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Trade-offs between sampling effort and data quality in habitat monitoring

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Abstract

The transect method has been widely used to monitor habitat conservation status and has been recently recommended as the best tool to monitor steep ecological gradients, such as those in coastal systems. Despite that, the effectiveness of the transect approach can be limited when considering the sampling effort in terms of time needed for sampling. Our work aimed at evaluating the efficacy of the transect approach in a Mediterranean coastal system. Specifically we aimed at evaluating the sampling effort versus the completeness of datasets obtained by performing belt transects in different ways specifically designed to progressively reduce the sampling effort: (i) sampling plots adjacently ("adjacent-plot transect"); (ii) sampling plots alternately ("alternate-plot transect"); (iii) sampling one plot at each plant community along the vegetation zonation ("zonation-plot transect"). We evaluated method efficiency in terms of number and type of habitats identified, spatial extent, species richness and composition, through multivariate analyses, null models and rarefaction curves. The sampling effort was measured in terms of time needed for sampling. The zonation-plot transect had the lowest sampling effort, but provided only an approximation of the state of the dunal communities. The alternate-plot transect showed the best trade-off between the sampling effort and the completeness of information obtained, and may be considered as a efficient option in very wide coastal systems. Our research provides guidelines that can be used in other coastal systems to choose the most cost-effective monitoring method thereby maximising the efficient use of monitoring resources.

Keywords Coastal sand dunes · Habitat risk assessment · Data collection · Sampling efficiency · Belt transect

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Introduction

The protection of species and habitats is an important challenge for biodiversity conservation. At European level, under Community law (Habitat Directive 92/43/EEC), Member States are required to provide a precise analysis of the conservation status of species and habitat types listed in the Habitat Directive and a regular monitoring and assessment of their trends (Evans and Arvela 2011).

Monitoring consists of regular field-based measurements of key indicators (e.g. population status and dynamics, species richness and composition), which are assumed to reliably convey the conservation status and trends of species and habitats (Lindenmayer and Likens 2010). Consistent estimate of a system state as well as robust projections of future trends depend on reliable science-based monitoring programs (Henle et al. 2013) and on the quality of input data (Meyer et al. 2016; Hughes et al. 2017). In particular, long term monitoring and detailed chronosequences better inform habitat conservation status and trends (Del Vecchio et al. 2015; Geri et al. 2016; Sperandii et al. 2018). On the other hand, since such detailed data usually require demanding and expensive surveys, monitoring is often criticized as being costly, wasteful, and unscientific (Lovett et al. 2007; Conn et al. 2016). To find a balance between the reliability of the monitoring program and its cost, efficient monitoring programs have to be based on a trade-off between the quality of data and the sampling effort, in terms of both costs and time (McDonald-Madden et al. 2010).

In environments such as river and lake edges, salt marshes and sand dunes, characterized by steep ecological gradients, the transect approach is considered as the most robust and cost-effective method for habitat monitoring (Stanisci et al. 2014; Prisco et al. 2016; Almeida et al. 2017). The transect method has been widely used to monitor the habitat conservation status (e.g. Ciccarelli 2014; Prisco et al. 2016; Šilc et al. 2016) in coastal dune systems, where factors such as wind intensity, nutrient availability and soil moisture change sharply from the coastline inlands (Maun 2009), thereby defining a complex mosaic of habitat types. Furthermore, the method has been recently recommended as the best tool to monitor the environmental and biotic heterogeneity in complex vegetation mosaics (Angelini et al. 2016; Gigante et al. 2016a).

For habitat monitoring, the most frequently used transects are line intercept transects, point intercept transects and, most commonly, belt transects (Hill et al. 2005). The belt transect approach consists in laying contiguous sampling plots (quadrats) of any size along the environmental gradient direction (Kent and Coker 1992). At each quadrat, plants are then identified and their abundance (normally percent cover) estimated. This method allows to explore the entire range of coastal plant communities (from the drift line to the fixed dune), to verify the distribution range of habitat types and the integrity of the coastal sequence, and to analyze the attributes (e.g. species richness and composition, spatial extent) of each community. Performed regularly (e.g. yearly), and compared over time, belt transects also guarantee an accurate identification of habitat trends (Angelini et al. 2016; Gigante et al. 2016a), both in spatial distribution and quality, the two main criteria used for assessing habitats conservation status (Keith et al. 2013; Bland et al. 2016; Gigante et al. 2016b; Janssen et al. 2016).

The belt transect approach is highly recommended for monitoring coastal dune habitat types, but its effectiveness is questionable when considering both the costs and the time needed for sampling. The environmental characteristics of the study area may require an increase in the sampling effort to obtain the same level of monitoring accuracy. These include the topography of the areas being sampled (e.g. size and complexity), the

heterogeneity (i.e. amount of change) of the vegetation mosaic and the type of boundaries between vegetation types (distinct or not distinct). Plant communities of coastal systems are in fact closely related to dune morphologies which govern the abiotic features (e.g. water supply, grain size and salinity), thereby shaping various small-scale gradients and patterns along the dune system (Fenu et al. 2012; Bazzichetto et al. 2016; Silan et al. 2017). Thus, the complexity of the vegetation pattern and the amount of change along the sea-inland gradient increase with increasing dune morphology complexity. The complexity of the vegetation mosaic coupled with the width of the system (i.e. the number of quadrats to be surveyed) affect the time needed to perform the transect. Arguably, the time efficiency will be further dependent on quadrat size. For example, cover estimates are more difficult and time-consuming in large quadrats than in small quadrats and where plants are small and intermingled. Finally, the availability of field operators and their expertise in plant identification may dramatically influence the time needed to perform the assessment.

