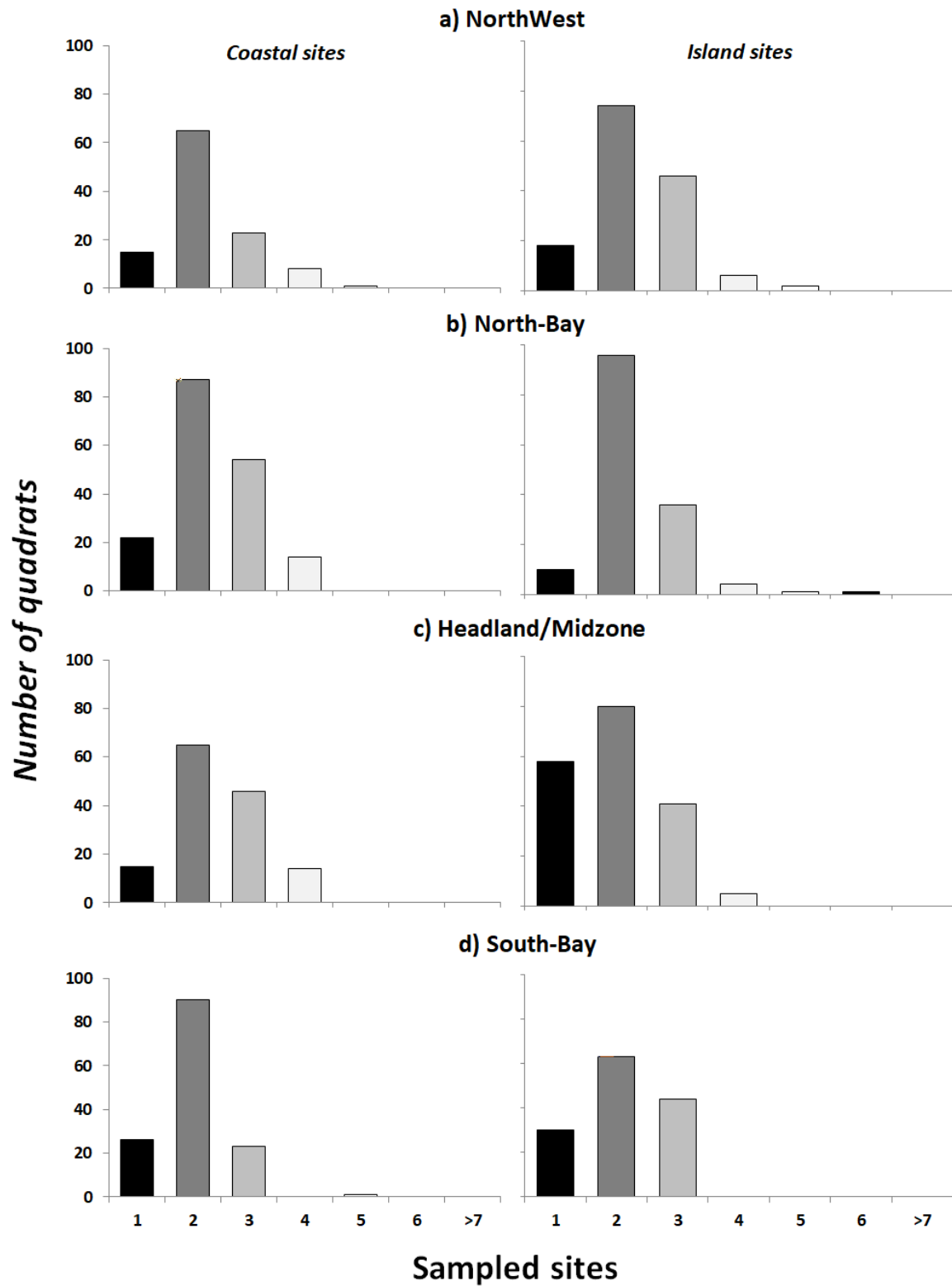


Figure 7 Number of quadrats with associated number of substrates per quadrat recorded in coastal and island sites sampled in each of 4 zones (a – d) across the whole of Clew Bay.

