Collision Risk Assessment:
Humber Gateway Offshore Wind Farm

Report to E.ON Renewables

Institute of Estuarine and Coastal Studies
University of Hull

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For and on behalf of the Institute of Estuarine and Coastal Studies	
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1. INTRODUCTION

The development of wind farms has the potential to impact upon birds in a number of ways, including direct habitat loss, indirect habitat loss as a result of disturbance or displacement, and the risk of collision with turbine blades. Barrier effects to diurnal or seasonal avifaunal movements can also be a potential issue that requires addressing within any assessment programme. The majority of studies of wind farm-avifauna interactions have focused on the prediction of post-construction habitat loss and disturbance, as well as in some specific cases, barrier effects. Although predicting collision mortality has received comparatively little attention, collision probability models have been developed and used to predict collision mortality risk (Band *et al.*, 2005; Tucker, 1996; Desholm *et al.,* 2005).

The Band *et al.* (2005) model has been widely used in the wind energy industry both at offshore and onshore locations to assess the risk of avian collision with wind turbine structures. This collision model can be used to estimate the number of bird collisions over a period of time and includes both a stage for estimating the volume of birds passing through the area 'swept' by the turbine blades and a stage for calculating the probability of collision of birds flying through the area swept by the rotor blades. The probability of collision combined with the number of bird passes through the rotors then provides an estimate of the likely collision rate, assuming that the birds take no action to avoid collision. However, practice studies have shown that most birds have a very high degree of avoidance and as such, avoidance rates for key species are therefore incorporated at the final stage into the collision risk calculation in order to derive a more 'realistic' prediction of the numbers and main species of birds expected to collide with the development.

In Europe, it has been acknowledged that even collision-prone bird species avoid collisions with wind turbines on most (98-100%) occasions (Percival, 1998; Still *et al.*, 1996; Winkelman, 1992). Nevertheless, the significance of the impact of the species colliding with the structures is likely to be linked to the individual population dynamics for each species. This is because species with high adult survival rates and correspondingly low breeding rates, such as many seabird species and raptors, may be more susceptible to population impacts (and in particular mortality of adult breeding birds) than, for instance, passerine species. Longer lived species would be less able to rapidly replace any population losses within the population structure than species with a relatively high annual mortality and correspondingly short lifespan.

Therefore, it cannot necessarily be assumed that a high collision avoidance factor for a species will lead to a low or zero risk of collision impact mortality for that population, in particular for seabirds, waterfowl and other long-lived species including raptors, particularly when such movements can occur on a diurnal basis, for instance between roosting and feeding sites. As such, individual wind farm impacts need to be assessed in the context of their site specific associated populations of avifauna (i.e. species which interact with the area of the development, either moving through it or feeding, roosting, breeding etc. within it).

It is acknowledged that given the relative paucity of avian collision data for many species, habitats and site function, as well as the development stage of the technique, current collision risk models such as that used in this document are at best only a rough tool, capable of indicating a possible order of magnitude of impact, rather than specific impact levels. As such, the empirical data derived from them should be used appropriately within the context of these deficiencies and predicted outcomes treated with care.

E.ON Renewables has retained the Institute of Estuarine and Coastal Studies (IECS) at the University of Hull to assess the collision risk to birds posed by the proposed development of the Humber Gateway offshore wind farm. In order to quantify the risk of collision, 28 months of avifaunal data were collected during a ship-based seabird survey programme (September 2003 to December 2005). The monthly survey employed the standard seabird census techniques for use on a boat platform as described by Camphuysen *et al.* (2003), with additional information recorded during the surveys to provide data for the collision risk assessment i.e. flight height and flight directions.

These data, together with operational information for the turbines provided by E.ON Renewables, were then input into the same collision risk model as that agreed between Scottish Natural Heritage (SNH) and the British Wind Energy Association (BWEA) for the prediction of collision risk for birds at wind farms (Band *et al.*, 2005; Percival *et al.*, 1999). The risk of birds to collide with the turbines is to be calculated for a "realistic worst case scenario", in accordance with the "Rochdale Approach". This approach, followed by other disciplines in the assessment process, has been taken because the definitive project details have not yet necessarily been finalised, and a number of options remain under consideration at the time of report production. Additionally, a precautionary approach was followed by using a range of collision rates to estimate the potential collision risk with the wind farm. A list of species to be included in the collision risk assessment was agreed with Natural England.

The aims of the present study are therefore as follows:

- Establish the probability of collision for Diver spp., Skua spp., Northern Gannet, Tern spp. and Gull spp. observed to fly through the risk window.

- Determine the annual predicted level of collision mortality and its impact on the populations of the key avian species, in terms of additional rates of mortality to those populations.

The following text described the basic assumptions and methods used to calculate collision probability, on a species/group basis, together with species accounts and discussion as required.

2. METHODOLOGY

The Band *et al.* model employed in this study has been used as a standard tool to estimate the number of bird collisions with wind turbines over a period of time. The model employs two stages of calculation; the first stage estimating the overall number of birds passing the sweeping area of the rotor and the second stage calculating the probability of collision for birds passing the area swept by the rotor blades (Band *et al.*, 2005). Detailed descriptions for the use of the collision risk model are set in a guidance document available on the Scottish Natural Heritage website (Scottish Natural Heritage, 2000). The methodology followed in the Humber Gateway Collision Risk Assessment Document complies with the rules set out in the aforementioned guidance document.

2.1 Stage 1: Number of Birds Flying Through the Wind Farm

2.1.1 CALCULATION OF RISK WINDOW

The risk window was identified as being the width of the wind farm perpendicular to the general flight direction of birds through the development site, as observed from the survey programme, multiplied by the maximum turbine height. The flight directions and numbers of registrations from the survey programme are summarised in Figure 1 and indicate the main movement to occur along a north south axis.

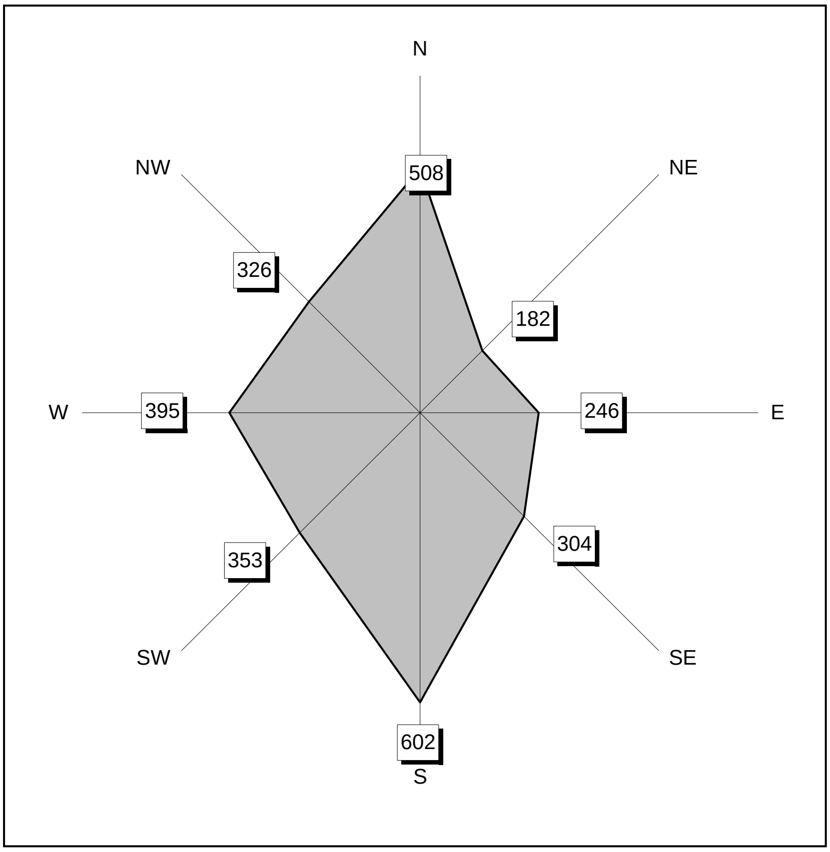

Figure 1: Flight Direction Rose (the grey area indicates the total numbers of birds recorded over the survey period)