Since coastal systems are among the most threatened environments worldwide (Brown and McLachlan 2002; Del Vecchio et al. 2018; Gigante et al. 2018; Ivajnšič et al. 2018), it is critically important to find suitable monitoring methods which guarantee accurate data with a reasonable sampling effort. Several options can contribute to limit the sampling effort. Some authors analyzed the effect of changing plot number and/or plot size on the description of a community or a habitat type (Jonsson and Moen 1998; Dengler 2009). Other researchers suggested monitoring only some particular groups of species ("indicator species") considered as good descriptors of habitat identity and quality (Martínez Pastur et al. 2016; Del Vecchio et al. 2016). Finally, an alternative approach to reduce the sampling effort involves the preferential (i.e. by expert judgment) selection of homogeneous stands considered as representative of a particular habitat type, and the survey of a quadrat of appropriate size at each new vegetation type (Hill et al. 2005).

In the light of the several sampling options proposed so far, the aim of this work is to compare the completeness of datasets obtained by three different types of belt transect specifically designed to progressively reduce the sampling effort: (i) laying plots adjacently; consisting of frame quadrats laid contiguously along the beach-inland direction, this approach can be time-consuming if all the species are to be recorded and many quadrats are used, but provides very detailed data on vegetation; (ii) laying plots alternately, thereby halving the number of plots as well as the time needed for sampling; and (iii) laying plots according to a preferential survey design, i.e. recording a quadrat whenever a new plant community is found along the vegetation zonation, thereby strongly reducing both the number of plots per transect and the time needed to perform the sampling. Datasets completeness was evaluated in terms of number and type of habitats identified, spatial extent, species richness and composition, while the sampling effort was measured in terms of time needed for sampling.

Methods

Study area

The comparison of the effectiveness of monitoring methods was carried out along the North Adriatic coast (Italy), which represents the north-eastern part of the Mediterranean Basin. We selected one of the best preserved coastal dune sector, which is included in the Site of Community Importance IT3270017 "Delta del Po: tratto terminale e delta

veneto" and in the Regional Park of the Po Delta, located in the southernmost part of the Venice lagoon. The coastal system is wider than 200 m. Dunes are well developed, foredunes elevation ranges between 2 and 5.8 m, while inland dune altitude reaches about 6 m (Simeoni et al. 2010). The vegetation sequence is complete (Caniglia 2007), ranging from pioneer annual communities on the beach to woody vegetation on fixed dunes (Table 1), thereby resembling the typical coastal zonation of Mediterranean coasts. Plant communities nomenclature in Table 1 follows specific literature (Buffa et al. 2007; Caniglia 2007; Gamper et al. 2008; Biondi et al. 2012; Sburlino et al. 2013).

Coastal system sampling

Coastal system sampling was performed in 2 consecutive days at the end of May (2017), which corresponds to the flowering period of the majority of coastal species in the North Adriatic region. Vegetation sampling was performed along two belt transects, laid perpendicularly to the coastline, walking twice along the same line. The transect location was selected in order to possibly include all the coastal communities along the vegetation zonation. Plant species together with their percentage cover were recorded in fixed-size plots, using the Braun–Blanquet scale (Westhoff and van der Maarel 1973; Dengler et al. 2008). We started from the edge of the Pine wood (at the beginning of the semi-fixed dune) and proceeded toward the seashore, until the vegetation of the drift line. In the first transect, "adjacent-plot transect", we sampled the vegetation in adjacent plots of 1 m × 1 m. The first plot of the transect was marked with poles and the beginning/end were georeferenced using a GPS unit. Afterwards, starting from the same point and following the same line, we sampled the vegetation in fewer larger plots, of 2 m × 2 m, a size considered as the most appropriate for describing coastal dune habitats (e.g. Acosta et al., 2007; Jucker et al. 2013). In this case, plots were located according to a preferential survey design, i.e. whenever a new plant community was found walking toward the coastline, following the vegetation zonation, "zonation-plot transect". In this case, the distance between the plots varied according to the vegetation changes. Thereafter, from the "adjacent-plot transect" we selected only the odd-numbered plots, to obtain an alternate sampling of the vegetation, "alternate-plot transect", with plots having a distance of 1 m from each others. Figure 1 represents the design of the three transect types.

Data analyses

Vegetation data were digitalized in Turboveg (Hennekens 1996) and converted from the Braun-Blanquet scale into percentages of the cover range, according to Hennekens (1996). From the adjacent-plot transect we obtained a matrix of 127 plots × 47 species, from the alternate-plot transect a matrix of 64 plots × 47 species, while from the zonation-plot transect a matrix of 8 plots × 39 species. Species nomenclature follows Conti et al. (2005).

