

# The influence of ship movements on the energy expenditure of fishermen. A study during a North Sea voyage in calm weather

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## ABSTRACT

**Background:** Former studies of professional fishing activities have indicated that movements of a ship, in itself, may increase the energy expenditure in addition to the traditional work carried out by fishermen. We have studied the effects of exposure to the ships movement during calm weather by examining the crude relation between the ship movement and the energy expenditure of the fishermen, thus ignoring the various tasks undertaken on board.

**Materials and methods:** We have recruited 4 fishermen on 2 contemporary steel trawlers who participated during the whole study period. Each of 4 participants recorded his activities and health conditions once an hour in a registration scheme for 4 days. Estimations of energy expenditure were done with a body monitoring system (SenseWear Pro 3) carried as an armband, placed at the surface on the right upper arm. Measurements of sea movements were obtained by a gyroscope placed in the vessels wheelhouse during fishing expeditions in the North Sea off the coast of Bergen. Data were analysed by linear regression.

**Results:** The exposure monitored in calm weather conditions was small for all measurements of heeling and pitch being less than 10° for both vessels. However, the fishermen's energy expenditure was influenced by these minor sea motions. Trends were seen in the individual graphs with increasing energy expenditure at higher exposures.

**Conclusions:** Our data suggest that even the heel and pitch in calm weather have an impact on the fishermen by increasing their energy consumption, but without any observation of discomfort or negative health outcomes. This study has demonstrated the feasibility of the applied methods, which should be repeated with larger samples and in rough weather.

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**Key words:** calm weather, fishing, energy expenditure

## INTRODUCTION

Maintaining balance during activities such as standing, walking or working on a fishing vessel's slippery, pitching or rolling deck, sometimes with major and unpredictable movements of the vessel at sea requires muscular effort greater than when staying on a stable platform. In addition to interference with the crew's task performance, perceived effort, and wellbeing in terms of, e.g. motion sickness,

disturbed sleep and fatigue [1, 2], these circumstances may influence the crew's energy expenditure on board.

Previous studies of oxygen uptake at sea during various physical loads and working tasks [3] have shown that the mere movement of the ship may increase the oxygen consumption by up to 70% at rough sea [4, 5], and that this level renders the workload of fishermen comparable to that of the heaviest industrial trades [6–10]. This is

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**Table 1.** Demographics of the studied subjects

Vessel	Position on board	Age [years]	Height [cm]	Weight [kg]	Body surface [m <sup>2</sup> ]*
Polaris	Skipper	53	196	126	2.58
	Apprentice	23	185	82	2.06
Luna	Fisher	45	180	88	2.08
	Machinist	37	183	80	2.02

\*The body surface (A) was estimated by the formula  $A = W^{0.425} \times L^{0.725} \times 0.007184$ , with W as the weight and L as the length.

in accordance with the reported tiredness, as well as increased heart rate and catecholamine release during fishing, which has been classified by many as ‘an extreme occupation’ [3, 11].

The few studies of energy expenditure during fishing operations, however, are not new and, therefore, may not reflect the current situation for several reasons. Contemporary fishing in Denmark is much less strenuous than previously. Many previous, severely hazardous tasks on board have now become mechanised, e.g. hauling the nets, shovelling ice in the hold, and filling of the catch into the hold. Furthermore, today’s Danish fishing vessels tend to be larger and much better constructed in terms of maintaining balance and stability during a voyage and while fishing. Consequently, compared with the past, the fishermen of today are likely to be less prone to the influences of the fishing vessel’s movements at sea, including those related to bad weather and rough seas. In spite of the improved construction of fishing vessel’s, however, the impact of weather in terms of wind and temperature, waves, and ship’s propulsion through the water, may still impose continuous strain to the fisherman during his work, and the total energy expenditure during work on board may be affected by the proportion of energy expenditure required for keeping balance during the work.

This study aims to assess the selective effects of the ships movements at sea on fishermen’s energy expenditure and show how they subjectively felt each hour during the study. In this initial study, we have aimed to study the crude relation between the energy expenditure of the fishermen and the ship movement during a voyage in calm weather, thus ignoring the various tasks undertaken on board.