2.1.2 NUMBERS OF BIRDS FLYING THROUGH THE RISK WINDOW PER ANNUM

Information on the flight height of birds through the wind farm survey area was derived from the data collected during the survey programme, and the proportion of birds flying within the altitude range of the rotor sweep was then calculated for a "Worst Case Realistic Scenario" identified, in accordance with the "Rochdale Approach". Of five layouts proposed by E.ON, ranging from the 3.6MW to up to 7.0MW, the 3.6MW layout was identified as being the worse case scenario in terms of the collision risk, as this scenario would involve the greatest numbers of turbines (83 turbines). Of the five layouts, although a single 7.0MW turbine has the greatest rotor sweep and the greatest probability of collision, the lower numbers of turbines in the 7.0MW layout (42 turbines), means that the total wind farm rotor swept area is less than the 3.6MW layout, and thus the risk of bird flying through the rotor swept area is lower. The 3.6MW layout was therefore used for the modelling.

Of the two rotor heights for the 3.6MW turbine: 76m above Mean High Water Spring (MHWS) and 83m above Lowest Astronomical Tide (LAT), the rotor height of 76m above MHWS was considered to be the worst case scenario, given that the majority of birds were observed to fly at an altitude of below 25m (Table 3), and thus at a greater risk of collision from this calculation. Rotor diameter as provided by E.ON was 107m for the 3.6MW scenario (E.ON, 2007).

The species identified as flying through the risk window of the wind farm survey area were incorporated into the collision risk assessment and numbers of transits per year were calculated. Observations totalling 129 hours were made during the survey programme. For the purpose of the calculations the number of birds in flight was expressed as birds per hour. The total number of movements for the year was then extrapolated assuming that there was no difference in diurnal and nocturnal activity (24 hours of movement), although this would be unlikely and as such an extreme worst case. All birds recorded in flight above within the rotor swept area (22.5m to 129.5m) were used in the collision risk modelling (Table 3), with all of those birds assumed to pass through the risk window (width of the wind farm to height of the turbines).

2.1.3 NUMBERS OF BIRDS PASSING THROUGH THE ROTORS

The second stage of the model set-up required the calculation of the rotor area as a proportion of the risk window ($A = N \times \pi R^2$ - where N is the number of rotors and R is the rotor radius), in order to identify the number of birds passing through a potential rotor swept area (number of birds passing through risk window x proportion occupied by rotors). The numbers of birds passing through the rotor area was derived for the 3.6MW wind farm layout identified above. In this instance the total rotor swept area of the layout exceeded the risk window by 15% due to turbine overlap in the risk window plane.

2.2 Stage 2: Probability of a Bird Being Hit When Flying Through the Rotor

2.2.1 PROBABILITY OF COLLISION

The probability of collision was calculated on the basis of the size of individual species moving through the site (both length and wingspan), the breadth and pitch of the turbine blades, the rotational speed of the turbine and the flight speed of the bird. Bird flight speeds were taken from Campbell and Lack (1985) and body measurements from Cramp (1998). A rotational speed of 13 revolutions per minute was considered to be the worst case scenario, as the probability of bird collision increases with the rotational speed, and this was applied to the model. The pitch of the blades is also variable and continuously re-positioned to take advantage of optimum conditions, e.g. depending on the direction of the wind. A pitch angle of 90 degrees was identified as being the worst case scenario for collision risk, and applied to the model. The chord width for the 3.6MW machine given by the constructor is 5m (E.ON, 2007), and this was used in the model set-up.

Based upon the set-up criteria outlined above, the probability of collision with a turbine blade can then combined with the expected number of bird passes through the rotor swept area, in order to produce an estimate of the likely collision rate.

2.2.2 COLLISION RATE

The probability of collision combined with the number of bird passes through the rotors produces an estimate of the likely collision rate, although this is without any 'avoidance behaviour' by an individual or flock being taken into account. As such, the inclusion of an avoidance factor into the data can offer a more realistic prediction of the probable number of avian collisions. The avoidance factor represents the proportion of birds which are likely to take effective avoiding action. For example a 50.00% avoidance factor would mean that five out of ten birds flying towards a wind farm would avoid the obstacle and five would enter the wind farm site and thus potentially be at risk of colliding with the turbines.

A precautionary approach was followed by using a range of collision factors (0.00%; 50.00%; 95.00%: 97.00% and 99.00%) to estimate the potential collision risk with the wind farm. Avoidance factors of 0.00% and 50.00% are clearly an extreme (and probably unrealistic) worst case scenario, but these avoidance factors serve to illustrate the magnitude of mortality that could potentially occur, particularly in potential worst case environmental conditions such as during periods of reduced visibility, strong wind etc.

In order to obtain a more realistic assessment of risk, modelling was also undertaken using what was considered a more ecologically reasonable avoidance factor (based on various published research studies undertaken on avifauna-wind farm interactions), which assumed an avoidance factor above 90.00%, this being conservatively based on data from existing collision studies. Avoidance rate data required in the collision risk assessment have been obtained by direct observation or calculations from a number of studies, with calculated avoidance based on recorded fatalities as a proportion of birds that fly toward an operational turbine. Fatality (dead bird) searches have been, and are, employed as an attempt to determine absolute numbers of birds killed through collisions with turbine operations (and other structures such as power lines), but in order to determine an avoidance rate it is also necessary to know the number of flights made by each species within the rotor swept area and the rate at which carcasses are naturally removed (due to natural scavenging etc.). By contrast, the avoidance rate obtained from direct observation is based on the behaviour of birds within the interaction zone of turbines at an operational wind farm. Tables 1 & 2 present avoidance rates which have been determined by research studies for a number of sites in Europe.

Tables 1 & 2, with the exception of the 87.00% avoidance factor reported at night (Winkelman, 1990), show avoidance factors derived from direct observation and fatality calculations are all above 97.00%, with the majority at 99.00% and above. These values can be considered as ecologically reasonable as these collision factors are derived from existing wind farms. However, the absence of detailed avoidance factors for offshore wind farms exhibiting similar environmental characteristics to those of the proposed Humber Gateway Offshore wind farm needs to be acknowledged when using the derived collision risk information. The paucity of such species and area specific data means that the application of a unique avoidance factor cannot currently be applied to the Humber Gateway development (or indeed almost any offshore development), although the use of appropriate surrogate data as applicable can to some extent offset these deficiencies, and where possible, these have been applied in the application of the model.

However, despite this, it has been considered prudent to apply a precautionary approach to the collision risk assessment procedures, and as such, the collision modelling runs have included a range of ecologically reasonable avoidance values i.e. 95.00%, 97.00% and 99.00% based on existing collision risk data as outlined in Tables 1 and 2.