To verify the consistency of number and type of identified plant communities across the three types of transect we adopted the statistical approach normally used in vegetation science (e.g. Peet and Roberts 2013). To classify plots according to species composition, each species × plot matrix was analyzed through Detrended Correspondence Analysis (DCA, on species cover data; Pc-ord 5.1; McCune and Mefford 2006) and Cluster analysis (using average-linkage method and Bray–Curtis distance, on species cover data). The groups identified by multivariate analyses were then assigned to Natura 2000 habitat types (Annex I of the Habitat Directive 92/43/EEC), according to their

Table 1 List and brief description of the plant communities present in the study area, arranged along the sea–inland gradient

Zonation	Drift line	Embryo dune	Mobile dune	Semi-fixed dune			Fixed dune		
Prevalent plant community	*Salsolo kali-Cakiletum maritimae*	*Sporobolo arenarii–Agropyretum juncei*	*Echinophoro spinosae-Ammophiletum australis*	*Sileno coloratae-Vulpietum membranaceae*	*Sileno conicae-Avellinietum michelii*	*Tortulo-Scabiosetum*	*Viburno lantanae-Phillyreetum angustifoliae*	*Vincetoxico-Quercetum ilicis*	*Pinus pinaster* and *P. pinea* comm.
Main species	*Cakile maritima, Chamaesyce peplis, Salsola kali*	*Cyperus capitatus, Elymus farctus, Eryngium maritimum*	*Ammophila arenaria, Echinophora spinosa, Medicago marina*	*Medicago littoralis, Silene canescens, Vulpia fasciculata*	*Avellinia michelii, Carex liparocarpos, Silene conica*	*Fumana procumbens, Teucrium chamaedrys, Thymus longicaulis*	*Juniperus communis, Phyllirea angustifolia, Viburnum lantana*	*Quercus ilex, Vincetoxicum hirundinaria, Rubia peregrina*	*Pinus pinaster, Pinus pinea, Quercus ilex*
Description	Annual, nitrophilous community of the upper zone of the beach, near the shoreline	Pioneer perennial community, dominated by the dune-forming *Elymus farctus* and other herbaceous species; low species richness and cover	Perennial community, dominated by the dune-forming *Ammophila arenaria*; low species richness, with high cover	Annual community with abundant ephemeral spring bloom; high species richness and sparse cover	Annual discontinuous community, dominated by short herbs and grasses, and some perennial species; high species richness, but scarce cover of mosses and lichens	Perennial community dominated by dwarf shrubs, herbaceous species, and a dense carpet of mosses and lichens; high species richness and cover	Shrubs community dominated by *Juniperus communis,* accompanied by lianas; low species richness, with high cover	Wood dominated by *Quercus ilex*; scarce shrub layer, herbal layer dominated by perennial species	Planted wood, dominated by *Pinus* species. Seedlings of Potential Natural Vegetation species (*Quercus ilex* wood) in the herbal layer
Habitat EC code	1210-Annual vegetation of drift lines	2110-Embryonic shifting dunes	2120-Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes)	2230-Malcolmietalia dune grasslands	2130*-Fixed coastal dunes with herbaceous vegetation (grey dunes)		2250*-Coastal dunes with *Juniperus* spp.	9340-*Quercus ilex* and *Quercus rotundifolia* forests	2270*Wooded dunes with *Pinus pinea* and/or *Pinus pinaster*

For each plant community the corresponding Habitat Type sensu 92/43/EEC Habitat Directive is also reported

*Priority habitats (EU Habitat Directive)

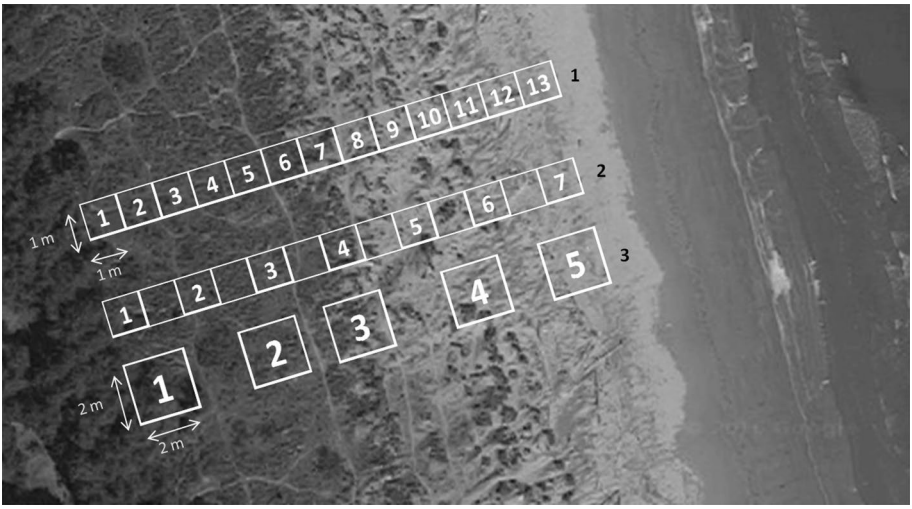

Fig. 1 Design of the three belt transect types used in the study. The picture is not to scale. 1 = Adjacent-plot transect; 2 = Alternate-plot transect; 3 = Zonation-plot transect

diagnostic and dominant species, as listed in Biondi et al. (2009), European Commission (2013) and specific literature (Buffa et al. 2007; Gamper et al. 2008; Sburlino et al. 2008; Prisco et al. 2012; Sburlino et al. 2013).