## MATERIALS AND METHODS

### FISHERMEN STUDIED

Participants were recruited with assistance from Hirtshals Fishermen’s Association. The owners (skippers) of 2 steel trawlers (Polaris HG 352 and Luna HG 350) and their crew (9 fishermen) were invited for the study. Two out of 5 fishermen from Polaris and 2 out of 4 fishermen from Luna participated during the whole study (Table 1). They were all right handed males and smokers. None



**Figure 1.** Luna



**Figure 2.** Polaris

of them took medications or suffered from any known disease. Demographic characteristics of the participants are illustrated in Table 1.

### VESSELS

Both vessels were relatively new steel trawlers. Luna HG 350, constructed in 1998 at Tjörn Varvet, Rönning, Sweden, had an overall length of 28.44 m, wideness 8.20 m and sticks 6.65 m. The gross tonnage was 306 tons (Fig. 1). Polaris HG 352, delivered in 2003 from Vestværflet ApS, Hvide Sande, Denmark, had a length of 23.50 m and was 7.00 m wide. The maximal draft was 5.62 m from the level of the shelter deck. It had a gross tonnage of 173.3 tons (Fig. 2).

## MEASUREMENTS OF THE VESSELS MOVEMENTS

A gyroscope (30 × 30 × 20 cm) with 2 inbuilt sonar sensors (Taeko scl-30a1, Foruna Industries, Esbjerg) was placed in the 2 vessel's wheelhouses, both of which were placed near the centre of the vessels. The gyroscope was connected to a handhold computer that was set to register one time per second the ship movements in 2 planes: rolls from side to side and pitch from fore to aft.

Prior to the measurements, the clock on the apparatus for measuring the energy consumption (Fig. 3) was synchronised with the time set on the computer on board. The simultaneously acquired 2 sets of data on roll and pitch were logged by computer software delivered by Picolog, Pico Technology [12]. Shifts in either direction were both stated as positive numbers.

Gyroscopic measurements were performed during fishing expeditions in the North Sea off the coast of Bergen, Norway. Recordings on Polaris were made from July 20<sup>th</sup>, 2010 at midnight until July 25<sup>th</sup>, 2010 at 04.00 a.m., and on Luna from October 2<sup>nd</sup>, 2010 at 8.21 p.m. until October 6<sup>th</sup>, 2010 at 10.02 p.m.

The weather conditions at both voyages were relatively calm. Polaris experienced wind velocities up to 10 m/s and an average air temperature of 14°C, while Luna sailed with wind speeds up to 14 m/s and temperatures about 12°C.

## PERCEIVED HEALTH EFFECTS

The participants were asked to write down in a registration scheme their tasks and health symptoms (pain, illness, tiredness, distress and general well-being), every hour for the whole voyage while awake.

## MEASUREMENTS OF ENERGY EXPENDITURE

Information about the body accelerations in 2 axes, the body temperature, the near-body temperature, the heat

flux, and the skin's galvanic response was collected and analysed by a versatile monitoring system carried as the armband (Fig. 3), placed at the surface of the upper right arm (SenseWear Pro 3 developed by BodyMedia [13–15]). The fishermen carried the SenseWear Pro 3 continuously for the whole voyage and thus the measurements included the sleeping periods.

The analyses of these data by the SenseWear professional 6.1 software [16] permitted calculating the energy expenditure by the hour for each fisherman. The program provides estimates of activities such as sleep, lying down, and steps, and therefore permits correlation to the registration schemes. Due to the anthropometric variations in between the participating fishermen, we have standardised the energy expenditure according to their body surface, thereby making the measurements comparable (Table 1).

## EXPOSURE

The fishermen's exposure to the ship's movements consists of 3 major indices: 1) the ship's heeling, 2) the ship's pitch, and 3) the frequency of heeling and pitch, respectively. Evidently, high frequency of heeling and/or pitch is associated with low amplitude of heeling and pitch, respectively, and *vice versa*. For that reason, a measure of exposure cannot be defined by combining these measures by simple addition.