Table 1: Direct Observation of Avoidance at Onshore/Coastal Wind Farms

Direct observation of avoidance	
Avoidance factor	**References**
100.00% - Barnacle, Greylag & White-fronted Geese (Sweden).	(Percival, 1998)
99.90% - Gulls (Belgium).	(Everaert *et al*., 2002, in Langston and Pullan, 2003)
99.80% - Common Terns (Belgium).	(Everaert *et al.,* 2002, in Langston and Pullan, 2003)
99.50% - Common Terns avoidance factor for power-lines.	(Henderson *et al.*, 1996)
99.00% - migrating birds- diurnal and nocturnal data - (Holland).	(Winkelman, 1992a)
97.50% - waterfowl and waders (Holland).	(Winkelman, 1992b, 1994)
87.00% - waterfowl and waders at night (Holland).	(Winkelman, 1990)

Table 2: Calculated Avoidance Factor at Onshore/Coastal Wind Farms

Calculated avoidance factor	
Avoidance factor	**References**
99.00% - avoidance reported for waterfowl, waders and Cormorants (i.e. recorded fatalities compared with measured utilisation rates).	(Percival, 2001)
99.0% - waterfowl, waders and Cormorants (UK).	(Percival, 2001)
99.00% - Common Eider, Herring Gull, Great Black-backed Gull and Black-headed Gull.	(Still *et al.,* 1999)
99.93% - Goose (USA). This is a mean of avoidance factors determined at four wind farm locations (Buffalo Ridge - 100.00%; Stateline - 99.91%, Klondike - 99.82%; and Nine Canyons - 100.00%)	(Fernley *et al*., 2006)

2.3 Stage 3: Annual Level of Collision Mortality and its Impact on Bird Populations

To place the numbers of predicted avian collisions into context and help determine if such mortality levels could be ecologically significant, estimates of the overall annual mortality of each species are given (BTO, 2007; Del Hoyo *et al*., 1992; Del Hoyo *et al.,* 1996), together with a calculation of additional mortality that the operation of the wind farm might have above natural mortality levels.

3. RESULTS

3.1 Predicted Numbers of Collisions Per Annum

The following outputs have been calculated using the methods outlined in the above sections. Detailed calculations using Red-throated Diver as an example can be found in Appendix 1 & 2.

3.1.1 NUMBERS OF BIRDS PASSING THROUGH THE ROTOR AREA

For the most representative results of potential collision risk, the data used for the model are based on actual observations within the area of the wind farm, i.e. numbers and flight heights, enabling the extrapolation and estimation of the numbers of birds which may collide with the wind farm rotors. Numbers and flight band heights of birds passing through the rotor sweep are shown in Table 3. A graphical representation of flight heights is also given in Appendix 3.

The proposed wind farm site which consists of 83 turbines, presents a risk assessment 22.5m to 129.5m. Predictions of the numbers of birds expected to pass through the rotor area are given in Table 4. The most abundant species predicted to move through the total rotor area is Mew Gull with a total of 15,107 individuals expected through the total rotor area per annum. Large numbers of Great Black-backed Gull (6,653), Black-Legged Kittiwake (4,937) and Northern Gannet (2,357) would also be expected to pass through the total rotor area each year.

It must be emphasised that at this stage of the modelling sequence, the figures represent the numbers of birds which may collide with the rotors, with the probability of a bird being hit when flying through the rotor area yet to be incorporated into the calculation.

Table 3: Flight Height Bands of Birds Flying Through the Rotor Sweep

Flight Height Bands	RH	GX	NX	AC	LU	BH	CM	KI	HG	GB	LB	HG/LB/GB	TE	CN	AE	CN/AE
0m-2m	2	70		1	4		2	15		4	7			3		1
2m-10m	7	87		3	14	7	67	58	5	13		1	11	34		16
10m-15m		30			4	1	79	43	3	11		2	24	4	2	
15m-25m	4	18		1	4	4	147	50	14	41	14		10	1	1	10
25m-50m		12	1				46	13	5	38		5	2	1		
50m-100m										6		1				
100m-200m																
Total	13	224	2	5	26	12	353	194	32	116	22	7	47	43	3	27
No Flying through rotor sweep	4	30	1	1	4	4	193	63	19	85	14	6	12	2	1	10

RH: Red-throated Diver; GX: Northern Gannet; NX: Great Skua; AC: Arctic Skua; LU: Little Gull; BH: Black-headed Gull; CM: Mew Gull; KI: Black-legged Kittiwake; HG: Herring Gull; GB: Great Black-backed Gull; LB: Lesser Black-backed Gull; HG/LB/GB: Gull sp (Herring Gull/Lesser Black-backed Gull/ Great Black-backed Gull; TE: Sandwich Tern; CN: Common Tern; AE: Arctic Tern; CN/AE: Commic Tern (Common Tern/Arctic Tern).

3.1.2 PROBABILITY OF BIRDS BEING HIT WHEN FLYING THROUGH THE ROTOR

This stage computes the probability of a bird being hit when making a transit through a rotor. The probability depends on the size of the bird (both length and wingspan), the breadth and pitch of the turbine, the rotation speed of the turbine, and the flight speed of the bird.

The probabilities of bird collision given in Table 4 were calculated for the worst case scenario, as descried in previous sections and in accordance with the Rochdale Approach. Detailed calculations are found in Appendix 2.

Table 4: Numbers of Birds Passing Through the Rotor Area per Annum and Probability of a Bird Being Hit.

Species	No of birds	Probability
Red-throated Diver	314	13.43%
Northern Gannet	2,357	15.24%
Great Skua	78	17.29%
Arctic Skua	78	16.68%
Little Gull	313	20.17%
Black-headed Gull	313	20.85%
Mew Gull	15,107	21.27%
Black-legged Kittiwake	4,931	13.52%
Herring Gull	1,487	16.34%
Great Black-backed Gull	6,653	19.00%
Lesser Black-backed Gull	1,096	22.37%
Gull sp.	469	19.91%
Sandwich Tern	943	20.08%
Common Tern	157	25.66%
Arctic Tern	79	25.70%
Commic Tern	783	25.66%

3.1.3 NUMBER OF BIRDS PREDICTED TO COLLIDE WITH THE WIND FARM

3.1.3.1 Red-throated Diver (*Gavia stellata)*

Table 5 shows numbers of expected collisions to be of 3 birds per annum using an avoidance factor of 95.00% (Table 4).

Table 5: Number of Red-throated Diver Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	43	22	3	2	1

All values rounded to the nearest whole number

3.1.3.2 Northern Gannet *(Morus bassanus)*

An avoidance factor of 95.00% resulted in a total of 18 individuals per year encountering the turbines (Table 6).

Table 6: Number of Northern Gannet Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	360	180	18	11	4

All values rounded to the nearest whole number

3.1.3.3 Great Skua *(Catharacta skua)*

The low numbers of passes through the site by Great Skua resulted in the low number of collisions per annum, as shown in Table 7. A realistic avoidance rate of 99.00% predicted approximately 1 death every 10 years.

Table 7: Number of Great Skua Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	14	7	1	1	1

All values rounded to the nearest whole number

3.1.3.4 Arctic Skua (*Stercorarius parasiticus*)

Based on the extrapolation of actual observations, the Band *et al.* model predicts a collision rate of less than one bird every year using a 95.00% avoidance factor. As with Great Skua, a more realistic avoidance factor of 99.00% predicted approximately 1 death every 10 years (Table 8).

Table 8: Numbers of Arctic Skua Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	14	7	1	1	1

All values rounded to the nearest whole number

3.1.3.5 Little Gull *(Larus minutus)*

The Band *et al.* model predicts for the proposed site a very low number of collisions (4 birds killed every year assuming a 95.00% avoidance factor). The Table 9 gives the expected collisions for Little Gull for a range of avoidance factors.

Table 9: Numbers of Little Gull Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	64	32	4	2	1

All values rounded to the nearest whole number

3.1.3.6 Black-headed Gull *(Larus ridibundus)*

Table 10 gives the expected number of collision for Black-headed Gull for a range of avoidance factors.

Table 10: Numbers of Black-headed Gull Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	66	33	4	2	1

All values rounded to the nearest whole number

3.1.3.7 Mew Gull *(Larus canus)*

Mew Gull were the most numerous bird recorded in all surveys flying at turbine height. An avoidance factor of 95.00% when applied to predictions assumes an extreme mortality rate of 161 birds per annum (Table 11).

Table 11: Numbers of Mew Gull Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	3,214	1,607	161	97	33

All values rounded to the nearest whole number

3.1.3.8 Black-legged Kittiwake *(Rissa tridactyla)*

Based on the numbers of bird passes each year through the area swept by the blades, the Band *et al*. model predicts a total of 34 collisions per year (based on a 95.00% avoidance factor).

