Biennial survey method of marine dunes in the French part of the North Sea shipping channel

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ABSTRACT: After a period of recurrence of three years for surveying and charting sand dune dynamics of some areas of the French part of the North Sea shipping channel, a decennial survey of the entire channel was realized. The measured movements served to propose a new monitoring approach of the channel based on the Multibeam Echo Sounder biennial survey of a few selected dunes. It was then decided that after a 10-year period, from 2013 to 2023, a decision would be made regarding the method of monitoring of this shipping lane. This paper presents the first results from the study of these 15 dunes surveyed in 2013, 2015 and 2017.

1 INTRODUCTION

During the 1980s, in the context of an agreement with the North Sea Hydrographic Commission (NSHC), the French Hydrographic Office conducted surveys of eight areas of the North Sea shipping lane which represents a quarter of all the area. Initially, survey recurrence was of one, three and five years, but as dune movements were of the same order as the location precision of this time, it was rapidly decided to perform these surveys only every three years. After data analysis, it appeared that the boundaries of these areas did not match the most hazardous sectors for shipping; in 1997 we proposed to replace these surveys by a decennial hydrographic survey of the entire shipping channel, in order to produce an extensive overview of the dunes distribution.

The data analysis of these surveys provided knowledge on dunes, for example whether they are isolated or grouped in fields. The measured movement speeds on 113 dunes that had been surveyed several times gave values between 0 and 30 meters/year, with slower movement observed in the dune fields compared to isolated dunes and the highest speeds in the underflow shear areas. Our results, obtained by the classical method of crest location to analyse rhythmic bed patterns, are comparable to those of scientific literature (Knaapen, 2004). This analysis was used to define a number of indicators characterising those dunes which are considered a hazard to shipping. Subsequently, a suggestion was made to monitor channel based on a few selected dunes, instead of the initially considered indefinite repeat of the decennial survey. Based on studies conducted since the 1990s a list of 15 dunes requiring biennial surveys was drawn up. It was then decided that, after a 10-year period (2013 – 2023), a decision would be made regarding the monitoring of this shipping lane. Indeed, as dune movements are slow, we need to wait at least 10 years to be able to draw any conclusion from this new mode of dune monitoring. The purpose of this paper is to present the results from the study of these 15 dunes surveyed in 2013, 2015 and 2017. This new method for the resurveying of sand dunes areas is different from the one used in other Hydrographic Offices of the North Sea (Dorst *et al* 2013). This is not due to the reduction in bathymetric survey capacity, but to the necessity to deploy the hydrographic survey capacities in other zones of the French continental shelf where the last bathymetric data were acquired before the Second World War.

2 DUNES BIENNIAL SURVEYS

The complete survey of the French part of the North Sea shipping channel displayed a number of sediment cells (Figure 1), which can be distinguished by the north-easterly or south-westerly direction of dune movement. In these cells, fifteen dunes were selected as the most representative of these cells and more generally of this part of this channel. Hydrographic surveys of these dunes were done in 2013, 2015 and 2017. We present here these initial data which have been studied to assess the need to adapt the survey procedure.

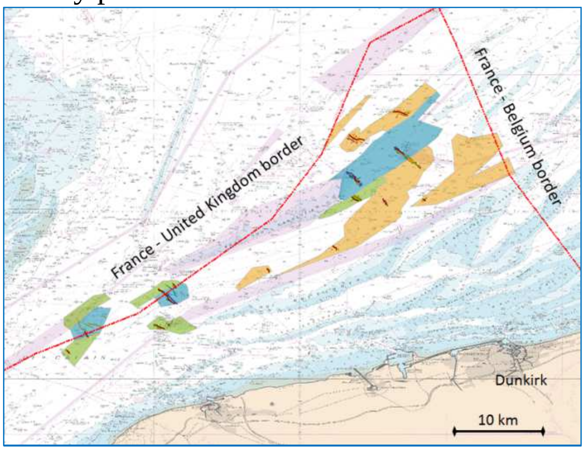

Figure 1. Location of sediment cells according to the direction of dune movement (■: movement towards the south-west; ■: movement towards the north-east; ■: undetermined movement).