To compare the accuracy and completeness of each monitoring method, we selected a list of variables to be measured based on the criteria established for assessing the risk of habitat collapse, that is a transformation of identity, a loss of defining features, and a replacement by a different ecosystem type (Keith et al. 2013), and the degree of endangerment (Janssen et al. 2016). The procedure involves the assessment of spatial symptoms (i.e. declining spatial distribution and/or spatial extent, and restricted spatial distribution) as well as functional symptoms (decline in quality due to either physical, abiotic degradation or the disruption of biotic interactions). Accordingly, we selected and measured a set of variables which are descriptors of habitat distribution range, spatial extent and quality. For each transect, we determined the number of habitat types recorded and the number of plots pertaining to each habitat type. Being performed along the sea-inland gradient, the transect method allows to evaluate the state of the entire dune system (i.e. the completeness of the typical plant communities zonation), to detect the presence of a habitat in a given location, thereby contributing to define its distribution range, and to identify the spatial extent of habitats. As descriptors of habitat quality, we calculated the following structural attributes: (i) mean total species cover per plot (%), (ii) mean vascular species cover per plot (%), (iii) mean moss layer cover per plot (%), (iv) mean species richness per plot, and (v) the cumulative number of species recorded in each habitat.

To evaluate the "indicator species" approach, for each habitat we calculated the number of focal, generalist and alien species. Focal species, i.e. species that characterize the habitat type, were identified according to the aforementioned literature, used for the identification of habitat types. Alien species were identified according to Celesti-Grapow et al. (2010), while generalist species, i.e. all native opportunistic species not specific to dune environments, were identified on the basis of specific vegetation studies on coastal dunes (Del

Vecchio et al. 2013, 2015, 2016). Finally, all the native species that were descriptors of dune habitats other than those identified, were classified as "other species".

Including all possible records that can be sampled in transects, we assumed the adjacent-plot transect as the most exhaustive sampling among the three chosen. Accordingly, results obtained through this method were assumed as a reference state of habitat types as well as of the coastal sequence, and used to evaluate the accuracy and completeness of the dataset provided by the alternate- and zonation-plot transects.

When possible (i.e. number of cases higher than 2), results were statistically compared by performing null models (Monte Carlo ANOVA). Within each habitat, we used the type of transect as grouping categorical variable, and the community attributes as dependent variables; the observed F index (F_{obs}) was contrasted with those simulated by 1000 random permutations (F_{exp}; EcoSim 7.0; Gotelli and Entsminger 2001). For each habitat, the cumulative number of species as well as the number of indicator species were compared through rarefaction curves (Estimates 9; Colwell 2013).

For each transect we estimated the sampling effort in terms of time needed to perform the transect, considering that the team of field operators was composed of two expert researchers (one senior and one junior researcher) and one beginner.

Results

The number and type of habitats identified were consistent among the three transects (Table 2). For each transect, the multivariate analysis highlighted the same number of groups of plots and the same plant communities, arranged along the environmental gradient from the edge of the Pine wood to the drift line (Table 2; Fig. 2; technical results of multivariate analyses are provided as supplementary data in Online Resource 1). According to diagnostic and dominant species we identified five habitat types of EU Community interest (Table 2; Fig. 2). Two communities (dominated by *Spartina versicolor* and *Helichrysum italicum* respectively) were not recognized as Natura 2000 habitat types (Table 2). Species composition and cover for each community in each type of transect are summarized in Online Resource 2.

Based on the adjacent-plot transect, all habitats normally occupied a wide extent, and were represented by several plots, with a maximum of 28 for the habitat 2230, with the exception of the habitat 1210, typical of the drift line, which had a limited extent and was recorded only in 2 plots (Table 2).

All types of transects detected the presence of habitat types in the study site, thereby contributing to define their distribution range. The identification of the spatial extent of each habitat type was explicit and unambiguous only for the adjacent-plot transect (Table 2), while the alternate-plot transect allowed only an approximation of habitat spatial extension (at least ± 1 m at each border). The zonation-plot transect did not provide any spatial information and only allowed to detect the presence of a given habitat type.

The adjacent- and alternate-plot transects did not show significant differences in the structural attributes taken into account (total percentage cover per plot, vascular species cover per plot, moss layer cover per plot, species richness per plot), with the exception of the habitat 1210 (Table 2; Monte Carlo F test: $P_{(Fobs \geq Fexp)} > 0.05$ in any case). Conversely, the dataset provided by the zonation-plot transect showed differences in the absolute values of the majority of structural attributes, often overestimating the mean species richness and

Table 2 Structural attributes (total percentage cover, cover of vascular species, moss layer, species richness, cumulative n. of species and number of indicator species) for each habitat, across the three types of transect