Table 12: Numbers of Black-legged Kittiwake Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	667	334	34	20	7

All values rounded to the nearest whole number

3.1.3.9 Herring Gull (*Larus argentatus)*

The results from the model indicate a maximum of 13 collisions per annum if Herring Gull had an avoidance factor of 95.00%. Based on a more realistic avoidance rate of 99.00%, the model predicts a total of 3 collisions per annum (Table 13).

Table 13: Numbers of Herring Gull Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	243	122	13	8	3

All values rounded to the nearest whole number

3.1.3.10 Great Black-backed Gull *(Larus marinus)*

Based on a total of 6,653 individuals passing through the total rotor area each year, it is calculated that 64 birds would collide with the turbine if the Great Black-backed Gull had an avoidance rate of 95.00% (Table 14).

Table 14: Numbers of Great Black-backed Gull Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	1,262	631	64	38	13

All values rounded to the nearest whole number

3.1.3.11 Lesser Black-backed Gull *(Larus fuscus)*

Table 15 gives the expected number of collisions to range between 3 individuals (avoidance rate of 99.00%) to 13 individuals (avoidance factor of 95.00%).

Table 15: Numbers of Lesser Black-backed Gull Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	246	123	13	8	3

All values rounded to the nearest whole number

3.1.3.12 Unidentified Large Gull (Larus argentatus/fuscus/marinus)

Unidentified large Gulls (i.e. Herring Gull, Great Black-backed Gull and Lesser Black-backed Gull) are predicted by the Band *et al*. model to collide with the wind turbines at a rate of 5 individuals per year (avoidance factor of 95.00%).

Table 16: Numbers of Unidentified Large Gull Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	94	47	5	3	1

All values rounded to the nearest whole number

3.1.3.13 Sandwich Tern (*Sterna sandvicensis*)

Based on a 95.00% avoidance factor, the output of the calculations predicts 10 birds to collide with the turbines. A more realistic avoidance factor of 99.00% would result in a total of 2 collisions per annum.

Table 17: Numbers of Sandwich Tern Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	190	95	10	6	2

All values rounded to the nearest whole number

3.1.3.14 Common Tern *(Sterna hirundo)*

Based on a total of 157 individuals passing through the rotor area each year, it is calculated that 3 birds would collide with the turbines if the Common Tern had an avoidance factor of 95.00% (Table 18).

Table 18: Numbers of Common Tern Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	41	21	3	2	1

All values rounded to the nearest whole number

3.1.3.15 Arctic Tern (*Sterna paradisea*)

Even by using an avoidance factor of 95.00%, the collision mortality figure given in the Table 19 is of very low magnitude, with a total of 2 birds per annum calculated as colliding with the wind turbines (95.00% avoidance factor).

Table 19: Numbers of Arctic Tern Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	21	11	2	1	1

All values rounded to the nearest whole number

3.1.3.16 Commic Tern (*Sterna hirundo/paradisea*)

Commic Terns (i.e. undistinguished Arctic and Common Terns) are expected to collide with the turbines at a rate of 11 individuals per year, if the two species had an avoidance factor of 95.00% (Table 20).

Table 20: Numbers of Commic Tern Predicted to Collide per Annum

Avoidance Rate	0.00%	50.00%	95.00%	97.00%	99.00%
Numbers of Collisions	201	101	11	7	3

All values rounded to the nearest whole number

3.2 Annual Level of Collision Mortality and its Impact on Bird Populations

The results of the collision risk assessment for each species are given in Tables 21 to 22. These have been expressed as the predicted number of collisions per year, based on avoidance rates of 95% and 99%. For each scenario, the additional mortality is examined in the context of the British summer population (breeding birds). To put this into context and help determine if such mortality levels would be significant, annual adult mortality rates are given (BTO, 2007; Del Hoyo *et al*., 1992; Del Hoyo *et al*., 1996), with the percentage difference that the predicted additional mortality from the proposed wind farm operation would produce, also calculated.

The potential for casualties is greatest amongst Mew Gull, Great Black-backed Gull, Black legged Kittiwake and Northern Gannet, and the impact of the added mortality induced by the proposed wind farm was shown to be the greatest for Great Black-backed Gull. The 64 extra deaths per year estimated using a 95.00% avoidance factor in the prediction equates to an increase in mortality of 1.14 in the British wintering population (Table 21). If the Great Black-backed Gull had an avoidance factor of 99.00%, the increase in mortality would be less than 0.5% (Table 22). Great Black-backed Gull feature a relatively high adult survival rate and a correspondingly low breeding rate, and the species is thus generally more susceptible to additional mortality, as they may be slower to replace any population losses. Additionally, the Great-black Backed Gull featured a small wintering population and thus mortality by collision accounts for a greater proportion than in a larger population size such as Black-legged Kittiwake.

Mew Gull were also subject to large numbers of collisions per annum, but this only resulted in a 0.06% the increase in the mortality of the British Mew Gull wintering population (Table 21). When put in the context of the British population, the numbers of collisions for Black-legged Kittiwake and Northern Gannet would represent a very small increase in mortality i.e. a less than 0.05% increase in mortality assuming a 95.00% avoidance factor (Table 21).

The Tern group (i.e. Sandwich Tern, Common Tern, and Commic Tern) were found to be subject to relatively low collision rates with the operation of the proposed wind farm site. However for Sandwich Tern, when this is put in the context of the British population, an increased mortality of 0.32% (95.00% avoidance factor) and 0.06% (99% avoidance factor) is generated (see Tables 21 and 22). The Red-throated Diver population is similarly predicted to be subject to a low number of collisions with the additional mortality caused by collision with the wind turbine equating to an increase in natural mortality of 0.39% (assuming an avoidance factor of 95.00%).

For the remainder of the avian species encountered on the site during the monitoring programme, the increase in mortality rates from the operation of the wind farm have been calculated as being below 0.15%.

Table 21: Annual Level of Collision Mortality Based on a 95.00% Avoidance Factor in the Context of the British Population

Species	Predicted Collisions per annum	British population [1]	% Additive mortality [2]	Annual mortality	% Increase in mortality [3]
Red-throated Diver	3	4,850 (W)	**0.06%**	16%	**0.39%**
Northern Gannet	18	454,000 (S)	**0.00%**	8%	**0.05%**
Great Skua	1	19,200 (S)	**0.01%**	7%	**0.07%**
Arctic Skua	1	4,200 (S)	**0.02%**	16%	**0.15%**
Little Gull	4	N/A	**N/A**	20%	**N/A**
Black-headed Gull	4	276,000 (S)	**0.00%**	24%	**0.01%**
Mew Gull	161	1,800,000 (W)	**0.01%**	14%	**0.06%**
Black-legged Kittiwake	34	7,600,000 (S)	**0.00%**	17%	**0.00%**
Herring Gull	13	450,000 (S)	**0.00%**	7%	**0.04%**
Great Black-backed Gull	64	80,000 (W)	**0.08%**	7%	**1.14%**
Lesser Black-backed Gull	13	500,000 (S)	**0.00%**	9%	**0.03%**
Gull sp.	5	492,000 (S)	**0.00%**	8%	**0.01%**
Sandwich Tern	10	26,000 (S)	**0.04%**	12%	**0.32%**
Common Tern	3	24,000 (S)	**0.01%**	10%	**0.13%**
Arctic Tern	2	106,000 (S)	**0.00%**	10%	**0.02%**
Commic Tern	11	130,000 (S)	**0.01%**	10%	**0.08%**

Note[1] S (Summer Population). **Note [2:]** % additive mortality = collisions per annum / British population. **Note [3]** % increase mortality= % additive mortality/annual mortality

Table 22: Annual Level of Collision Mortality Based on a 99.00% Avoidance Factor in the Context of the British Population