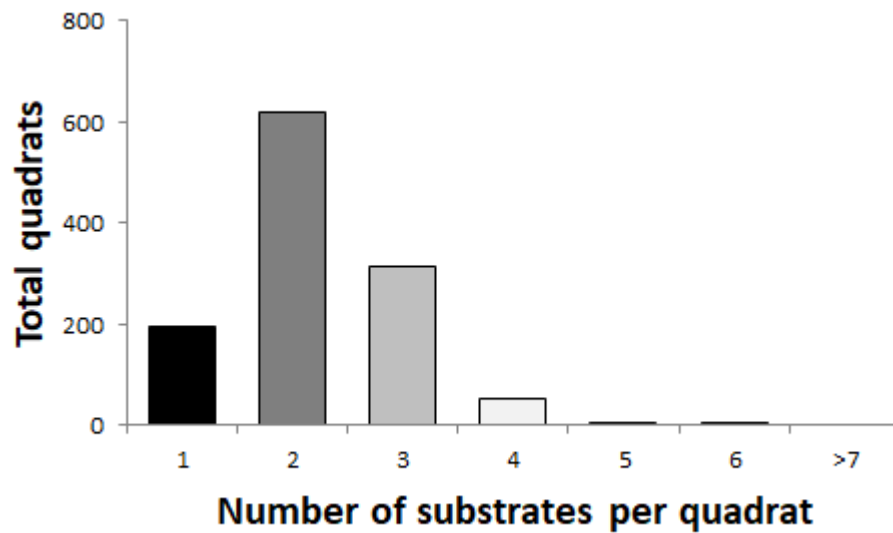


Figure 8 Total quadrats sampled with associated number of substrates per quadrat across the whole of Clew Bay.

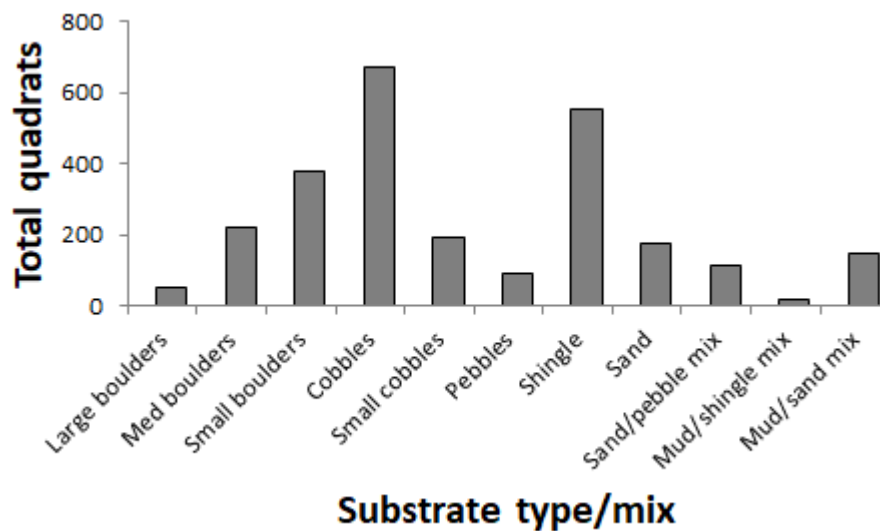


Figure 9 Total quadrats sampled for each of the substrates types/mixes recorded across the whole of Clew Bay.

4. Conclusion

The stratified random sampling approach undertaken as part of this study has resulted in more precise estimates of the standing stock of *A. nodosum* biomass across the Clew Bay complex in comparison with previous estimates. That said, the overall biomass estimate for the bay derived from the current study was only 14% lower than the estimate made as part of the BioAlantis application. In 1998, Hession et al. published an estimate of harvestable biomass of 18,000 tonnes per annum, which included an estimate of 13,000 tonnes per annum for the islands of mid-Clew Bay. These estimates were based on projections from aerial photographs and did not include any systematic ground-truthing. The findings here in this study highlight the value of quantitative systematic ground truthing of visual estimates, to give more precise and reliable estimates of the resources for harvesting in the Clew Bay complex. In addition, the rigorous sampling program employed in this study at a subset of sites allows for a clear indication of where biomass is concentrated in sites/areas within the Clew Bay complex (as described in the Results) so that harvesting can be appropriately targeted.

This survey also provides evidence of the biomass (kg/m^2) of *F. vesiculosus* at all sampled sites in the Clew Bay complex albeit at much lower values in comparison to the other macroalgal species described above.

In terms of existing harvesting, this survey provides evidence that there is substantial existing harvesting occurring within the bay and that intensity of harvesting varies from site to site.

Appendix

Table A1 Complete list of selected sites sampled in each of the zones using the BioAtlantis coding scheme across the Clew Bay complex with expected resources of *A. nodosum*.

a) Northwest zone		b) North-Bay zone	
Coastal sites	Islands	Coastal sites	Islands
CZ5.17	IS7	CZ3.7	IS1
CZ5.15	IS9	CZ4.13	IS4
CZ5.13	IS18	CZ4.3	IS38
CZ5.8	IS19	CZ5.7	IS48.1
CZ5.10	IS6	CZ4.8	IS25
	IS32		IS31
c) Headland/Midzone		d) South-Bay zone	
Coastal sites	Islands	Coastal sites	Islands
CZ2.10	IS53	CZ1.13	IS68
CZ3.2	IS57.2	CZ1.2	IS70
CZ3.3	IS58.1	CZ1.5	IS79
CZ3.6	IS61	CZ2.6	IS80
CZ2.16	IS59	CZ1.8	IS67
	IS57.1		