	Adjacent			Alternate			$P_{(Fobs \geq Fexp)}$	Zonation		
Number of species per transect	47			47				39		
Habitat type/plant community	No. of plots	Mean	±SD	No. of plots	Mean	±SD		No. of plots	Value	±SD
2250* Coastal dunes with *Juniperus* spp.										
Total cover (%)	23	98	4.9	11	99.5	1.5	0.44	1	100	–
Vascular species cover (%)		93.7	12.2		93.6	7.1	1		100	–
Moss layer cover (%)		42.2	39.4		43.6	39.6	0.91		0	–
Mean species richness		6	2.6		6.3	2.7	0.78		13	–
Cumulative n. of species		23	–		19	–	–		13	–
Focal species (n.)		4	–		4	–	–		3	–
Alien species (n.)		1	–		1	–	–		1	–
Generalist species (n.)		3	–		3	–	–		3	–
Other species (n.)		15	–		11	–	–		6	–
2130* Fixed coastal dunes with herbaceous vegetation (grey dunes)										
Total cover (%)	27	85.4	20.9	15	85.7	22.4	0.97	2	90	14.1
Vascular species cover (%)		40.7	11.5		42	11.3	0.77		47.5	10.6
Moss layer cover (%)		80.2	21.9		82	23.7	0.81		82.5	17.7
Mean species richness		9.4	3		9.7	3.5	0.81		14.5	3.5
Cumulative n. of species		29	–		29	–	–		19	–
Focal species (n.)		8	–		8	–	–		8	–
Alien species (n.)		2	–		2	–	–		2	–
Generalist species (n.)		5	–		5	–	–		4	–
Other species (n.)		14	–		14	–	–		5	–

Table 2 (continued)

	Adjacent			Alternate			$P_{(Fobs \geq Fexp)}$	Zonation		
Number of species per transect	47			47				39		
Habitat type/plant community	No. of plots	Mean	±SD	No. of plots	Mean	±SD		No. of plots	Value	±SD
Helichrysum italicum comm.										
Total cover (%)	20	99	4.5	9	97.8	6.7	1	1	70	–
Vascular species cover (%)		78.5	14.2		77.8	14.6	0.82		60	–
Moss layer cover (%)		31.3	25.8		27.2	21.7	0.7		40	–
Mean species richness		9.1	1.8		9.1	1.5	1		15	–
Cumulative n. of species		23	–		15	–	–		15	–
Alien species (n.)		3	–		2	–	–		2	–
Generalist species (n.)		5	–		3	–	–		3	–
Other species (n.)		15	–		10	–	–		10	–
Spartina versicolor comm.										
Total cover (%)	12	53.3	18.7	4	67.5	12.6	0.23	1	60	–
Vascular species cover (%)		50.8	16.8		67.5	12.6	0.13		60	–
Moss layer cover (%)		5.8	20.2		0	0	1		0	–
Mean species richness		7.6	1.7		7.5	1	1		11	–
Cumulative n. of species		21	–		17	–	–		11	–
Alien species (n.)		4	–		4	–	–		2	–
Generalist species (n.)		4	–		3	–	–		2	–
Other species (n.)		13	–		10	–	–		7	–

Table 2 (continued)

	Adjacent			Alternate			$P_{(Fobs \geq Fexp)}$	Zonation		
Number of species per transect	47			47				39		
Habitat type/plant community	No. of plots	Mean	±SD	No. of plots	Mean	±SD		No. of plots	Value	±SD
2230 Malcolmietalia dune grasslands										
Total cover (%)	28	45	29.2	16	44.7	30	0.98	1	40	–
Vascular species cover (%)		35.7	13.4		35	13.3	0.83		40	–
Moss layer cover (%)		11.3	24.9		14.4	28.5	0.75		0	–
Mean species richness		7.1	2.7		7.4	3	0.72		11	–
Cumulative n. of species		25	–		26	–	–		11	–
Focal species (n.)		6	–		7	–	–		3	–
Alien species (n.)		3	–		3	–	–		3	–
Generalist species (n.)		5	–		5	–	–		–	–
Other species (n.)		11	–		11	–	–		5	–
2120 Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes)										
Total cover (%)	15	50	37.6	8	51.3	37.4	0.95	1	70	–
Vascular species cover (%)		50	37.6		51.3	37.4	0.95		70	–
Moss layer cover (%)		0	0		0	0	1		0	–
Mean species richness		4.1	1.5		4.1	1.8	1		6	–
Cumulative n. of species		10	–		9	–	–		6	–
Focal species (n.)		3	–		3	–	–		3	–
Alien species (n.)		2	–		2	–	–		1	–
Generalist species (n.)		1	–		1	–	–		1	–
Other species (n.)		4	–		3	–	–		1	–

Table 2 (continued)

	Adjacent			Alternate			$P_{(Fobs \geq Fexp)}$	Zonation		
Number of species per transect	47			47				39		
Habitat type/plant community	No. of plots	Mean	± SD	No. of plots	Mean	± SD		No. of plots	Value	± SD
1210 Annual vegetation of drift lines										
Total cover (%)	2	30	28.3	1	10	–	–	1	25	–
Vascular species cover (%)		30	28.3		10	–	–		25	–
Moss layer cover (%)		0	0		0	–	–		0	–
Mean species richness		3	0		3	–	–		3	–
Cumulative n. of species		5	–		3	–	–		3	–
Focal species (n.)		3	–		3	–	–		2	–
Alien species (n.)		–	–		–	–	–		–	–
Generalist species (n.)		–	–		–	–	–		–	–
Other species (n.)		2	–		–	–	–		1	–
TOT	127			64				8		