Species	Predicted Collisions per annum	British population [1]	% Additive mortality [2]	Annual mortality	% Increase in mortality [3]
Red-throated Diver	1	4,850 (S)	**0.02%**	16%	**0.13%**
Northern Gannet	4	454,000 (S)	**0.00%**	8%	**0.01%**
Great Skua	1	19,200 (S)	**0.01%**	7%	**0.07%**
Arctic Skua	1	4,200 (S)	**0.02%**	16%	**0.15%**
Little Gull	1	N/A	**N/A**	20%	**N/A**
Black-headed Gull	1	276,000 (S)	**0.00%**	24%	**0.00%**
Mew Gull	33	1,800,000 (W)	**0.00%**	14%	**0.01%**
Black-legged Kittiwake	7	7,600,000 (S)	**0.00%**	17%	**0.00%**
Herring Gull	3	450,000 (S)	**0.00%**	7%	**0.01%**
Great Black-backed Gull	13	80,000 (W)	**0.02%**	7%	**0.23%**
Lesser Black-backed Gull	3	500,000 (S)	**0.00%**	9%	**0.01%**
Gull sp.	1	492,000 (S)	**0.00%**	8%	**0.00%**
Sandwich Tern	2	26,000 (S)	**0.01%**	12%	**0.06%**
Common Tern	1	24,000 (S)	**0.00%**	10%	**0.04%**
Arctic Tern	1	106,000 (S)	**0.00%**	10%	**0.01%**
Commic Tern	3	130,000 (S)	**0.00%**	10%	**0.02%**

Note[1] S (Summer Population). **Note [2]:** % additive mortality = collisions per annum / British population. **Note [3]** % increase mortality= % additive mortality/annual mortality

4. DISCUSSION

Although difficult to determine accurately, given the caveats surrounding the derivation of the Band *et al* model discussed in Sections 1 and 2, it is considered that the collision rates estimated from the above studies allow a reasonable indication of the order of magnitude of bird mortality levels likely to be encountered at the proposed Humber Gateway Wind Farm site, based upon data derived from 28 ship-based seabird surveys. Extrapolation from these data to provide an annual level of collision mortality should however be considered as indicative only, and to that end, as a precautionary approach a conservative range of avoidance rates were used.

However, this is unrealistic as birds undertake avoidance behaviour in most conditions. Using a range of ecological avoidance rates, which have been observed or calculated at existing wind farms offered a more realistic approach to operation of the collision risk model. Most studies conducted in Europe have indicated the level of avoidance rate to be above 99.00%. Run with a 99.00% avoidance factor, the increase in the level of annual mortality predicted to result from the proposed development was below 0.25% in the context of British population (winter or summer when appropriate).

However, given the size of the relative populations and natural population dynamics, the outcomes from the model and associated population impact calculations would suggest that although the elevated mortality rates were of interest, they would not lead to excessive impacts within the wider population and ecological context for the respective species.

A more realistic scenario might be to use the avoidance rates from the coastal wind farm at Blyth with reported avoidance rates for the bird assemblage at the site above 99.00%. It is anticipated that such avoidance rates when applied to the predictions would produce a nett reduction in the numbers of collisions. However considering the limited numbers of real case studies at coastal locations, whilst the use of a 99.00% avoidance factor is considered to be an appropriate approach that is consistent with likely realistic avoidance rates, for the precautionary principle adopted throughout this study a figure of 95% might be considered a precautionary worst case.

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6. APPENDICES

Appendix 1: Red-throated Diver Collision Risk Model for the Humber Gateway Offshore Wind Farm - 3.6 MW Scenario.

1. Wind farm characteristics

Rotor diameter: 107m
Rotor height: 76m
No Turbines: 83
Numbers of Blades: 3

2. Red-throated Diver characteristics

Bird Speed: 17 m/sec
Bird Length: 0.61m
Wing Span: 1.11m

3 Number of birds flying through the wind farm

3.1 Calculation of risk window

Risk window = width of wind farm perpendicular to the general flight direction * maximum turbine height
Risk window = 5000m*129.5m
Risk window = 647500 m^2

3.2 Numbers of birds flying through risk window per annum

Number of birds per hour sampled = Total No recorded flying at rotor height through wind farm / No of hours sampled
No of birds per hour sampled = 4/129
No of birds per hour sampled = 0.031007752

Number per day = No per hour * length of day in hours
Number per day= 0.031007752 * 24
Number per day= 0.744186047

Number per annum = No per day * No of days per year
Number per annum = 0.744186047 * 365
Number per annum = 271.627907

3.3 Numbers of birds passing through the rotors

3.3.1 Proportions of risk window occupied by rotors

Rotor swept area = No of turbines*(rotor dimater/2) ^{2}*π
Rotor swept area = 83 *(107/2) ^{2}*3.14
Rotor swept area =746337.9565
Rotor proportion = Rotor swept area/risk window
Rotor proportion = 746337.9565/647500 m^2
Rotor Proportion = 1.152645493

3.3.2 Number of birds passing through the rotor area per annum

No passing through rotors = No per annum flying through risk window * Rotor Proportion
No passing through rotors = 271.627907* 1.152645493
No passing through rotors = 314.3042125

4. Probability of a bird being hit when flying through the rotor

See appendix 2

5. Predicted numbers of collision per annum (no avoidance rate)

No of collision per annum = No passing through rotors * Probability of collision
No of collision per annum = 314.3042125 * 13.43%
No of collision per annum = 42.20744508

Appendix 2: Calculation of Collision Risk for Red-throated Diver Passing Through the Rotor Area - 3.6MW Scenario

K: [1D or [3D] (0 or 1)	1	
NoBlades	3	
MaxChord	5	m
Pitch (degrees)	90	
BirdLength	0.61	m
Wingspan	1.11	m
F: Flapping (0) or gliding (+1)	0	
Bird speed	17	m/sec
RotorDiam	107	m
RotationPeriod	4.60	sec
Bird aspect ratioo: β	0.54	

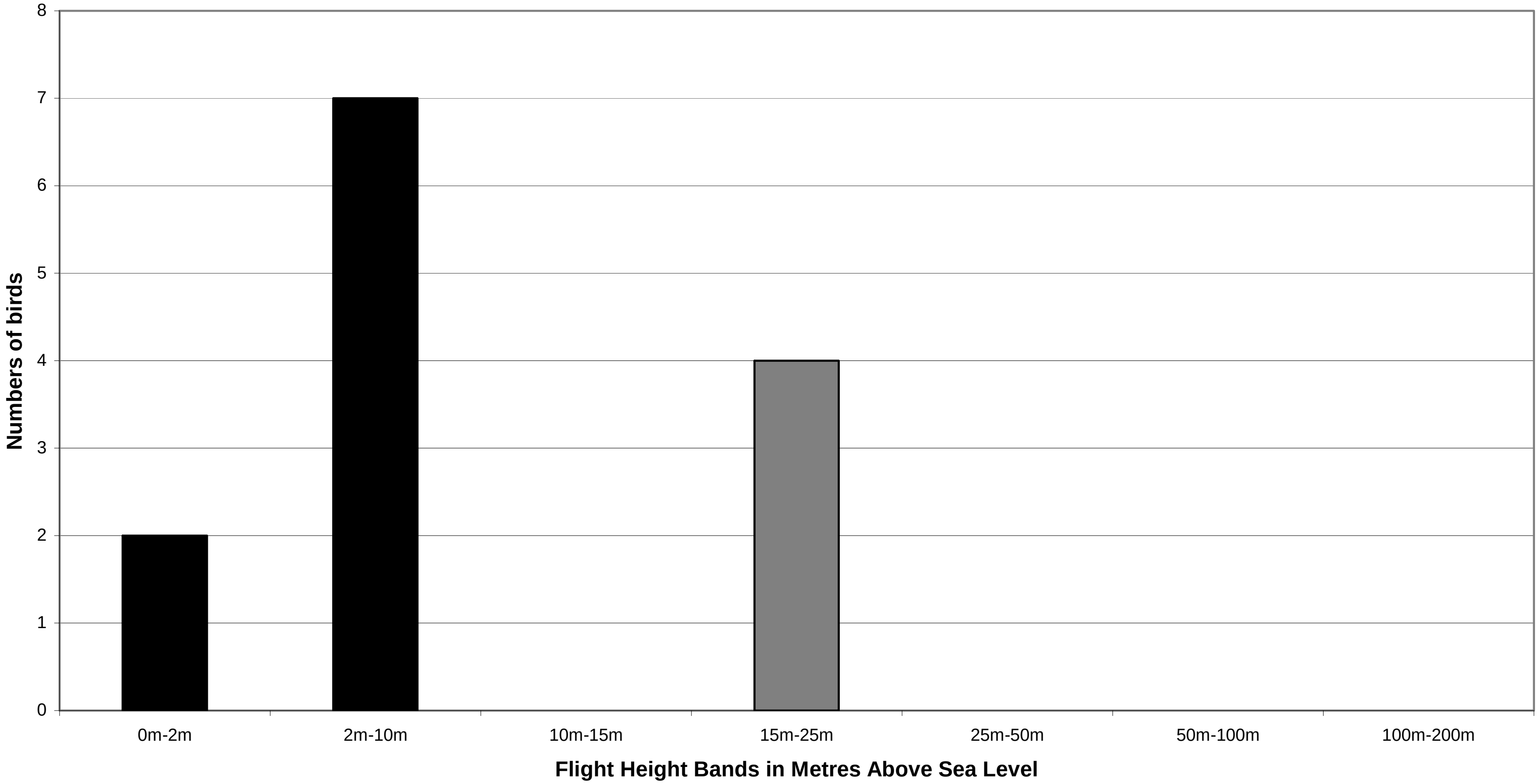
Calculation of alpha and p(collision) as a function of radius