2.1 Overview of initial guidelines

Geographical cells have been defined all along the French part of the North Sea shipping channel according to their depth, height and movement speed characteristics. One or two dunes have been selected in each of these cells. For each dune, the hydrographic survey starts with one or two cross profiles that allows marking the position of the crest and its external limits. The survey continues with a series of profiles, longitudinal to the crest, to cover the entire dune. A Digital Elevation Model (DEM) constructed from the data is intended to allow the calculation of volumes and slope angles required for the study of sediment dynamics and to configure future models.

The dune surveys are conducted:

- always at the same period of the year, in order to ensure similar hydrodynamic conditions and to guarantee similar times between surveys. So the three first surveys were all done in July;
- in a single survey operation (i.e. over a period of one to two weeks), such that all the dunes may have experienced the same tide and storm conditions.

As one of the surveys of Dune 3 is not complete, the three surveys of 2013, 2015 and 2017 were compared for each of the 14 other dunes, between themselves and against previous MBES data (Figure 2).

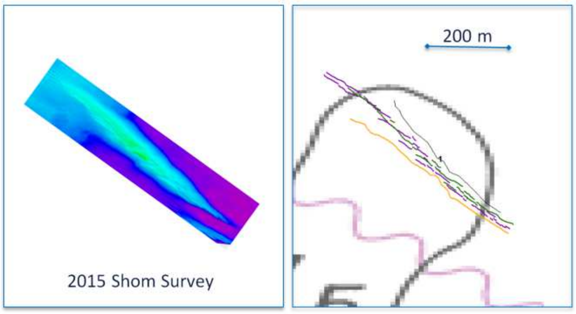

Figure 2. DEM of D1 in 2015 and evolution of the crest of Dune 1 in 2002: ▬, 2013: ▬, 2015: ▬, 2017: ▬)

2.2 Midway overview of biennial surveys of North Sea dunes

The Shom (French National Hydrographic and Oceanographic Office) is developing a new software to calculate dune parameters (Ogor, 2018), to replace the previous software "DuneS". For this initial study, mean dune travel is calculated from between crest measurements made at 10 points regularly spaced along previously digitised crests. Dunes do not move in a uniform manner and different sections of a dune may move in opposite directions. By convention, northwards movements are considered to be positive, while southwards movements are negative. Dune movement is thus expressed as a mean movement, which is reduced in the presence of such inversions.

2.2.1 Direction of dune movement

The first observation derived from the study of biennial surveys is that the dunes occasionally display inversion in their direction of movement (Figure 2). Table 1 summarizes these observations (Table 1). Grey cells indicate movement to the north-east or north, while the others represent movement to the south-west or south.

Our previous studies established that the movements of dunes 1, 4, 6 and 10 were to the north-east or north, that the dunes 2, 5, 7, 8, 11 and 14 movements were to the south-west or south, that the dunes 9, 12, 13 and 15 were stable.

Table 1: Direction of dune movements for the various time periods: to the north-east or north (N to NE), to the south-west or south (S to SW), and stable dunes (*Stable*).

	X-2013	2013-2015	2015-2017	X to 2017
D1	S to SW	N to NE	S to SW	S to SW
D2	S to SW	N to NE	S to SW	S to SW
D4	N to NE	N to NE	S to SW	S to SW
D5	S to SW	N to NE	N to NE	N to NE
D6	S to SW	N to NE	N to NE	N to NE
D7	S to SW	N to NE	S to SW	S to SW
D8	S to SW	N to NE	S to SW	S to SW
D9	*Stable*	N to NE	*Stable*	*Stable*
D10	N to NE	N to NE	N to NE	N to NE
D11	S to SW	S to SW	S to SW	S to SW
D12	*Stable*	N to NE	*Stable*	*Stable*
D13	*Stable*	N to NE	*Stable*	*Stable*
D14	S to SW	S to SW	S to SW	S to SW
D15	*Stable*	N to NE	S to SW	S to SW

Upon completion of the analysis of biennial surveys (Table 1), it appears that:

- the 2013-2015 period displayed overall northward movement,
- only dunes 11 and 14 did not move in this northward direction during this period, possibly due to their protection by the *Sandettié* shoal,
- dunes 9, 12 and 13, classified as stable, i.e. displaying speeds of less than or equal to 1 m/year, displayed for the 2013-2015 period a northward movement at speeds of 6 to 8 m.