Plant communities/Habitat types are arranged along the sea-inland vegetation zonation, from the edge of the pine wood to the strand line. For the adjacent- and alternate-plot transects, values represent the mean per plot (± Standard Deviation). For the zonation-plot transect values are means only for the habitat 2130*, since in all other cases habitats were represented only by one plot. "P" represents the probability that the observed F (F_{obs}) differs from that expected by chance (F_{exp}, calculated on the 1000 simulated matrices). The zonation- plot transect as well as the habitat 1210 of the adjacent- and alternate- plot transect were excluded from the test being represented only by 1 or 2 plots. Focal species were only defined for Natura 2000 habitat types. * Priority habitats (EU Habitat Directive)

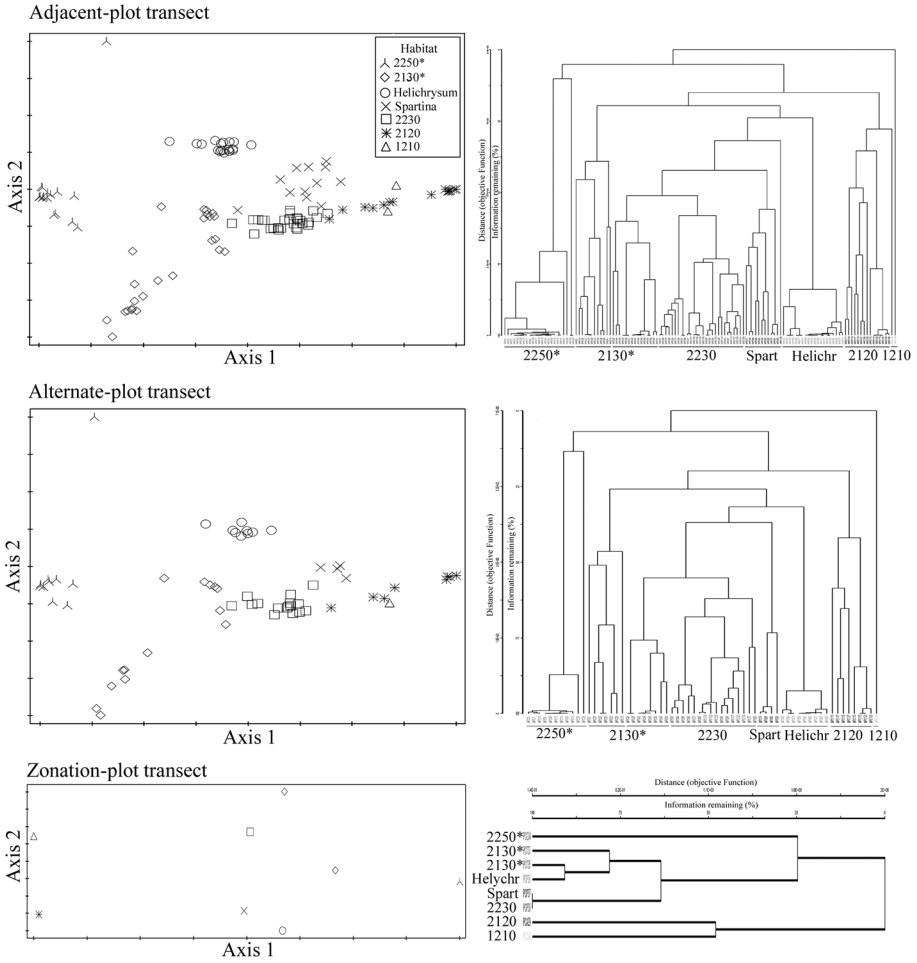

Fig. 2 Comparison of DCA scatter diagrams and cluster analysis dendrograms for the three types of transects

cover per plot, and underestimating the cover of the moss layer, although it was not possible to test the significance (Table 2; Online Resource 2).

Rarefaction curves showed that the cumulative number of species as well as the number of the indicator species detected by the adjacent- and alternate-plot transects were comparable, except for the habitat 1210 (Table 2; Fig. 3; rarefaction curves of the indicator species are provided in Online Resource 3). On the contrary, the zonation-plot transect detected a lower cumulative number of species for almost all of the habitat types. While the number of focal species was comparable, the number of the other indicator species groups was generally understimated (Table 2; Online Resource 2 and 3).

The sampling effort, measured as the time spent to perform the transect, greatly differed among the three types of transects. The adjacent-plot transect required the longest time to be completed, corresponding to 12 h, i.e. 2 working days, while the zonation-plot transect was performed in 3 h. For the alternate plot transect we estimated 6–8 h (Table 3).