			Upwind:			Downwind:		
r/R radius	c/C chord	α alpha	collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r
0.025	0.575	9.31	13.20	0.51	0.00063	13.20	0.51	0.00063
0.075	0.575	3.10	6.32	0.24	0.00182	6.32	0.24	0.00182
0.125	0.702	1.86	5.57	0.21	0.00267	5.57	0.21	0.00267
0.175	0.860	1.33	5.78	0.22	0.00388	5.78	0.22	0.00388
0.225	0.994	1.03	6.12	0.23	0.00528	6.12	0.23	0.00528
0.275	0.947	0.85	5.67	0.22	0.00598	5.67	0.22	0.00598
0.325	0.899	0.72	5.29	0.20	0.00659	5.29	0.20	0.00659
0.375	0.851	0.62	4.94	0.19	0.00711	4.94	0.19	0.00711
0.425	0.804	0.55	4.63	0.18	0.00754	4.63	0.18	0.00754
0.475	0.756	0.49	4.39	0.17	0.00800	4.39	0.17	0.00800
0.525	0.708	0.44	4.15	0.16	0.00836	4.15	0.16	0.00836
0.575	0.660	0.40	3.91	0.15	0.00863	3.91	0.15	0.00863
0.625	0.613	0.37	3.67	0.14	0.00881	3.67	0.14	0.00881
0.675	0.565	0.34	3.44	0.13	0.00890	3.44	0.13	0.00890
0.725	0.517	0.32	3.20	0.12	0.00889	3.20	0.12	0.00889
0.775	0.470	0.30	2.96	0.11	0.00880	2.96	0.11	0.00880
0.825	0.422	0.28	2.72	0.10	0.00861	2.72	0.10	0.00861
0.875	0.374	0.27	2.48	0.10	0.00833	2.48	0.10	0.00833
0.925	0.327	0.25	2.24	0.09	0.00796	2.24	0.09	0.00796
0.975	0.279	0.24	2.00	0.08	0.00750	2.00	0.08	0.00750

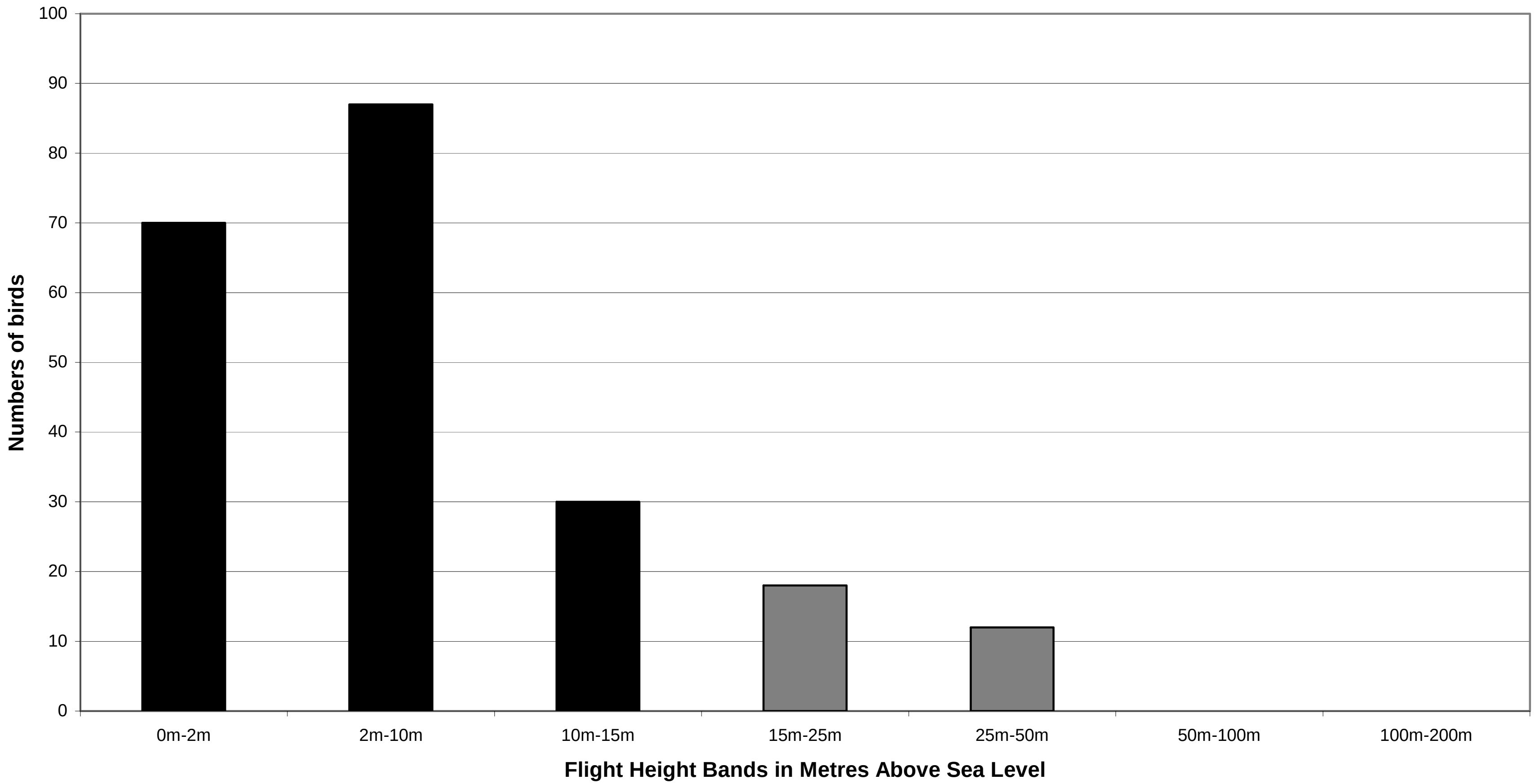
Overall p(collision) = **Upwind** **13.4%** **Downwind** **13.4%**