With the exception of dunes 10, 11 and 14, all of the dunes display back and forth movements, as had already been observed on several dunes in the south of this zone (Le Bot et al., 2000). As the number of spring tides is of the same order each year, tidal forcing is similar and cannot explain such movement inversions. The observed movements are thus likely to be the result of surge currents caused by storms.

The inversion in the direction of movement observed here shows that the phenomenon is at a regional scale. That or those storm(s) amplified the speed of dunes which has a similar direction of movement to that of the storm (D10), it generated a slower apparent movement for dunes conventionally moving towards the south (D1, 2, 7, 8, 11, 14) and it triggered the movement of normally immobile dunes (Dune 9, 12 and 13). The too large time period between the surveys prevents us from determining whether this northward movement arose from the impact of several storms or from the cumulative impact of a powerful storm during a spring tide. Subsequent surveys, along with the studies that will be conducted on the relation between inversion and climate whould enable us to determine the storm conditions that generated this phenomenon. The quarterly surveys scheduled in the context of the DUNES project, submitted to the latest France Energie Marine call for tenders, could supplement the biennial surveys to provide information regarding the short-term effects of storms.

2.2.2 Speed of dune movement

The mean annual movement for the various periods (Table 2) shows that the storm phenomenon, previously mentioned, causes dune 10, which is the only one to systematically have northward movement, to display during the 2013-2015 period a speed 11 m higher than its usual speed. Over this period, it displayed a movement of 34 m/year. Conversely, the speed of movement of those dunes that usually move southwards dropped during this period, even reversing for dunes with a usually low southward dynamic. Finally, the 3 stable dunes displayed mean northward migration rate of 6 to 8 m/year during this period.

Table 2: Migration rates in meters per year of the 14 dunes included in the biennial surveys

	X - 2013	2013-2015	2015-2017	X-2017
D1	7.1	**23.1**	2.3	*2.5*
D2	8.3	11.5	13.8	*6.8*
D4	4.1	15.5	9.7	*4.0*
D5	1.5	**22.9**	9.1	*5.8*
D6	7.2	**22.4**	6.7	*1.0*
D7	5.6	6.2	7.7	*2.7*
D8	7.5	8.7	4.0	*4.6*
D9	0.4	7.7	1.0	*0.6*
D10	**24.6**	**34.4**	**22.8**	*26.3*
D11	12.3	10.5	9.5	*11.8*
D12	0.4	8.3	0.0	*0.4*
D13	0.5	6.1	0.3	*0.7*
D14	7.8	2.3	6.0	*5.8*
D15	0.6	5.2	3.3	*2.3*
Mean	*6.3*	*13.2*	*6.9*	

From this table we can put forward the following hypothesis:

- the storm or storms generated a movement of all dunes of circa 15 m northward.
- stable dunes may in fact move, but the slow southward movements of only a few meters per year caused by the tidal currents would appear to compensate by the inverse currents of storm surges.

To be confirmed, these hypotheses will obviously need to be substantiated by new data and by a study of storm activity.

A previous analysis of MBES surveys conducted by the Shom from 2000 to 2007 allowed the migration rate of 113 dunes to be measured. Those rates, compared to the results of the biennial survey (Table 3), show that movements for the 2013-2015 period are comparable to the means obtained for the 113 dunes of the previous surveys. As the extreme and mean values are comparable, this confirms that the group of 14 dunes is relatively representative of the shipping lane, but we need more recurrences to draw further conclusions.