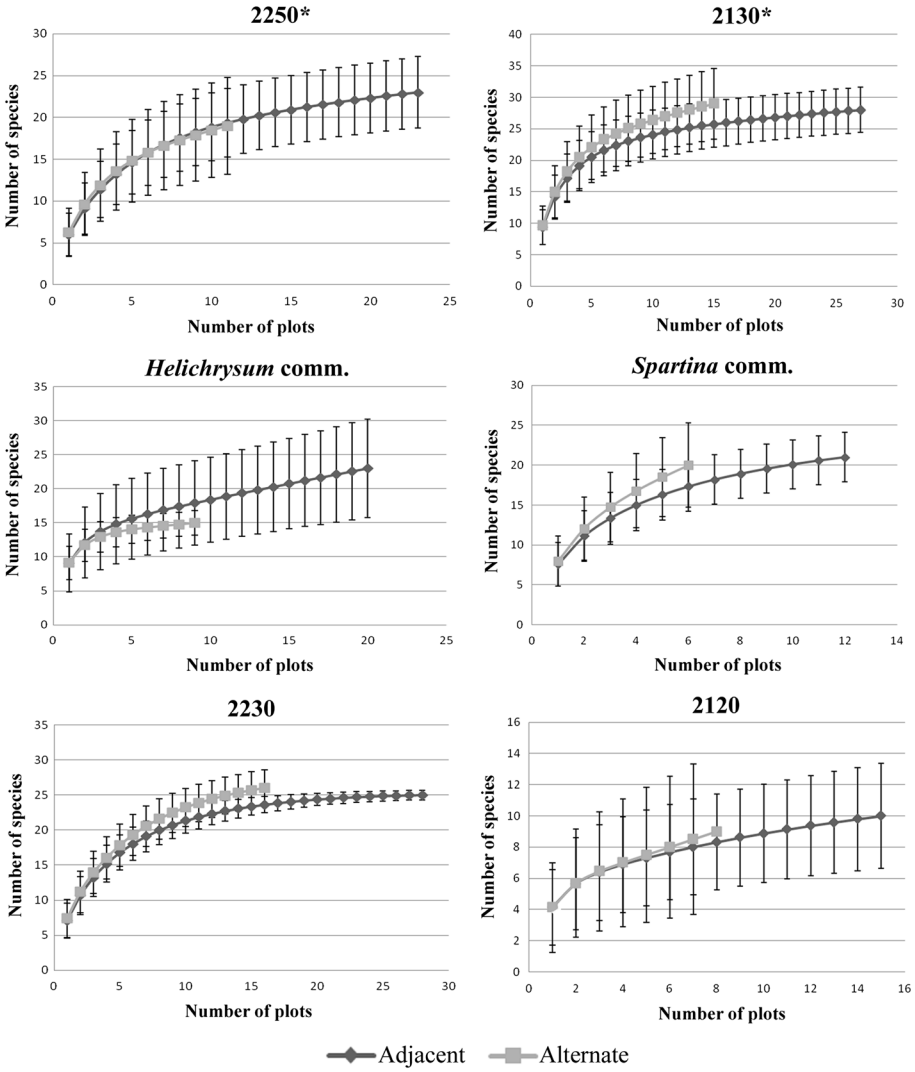

Fig. 3 Rarefaction curves of the cumulative number of species for each habitat, in the adjacent- and alternate-plot transect. Bars represent the 95% confidence interval. The zonation-plot transect, as well as the habitat 1210 are not shown

The sampling effort, measured in terms of time needed for sampling, progressively decreased from the adjacent-plot transect to the zonation-plot transect. Based on the trade-off between dataset completeness and time spent for surveying, the alternate-plot transect resulted the most effective sampling method. Indeed, despite a halved sampling effort, the method allowed the detection of habitat types presence, and provided complete information on species composition and the structural attributes considered, being the only weak point an imprecise detection of habitats spatial extent.

Table 3 Characteristics of each type of belt transect relative to dataset completeness, sampling effort (time required for sampling) and operator skills

	Adjacent-plot	Alternate-plot	Zonation plot
Data completeness	Detection of habitat presence Detection of coastal zonation Explicit and unambiguous measure of habitat spatial extent Complete information on habitat structure (species richness and composition, total cover and species cover) Reliable use of indicator species Possible oversampling of very extended habitats	Detection of habitat presence Detection of coastal zonation Approximate measure of habitat spatial extent Complete information on habitat structure (species richness and composition, total cover and species cover) Reliable use of indicator species Possible underrepresentation of habitats with a narrow extent	Detection of habitat presence Detection of coastal zonation Does not provide measure of habitat spatial extentLow data completeness (biased values on species richness and composition, total cover and species cover)Possible underestimation of undesired groups of species: biased indicator species analysis
Time required for sampling	Variable, depending on system width and vegetation complexity; can become very high in wide systems	Variable, depending on system width and vegetation complexity; can become high in wide systems	Variable, depending on system width and vegetation complexity; normally much lower
Field operator skills	Comprehensive plant identification skills	Comprehensive plant identification skills	Comprehensive plant identification skills Comprehensive knowledge of habitats Ability to recognize habitat boundaries

Discussion

The three methods were equally good in detecting the sequence of habitat types present along the sea-inland ecological gradient. This represents a key feature to assess the overall conservation status of coastal systems, since the lack of one habitat typically indicates disturbance, degradation, and habitat transformation or decline (Acosta et al. 2007; Buffa et al. 2007). Furthermore, the failure in detecting the presence of a given habitat type could lead to an incorrect definition of its distribution area, with consequences in the process of risk assessment, and possibly to overlook local extinctions (Janssen et al. 2016). However, habitat monitoring should also take into account the area shrinkage or decline and the negative effects of increasing habitat fragmentation (Keith et al. 2013). In this regard, only the adjacent-plot transect assured reliable estimates, allowing to precisely define the boundaries and the spatial extent of each habitat type in a given location, and to detect habitat regression or expansion when compared over time. On the contrary, the alternate-plot method provided an imperfect detection that would not be precisely comparable over time and might consistently produce biased values of habitat regression or expansion, while the zonation-plot transect did not involve any spatial measurement and could only give information on the presence/absence of a habitat type.