To overcome this challenge, we have developed an exposure matrix that expresses what we regard as a relevant marker of exposure: the addition for each hour of the maximal angular velocity (upper quartile) in degrees for heeling and pitch in both directions, respectively. We have used the maximal of the simultaneously recorded parameters

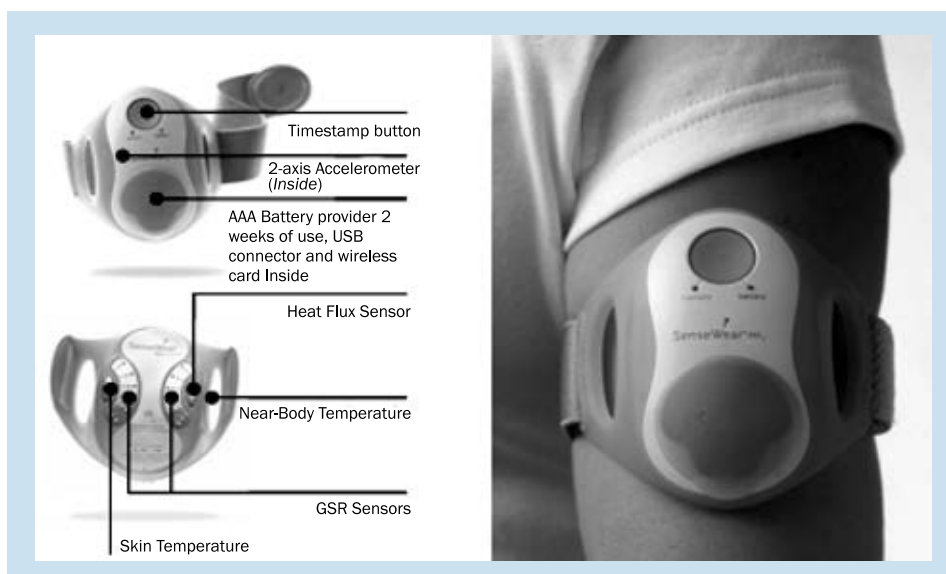
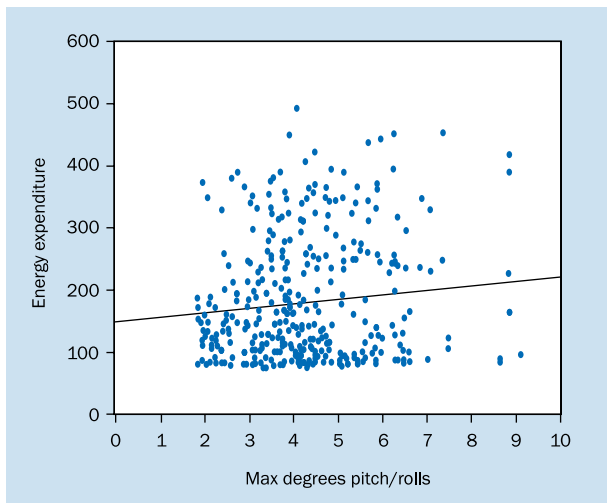
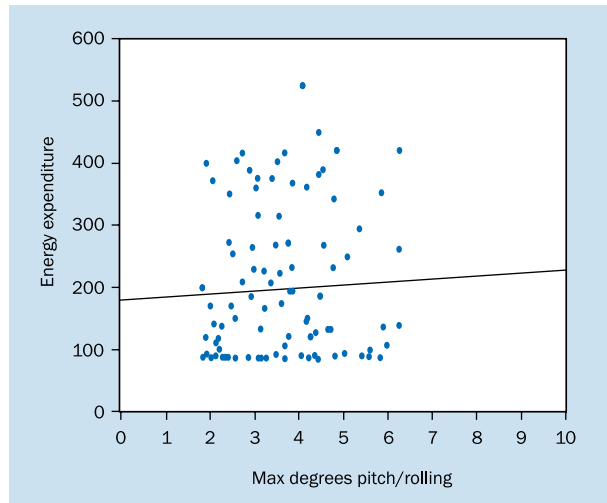