Average **13.4%**

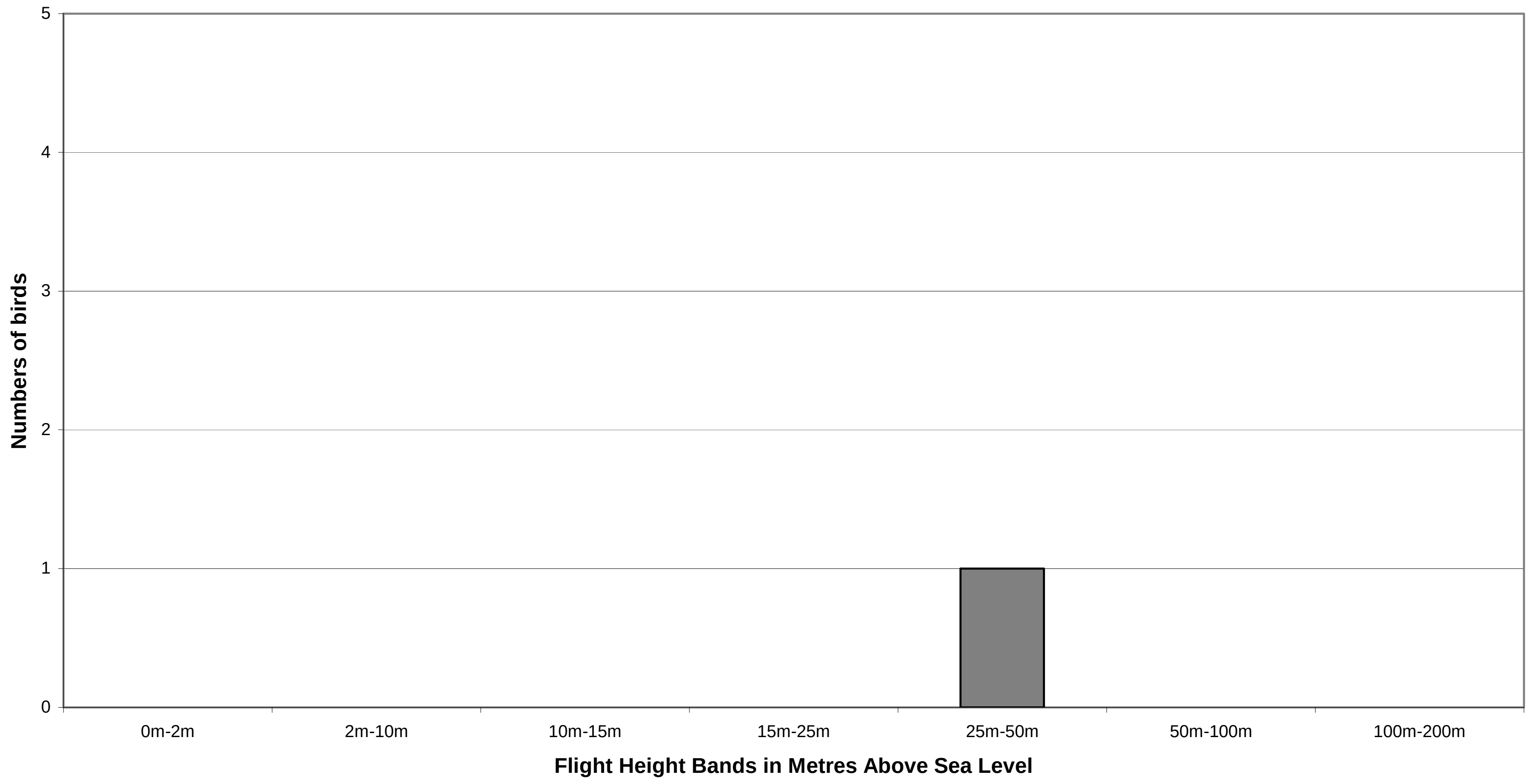
Appendix 3: Species Flight Heights



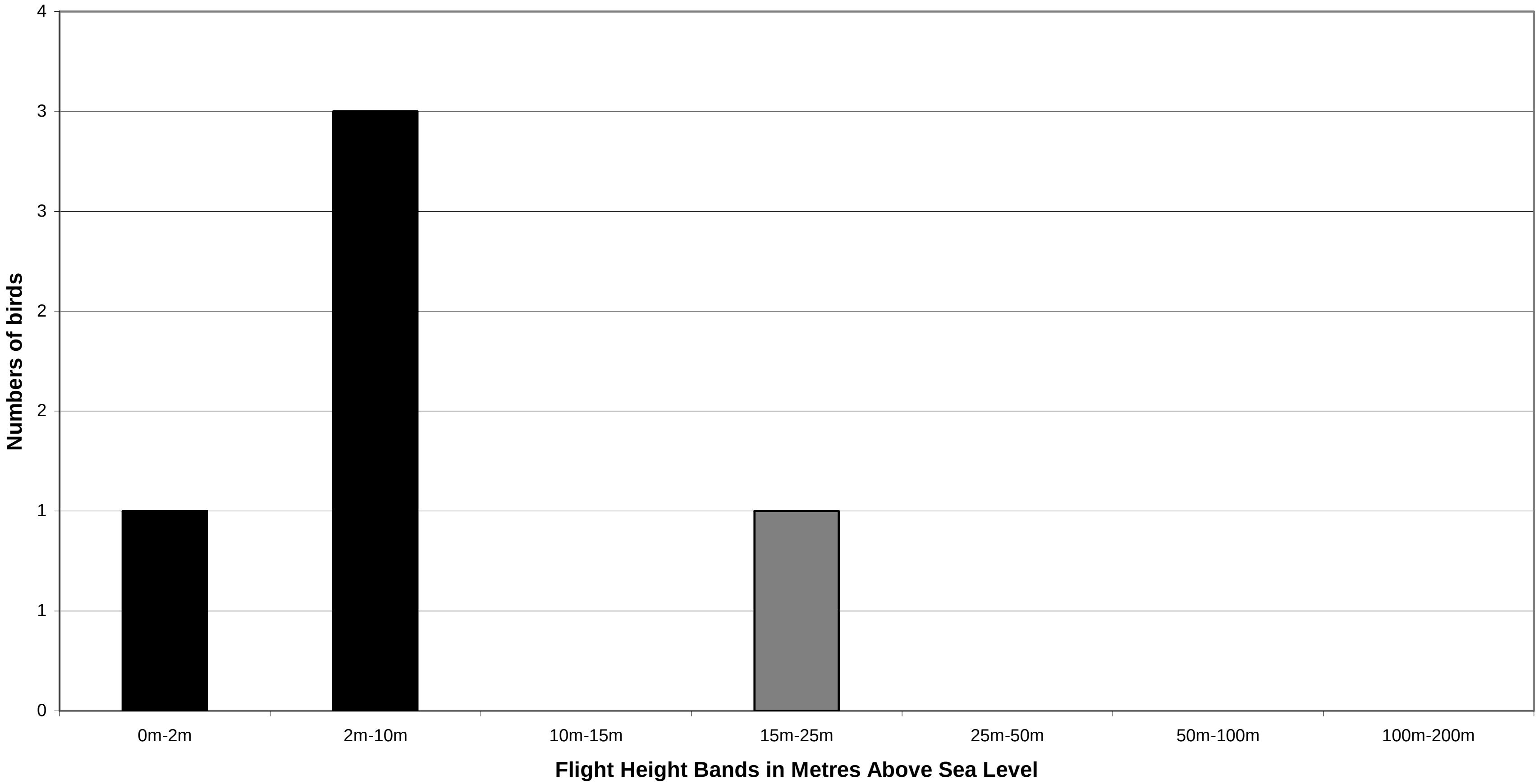
Appendix 3.1: Red-throated Diver Flight Heights (the grey shading represents birds flying within the rotor sweep)