Table 3: Comparison of mean dune speeds in meters/year from previous surveys with those from the biennial surveys

	Speed of 113 dunes	Speed of the 14 biennial dunes		
	2000-2007	X-2013	2013-2015	2015-2017
min	0.0	0.4	2.3	0.0
mean	10.2	6.3	13.2	6.9
max	32.1	24.6	34.4	22.8

2.2.3 Dune height variability

During the pre-2011 studies on the few available MBES surveys, it was noted that dune height appeared to vary from one survey to the next. Megaripple dynamics superimposed on dunes and dune deformation during migration may cause longitudinal changes in the high point of the dune along its crest over time. While the crest-line can easily be digitized, calculating dune height is more complicated: the results must be reworked with the dune automatic parameter calculation software not to be attributable to human interpretation. The height of the 14 dunes, defined between the base of the dune and its highest point for the 3 biennial surveys provide new elements regarding dune height. The observed variations are greater than previous data had suggested, so it seems that the risk, from a hydrographic standpoint, seems to be significant (Table 4).

Table 4: Maximum dune height of the dunes in meters

	2013	2015	2017	Δ max
D1	7.0	7.6	8.7	*1.7*
D2	6.7	8.5	7.9	*1.8*
D4	5.1	6.7	7.4	*2.3*
D5	4.0	6.0	6.4	*2.4*
D6	5.0	5.9	8.3	*3.3*
D7	7.3	8.0	8.0	*0.7*
D8	6.4	8.0	7.2	*1.6*
D9	5.5	4.9	4.0	*1.5*
D10	4.0	3.4	4.5	*1.1*
D11	4.3	6.0	6.4	*2.1*
D12	2.5	3.4	5.2	*2.7*
D13	3.0	2.0	2.0	*1.0*
D14	5.0	7.3	6.7	*2.3*
D15	5.0	8.2	8.6	*3.6*
Mean	*5.1*	*6.1*	*6.5*	

As a first approximation, the mean height of the 14 dunes increased progressively between 2013 and 2017; this progression was very clear for dunes 1, 4, 5, 6, 11, 12 and 15. This appears correlated neither to the direction, nor to the speed of movement. With the exception of dune 7, this increase seems major as the height difference for some dunes is greater than 50%. This change in dune height may come from:

- the improvement in MBES accuracy, leading to improved integration of megaripples covering the dunes,
- the action of storms, which tend to level the tops of the dunes, and from tidal currents which tend to rebuild them,
- the faster movement of small dunes, which, by combining with the larger dunes, can in theory increase their volume,
- changes in sediment granularity; an increase in grain size leading to an increase in height (Flemming, 2000).

It first appears important to be able to confirm these observations through an automated calculation, which should be more precise thanks, for example, to the integration of the slope effect. This software calculation will serve to consolidate the results, to allow comparison to previous surveys and to supplement this parameter with the study of dune top depth. It will also be necessary to study the behaviour of small dunes located upstream. This already implies that the survey area around each dune must be increased to systematically encompass the entire dune and dune crest located upstream.

2.3 Addition of 6 new dunes

The north eastern part and the region bordering Belgium were recently surveyed, leading to the definition of 5 new dunes selected for their height and their representativeness. They will be added to upcoming biennial surveys. Moreover, an area close to the Sandettié Sandbank presents barchans which display the highest movement speeds observed in this region (more than 50 m/y). So, 21 dunes will be studied for the next biennial surveys (Figure 3).

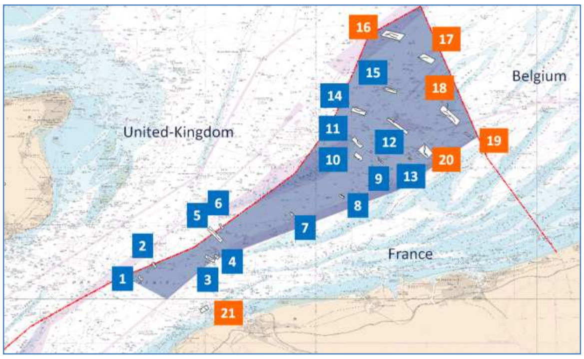

Figure 3: the shipping lane and tracking of dunes to survey during the biennial surveys