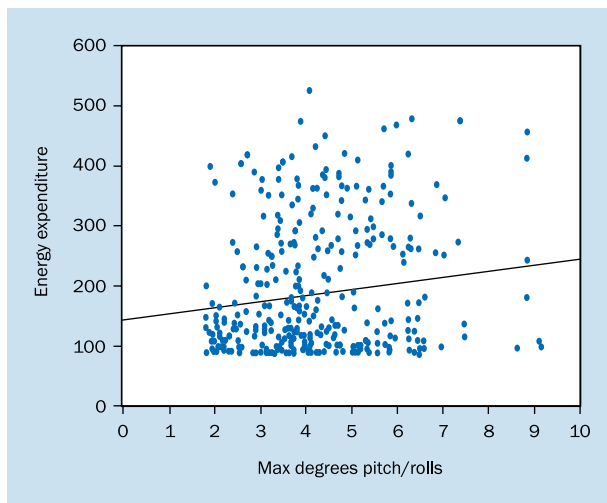
Figure 3. SenseWear apparatus



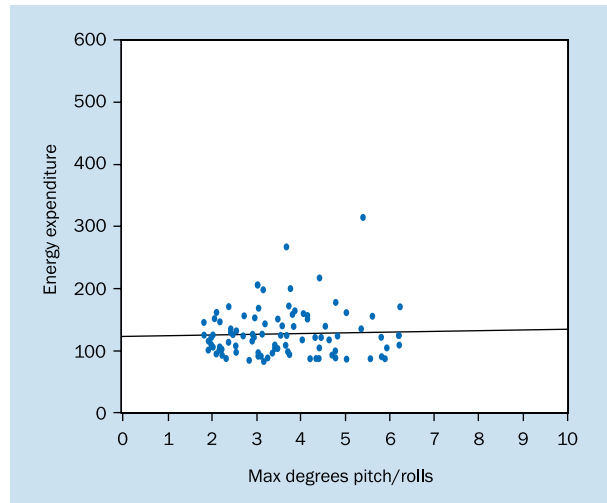
**Figure 4.** Correlation between the ships movement and the energy expenditure for all fishermen together (unadjusted)



**Figure 6.** Correlation between the ships movement and the energy expenditure for apprentice – Polaris (adjusted for surface area)



**Figure 5.** Correlation between the ships movement and the energy expenditure for all fishermen together (adjusted for body surface area)



**Figure 7.** Correlation between the ships movement and the energy expenditure for skipper – Polaris (adjusted for surface area)

(pitch/rolls) as the most reliable measure for movements, thereby meaning the highest exposure at a time. These figures served as exposure indices hour for hour.

**STATISTICS**

The indices for exposure, e.g. ships movements summarised for every hour, were transferred as comma separated files and analysed by SAS statistical software. These data were synchronised in time with the energy expenditure measured by the SenseWear apparatus, thereby making correlations possible.

The exposure indices with any activity were compared by linear regression statistics to the measured energy expenditure on an hourly basis. The correlation was studied individually for each of the 4 participants and for all 4 together (Figs. 4–9).

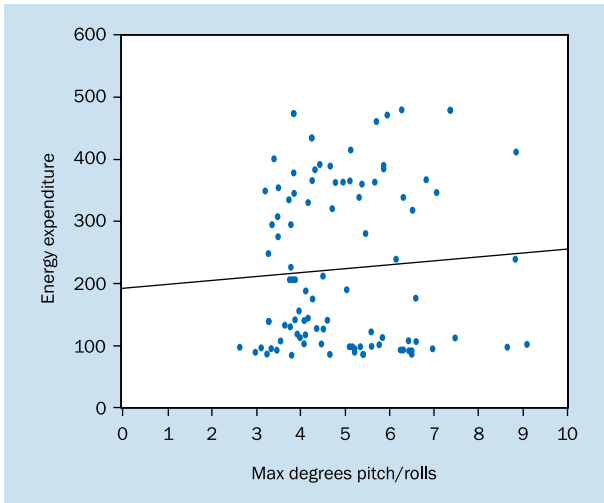
**RESULTS**

None of the fishermen reported any discomfort or negative health outcomes during 4 days at sea.

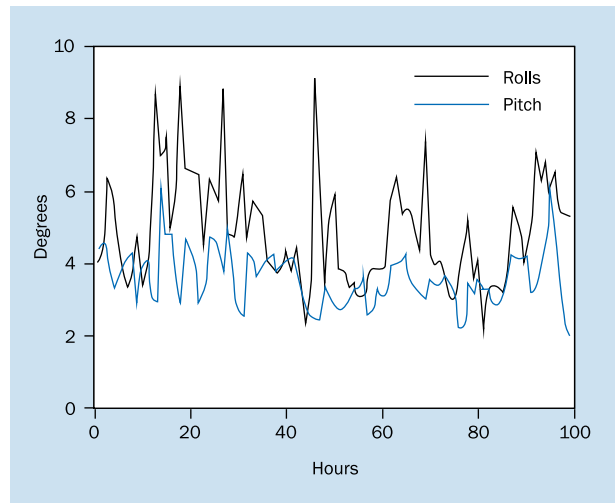
The exposure in terms of starboard to portside rolls and fore to aft pitches is illustrated in a time scale with plots for every hour (Figs. 10, 11). Both were limited and at any time less than 10°.