The three methods also differed in the description of each habitat type. Being comprehensive of all possible records that can be sampled in transects, the adjacent-plot transect provided the most complete dataset, i.e. the most precise representation of habitat types. The only remarkable drawback it evidenced concerned the time needed to perform the sampling, which largely drive the cost of a survey (Hill et al. 2005). The time needed to survey depends on several variables such as the morphological complexity of the area, its accessibility, the complexity of the vegetation mosaic and the skill of the field operator. However, in very complex and wide dune systems, where the most inland habitats can be found at a distance of 150 m or more from the coastline as in our case study, the application of traditional adjacent-plot transects can be limiting mostly due to the high number of quadrats to be recorded. When the vegetation sampling, performed by two experts and one beginner researcher exceeds 8 h, the monitoring may become unsustainable. It is also worth considering the potential reduction in data quality associated with surveyor physical fatigue.

Despite the different number of plots surveyed and the different amount of time allocated to surveying, the alternate- and adjacent-plot transect provided comparable values of the structural attributes as well as of the indicator species detected, suggesting that the sample size (i.e. the number of plots), and the sampling effort, might be reduced without significantly losing information. Our results indicated that in well preserved coastal systems, where habitat types can extend for several meters, the reduction in the number of plots did not affect the representation of habitats, maintaining comparable values of mean species richness, cumulative number of species as well as the number of the indicator species detected. Our findings are consistent with those of Mikulyuk et al. (2010), who stated that a higher sampling effort does not always result in an increase in data accuracy and completeness. Indeed, different results emerged only in the comparison of habitats with a narrow extent, represented by a low number of plots (e.g. the habitat 1210 which belt was only 2 m wide). In this case, reducing an already low number of plots potentially affects the outcome. Thus, when habitat types have a narrow extent, either naturally or following disturbance events, the alternate-plot transect should be avoided.

The zonation-plot transect was the most effective in reducing the sampling time. However, the presence of at least one expert field operator, able to recognize boundaries between different plant communities in the field and to lay the plot in the point that best represented the characteristics of the community was compulsory to perform the transect. Thus, while for the adjacent- and alternate-plot transects surveyors should be competent field botanists, able to identify the species in the field, performing a zonation-plot transect requires comprehensive plant identification skills, comprehensive knowledge of habitats and the ability to recognize habitat boundaries. The involvement of such field operators may represent a limit, since it can be expensive thus increasing the costs of monitoring (Carpaneto et al. 2017). Moreover, the extreme reduction in the number of plots per habitat type resulted in a loss of data accuracy and completeness. The relationship between the number of replicates and the completeness of information is well-known in data analysis (e.g. Rocchini et al. 2017), and this pattern clearly emerged from our results. Although placed in the most representative location of the community, one single plot proved to be inadequate to thoroughly describe the features of the habitat types (e.g. species richness and cover, cumulative number of species). Furthermore, the enlargement of the plot size did not assure data completeness and was not enough to retrieve information lost due to the reduced number of plots.

The zonation-plot transect also was less precise in detecting the indicator species groups. Arguably, this is mainly due to the subjective plot selection by the field operator: choosing the location that best represents the plant community, undesired groups of species, such as generalists or aliens, have less chance to be included in the survey, due to the tendency to avoid disturbed communities (Swacha et al. 2017). In monitoring programs requiring minimal error and maximum accuracy, all the groups of species should be reliably detected, because habitat degradation, or the shifting toward different habitats due to the increase of other species, can be detected by a decline in focal species, with generalist, alien and other species remaining constant, or vice versa, by an increase in these groups of species, with focal species remaining constant (Biondi et al. 2012; Del Vecchio et al. 2016; Sperandii et al. 2018). This represents a major shortcoming of this method when applied to monitoring, unless plots represent permanent sampling locations and sufficient samples are taken to maximize the representativeness.

In summary, although the zonation-plot transect had the lowest sampling effort, it provided only an approximation of the state of the dunal communities, and the accuracy was low. The alternate-plot transect showed the best trade-off between the sampling effort, in terms of time spent for surveying, and the completeness of information obtained.

Selecting the most appropriate method is an important step in any monitoring plan. To maximise the efficient use of monitoring resources the most cost-effective method appropriate to the monitoring objective should be used. The results emerged from our study can support the selection of the best sampling procedure according to monitoring objective, field conditions, available resources and personnel, and can be applied to other coastal systems.

On the basis of our research, we suggest the following best practices to set monitoring programs: (1) use the adjacent-plot transect, whenever it is possible; however, in case of wide and complex coastal system where the field survey might exceed 8 h, the implementation of alternative sampling methods might be taken into consideration; (2) use the alternate-plot transect as a first choice alternative to the adjacent-plot transect, being aware of its weakness in case of habitats with limited spatial extent; (3) if the sampling effort has to be extremely reduced (e.g. due to resource constrains), the zonation-plot transect can be

used as well, with the caution of involving at least one expert field operator, and possibly performing more than one plot for each plant community.

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