3 CONCLUSIONS

Dune movements obtained by analysis of the latest surveys are nearly all smaller than those predicted in 2011 based on the analysis of older surveys. This may be ascribed to improved tracking precision and better accuracy of the MBES, allowing the observation of previously difficult to distinguish megaripples. The dune crests, which appeared continuous and linear in previous low resolution Multibeam Echo-Sounder survey, are now frequently defined by series of sections separated by several meters. The speed change is, however, also due to an exceptional storm, or to several storms that occurred during the 2013-2015 period. This event leading to a generalized dune migration to the north, whereas the dune movement is usually variable. This phenomenon may be exceptional, but it could also be caused by climate change and the evolution of storm activity.

Of all the fifteen monitored dunes, the one that display the greatest movement is dune 10, which travelled 290 m in 11 years. This represent a difference of 0.4 cm on the local chart at 1/75000 scale. All the other dunes give a difference in positioning on the chart of less than 1.6 mm after a period of 10 years. Those results support shipping safety and confirm that an exhaustive survey of the shipping lane is not at this stage necessary.

Analysis of the 2013, 2015 and 2017 surveys shows that the survey methods need to be refined. It appears necessary, in particular, to specify the areas to be covered rather than defining the survey areas on location. Therefore polygons within which the dunes should be located in the next 6 years have been defined for the future surveys.

As dune height is linked to sediment grain size, it would appear necessary to collect sediment samples from at least 2 or 3 of the dunes most sensitive for this parameter. The aim of future models will mainly be to calculate dune height variability along with the theoretical maximum height. During the upcoming three surveys, sediment samples should be collected from 2 dunes displaying significant heat variations.

From now to 2023, we shall conduct the following studies:

- about temporal variation of dune grain size distribution and height
- on survey procedure according to dangerousness of dunes defined by height, depth and relation between the movement speed to the representation chart scale.

Upon completion of the 10-year biennial survey period, i.e. in 2023, the North Sea hydrographic survey procedure will be redefined. It does not currently appear possible to further reduce the hydrographic surveys. The possibilities considered for the 2023-2033 period are:

- to continue the biennial surveys.
- to adapt these biennial surveys during a further decennial cycle by performing surveys every 2 years for dunes having displayed movements of more than 20 m, and every 4 years for all the 21 dunes.
- to continue the biennial surveys, supplementing them with some surveys of sectors having displayed large changes.
- if the height variability studies confirm the increase observed over the 2013-2017 period, to resume the surface survey of all sectors where the dune tops are, or could have been, at a depth of less than or equal to 26 meters; international regulations impose that such depths must be guaranteed.

The biennial survey data acquired between 2013 and 2023 will provide a sufficient dataset to enable the sediment dynamics modelling expert to study and validate the modelling of the shipping lane dunes. The aim is to have, by 2025, a model capable of calculating dune movements and height changes in order to predict the date and location of surveys to conduct.

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4 REFERENCES

Dorst, L., Dehling, T., Howlett, C., 2013. Developments in North Sea wide resurveying and charting of dynamic sand wave areas. Proc. Marine and River Dune Dynamics (MARID IV), Bruges, Belgium, 81-88.

Flemming, B.W., 2000. The role of grain size, water depth and flow velocity as scaling factors controlling the size of subaqueous dunes. Proc.Marine Sandwave Dynamics, Lille, France, 55-61.

Knaapen, M.A.F., 2004. Measuring sand wave migration in the field. Comparison of different data sources and an error analysis. Proc. Marine Sandwave and River Dune Dynamics (MARID II), Enschede, the Netherlands, 152-160.

Le Bot, S., Trentesaux, A., Garlan, T., Berné, S., Chamley, H., 2000. Impact of storms on tidal dune mobility on the Pas-de-Calais strait. Oceanologica Acta, 23/2, 129-141.

Ogor, J., 2018. Design of algorithms for the automatic characterization of marine dune morphology and dynamics. PhD Thesis, University of Bretagne Occidentale-DGA, 255 pp.