The minimal, mean and maximal hourly energy expenditures during 4 days of observation at sea are showed in Table 2.

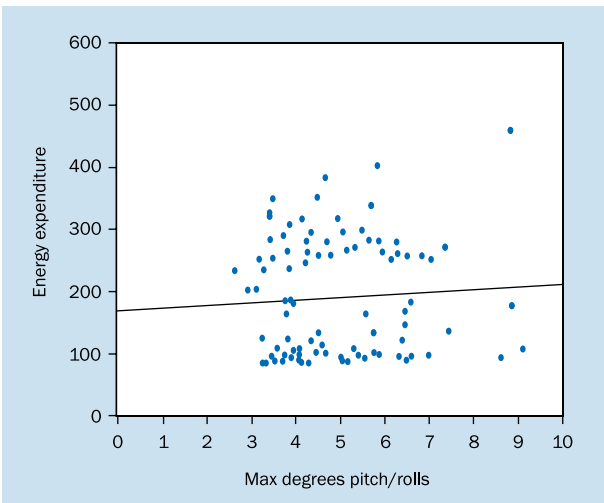
When adjusted for body surface there was a significant correlation between the exposure indices and the energy expenditure for all the fishermen together (Table 3). In addition, trends were seen in the scatter plots for each



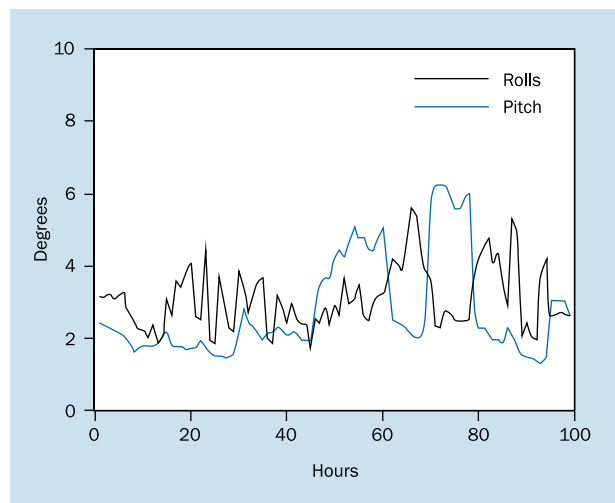
**Figure 8.** Correlation between the ships movement and the energy expenditure for fisherman – Luna (adjusted for surface area)



**Figure 10.** Heeling and pitch for Luna



**Figure 9.** Correlation between the ships movement and the energy expenditure for machinist – Luna (adjusted for surface area)



**Figure 11.** Heeling and pitch for Polaris

individual fisherman. The slight slopes of the trend lines indicate increasing energy expenditure at higher exposures, although these were not significant (Figs. 4–8).

## DISCUSSION

Working fishermen’s energy expenditure during extended periods of time (days) has, as far as we know, never been studied. When analysing for the combined energy spent for all the crew members, we have found that their energy expenditure was influenced by heeling and pitch of a magnitude of less than 10°, which is far below what would occur in rough seas. In spite of the increased energy expenditure, none of the studied fishermen had any complaints or affected well-being. We failed to demonstrate

a statistically significant relation between the ship’s movement and the energy expenditure for each individual fisherman. This might be explained by the limited number of observations for the analyses on the individual level (n = 96), compared with the higher number of observations available for analysis of the association for all crew members (n = 384). Our findings are in line with previous studies [1–3, 5–10], describing that keeping balance on the moving deck of a vessel increases the energy expenditure and, consequently, the metabolic rate of the fisherman. However, several of these studies have compared the oxygen consumption of fishermen during various tasks on board with laboratory measurements of their maximum oxygen uptake capacity. These studies have demonstrated mean levels at about 40% of maximum capacity with

**Table 2.** Hourly energy expenditure during voyage (calories/hour)

	Minimal		Mean		Maximal	
	Unadjusted	Adjusted*	Unadjusted	Adjusted*	Unadjusted	Adjusted*
Apprentice	80.1	85.2	185.5	197.2	493.8	525.0
Skipper	99.8	84.7	149.6	127.0	368.0	312.4
Fisherman	79.3	83.5	210.1	221.2	453.4	477.4
Machinist	76.9	83.4	172.9	187.4	419.3	454.6
Mean for all the crew	76.9	83.4	179.5	183.2	493.8	525.0

\*Adjusted for body surface [m<sup>2</sup>]**Table 3.** Correlation by linear regression statistics between exposure indices and energy expenditure during all activities

	N	R <sup>2</sup>	$\alpha$	P	R <sup>2</sup>	$\alpha$	P
All crews in combination	384	0.0177	9.78358	0.0091	0.0101	6.82098	0.0488
Apprentice	96	0.0024	4.80647	0.6385	0.0024	4.52116	0.6385
Skipper	96	0.0021	1.49159	0.6555	0.0021	1.75722	0.6555
Fisherman	96	0.0039	5.57765	0.5436	0.0039	5.48745	0.5436
Machinist	96	0.0030	3.71543	0.5935	0.0030	3.42702	0.5935

N represents the number of observations. The correlation R<sup>2</sup> measures the degree of the linear relationship between the independent variable (pitch/rolls) and the dependent variable (energy expenditure).  $\alpha$  represents the slope of the regression line. P represents the level of significance.

peak levels up to more than 70% in fishermen engaged in ordinary working tasks on board [3, 8, 9, 17], reflecting a rather tough occupation in terms of physical demands, which is quite far away from the conditions measured in the present study. In this study we have assessed the energy expenditure regardless of the fishermen activities. Future analyses of the collected data will take into account task orientated occupational variables.

The SenseWear system used has been developed and optimised through continuous updates and evaluations of algorithms for data analysis. Validations with invasive methods regarded as gold standards [15], e.g. the doubly labelled water stable isotope (2H,18O elimination) method and metabolic carts (oxygen and carbon dioxide inhalation and exhalation) have shown a good correlation between these methods [14, 18].

The gyroscope applied in this study was constructed specifically for the Danish Fishermen's Occupational Health Service and meant for the evaluation of the vessel's stability and behaviour in terms of heeling/pitch under different conditions of weather, waves and loads. The gyroscope has proved its value in terms of assessing the fishing vessel's stability, but there has been no further testing of its validity. Therefore, a certain degree of inaccurate exposure measurements cannot be excluded.

The present study is a pilot one and further investigations are needed to verify our observations. Fishing vessels will behave differently at sea depending on their construc-

tions, sizes, as well as catching methods and loads. For that reason, transferring the results into settings involving other vessels, fishing gear and catches may be limited. However, the studied, rather modern fishing vessels are likely to represent favourable conditions in terms of movements at sea and the ensuing influence on the fishermen's energy expenditure.

This study has focussed on the heeling and pitch, and ignored other potential effects on the fishermen's energy expenditure from movements of the deck, such as whole body vibration, the ships propulsion through the water, and the variations of physically demanding tasks at sea. These exposure factors are likely to contribute to the total energy expenditure.

Despite exposure factors not accounted for, our data suggest that exposure to heel and pitch less than 10° during 4-day voyages on contemporary fishing vessels in calm weather conditions has an impact on the fishermen by increasing their energy consumption, but without any observation of discomfort or negative health outcomes. The demonstration of significantly increased energy consumption by the SenseWear Pro 3 with even minor movements of the vessel, suggests the feasibility of measuring the fisherman's energy expenditure during staying and working aboard a fishing vessel in rough weather conditions and that this may be found to be high. Future assessment of the energy expenditure under such condition may show whether fishing today, e.g. with contemporary vessels and gear is as extreme as previously found.



## CONCLUSIONS

Our data suggests that even the heel and pitch in calm weather have an impact on the fishermen by increasing their energy consumption but without any observation of discomfort or negative health outcomes. This study has demonstrated the feasibility of the applied methods that should be repeated with larger samples and in rough weather.

## ACKNOWLEDGEMENTS

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