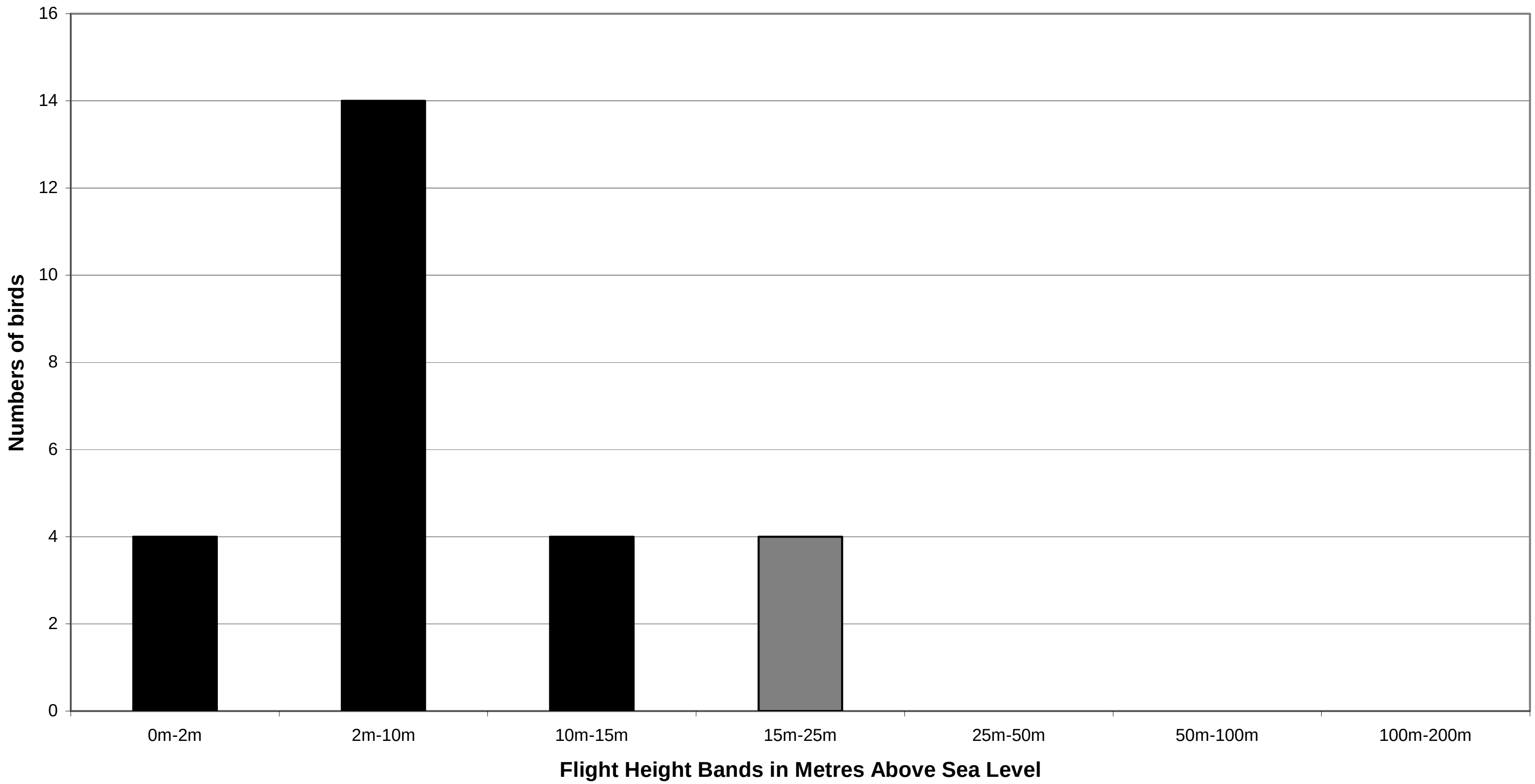
Appendix 3.2: Northern Gannet Flight Heights (the grey shading represents birds flying within the rotor sweep)



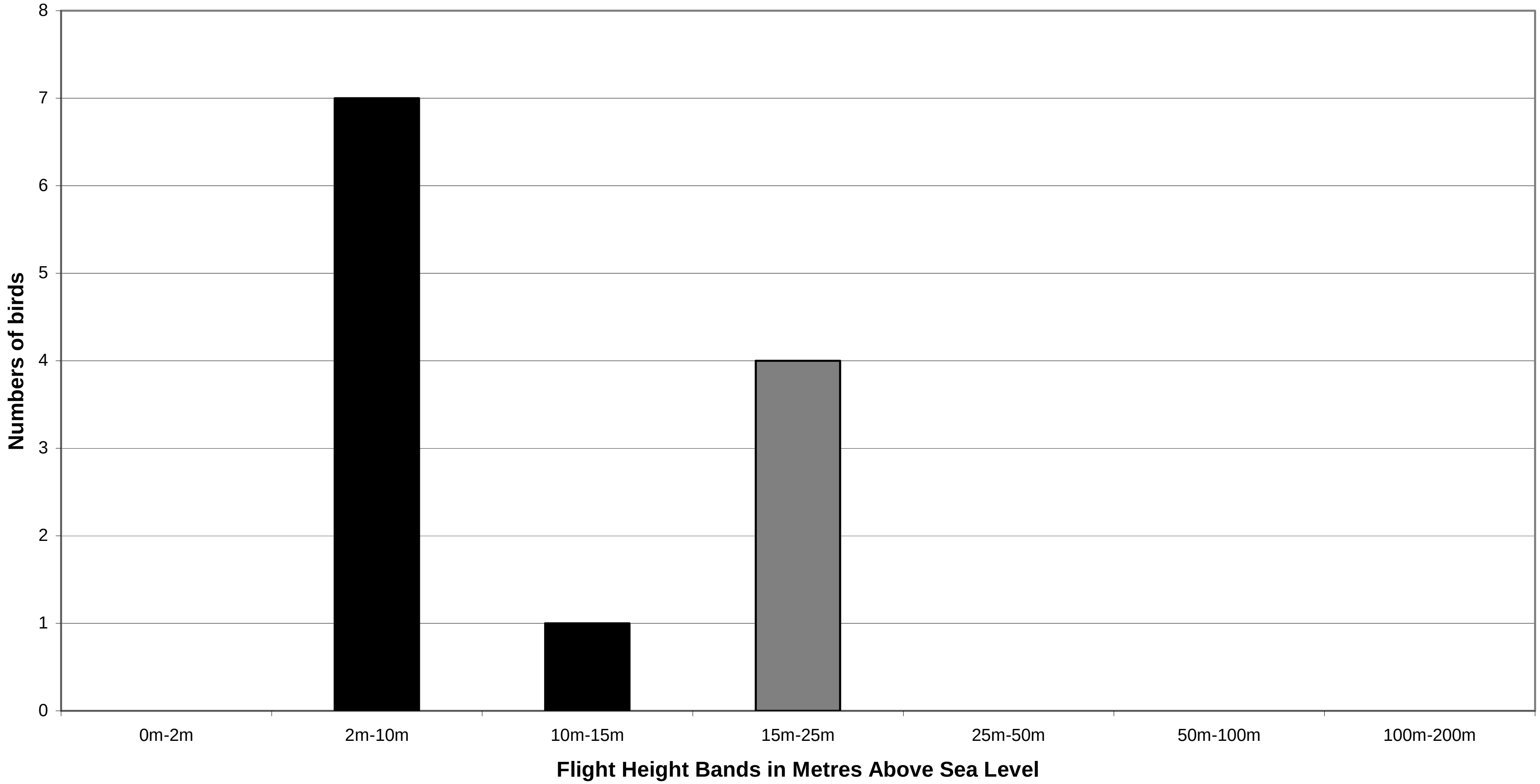
Appendix 3.3: Great Skua Flight Heights (the grey shading represents birds flying within the rotor sweep)



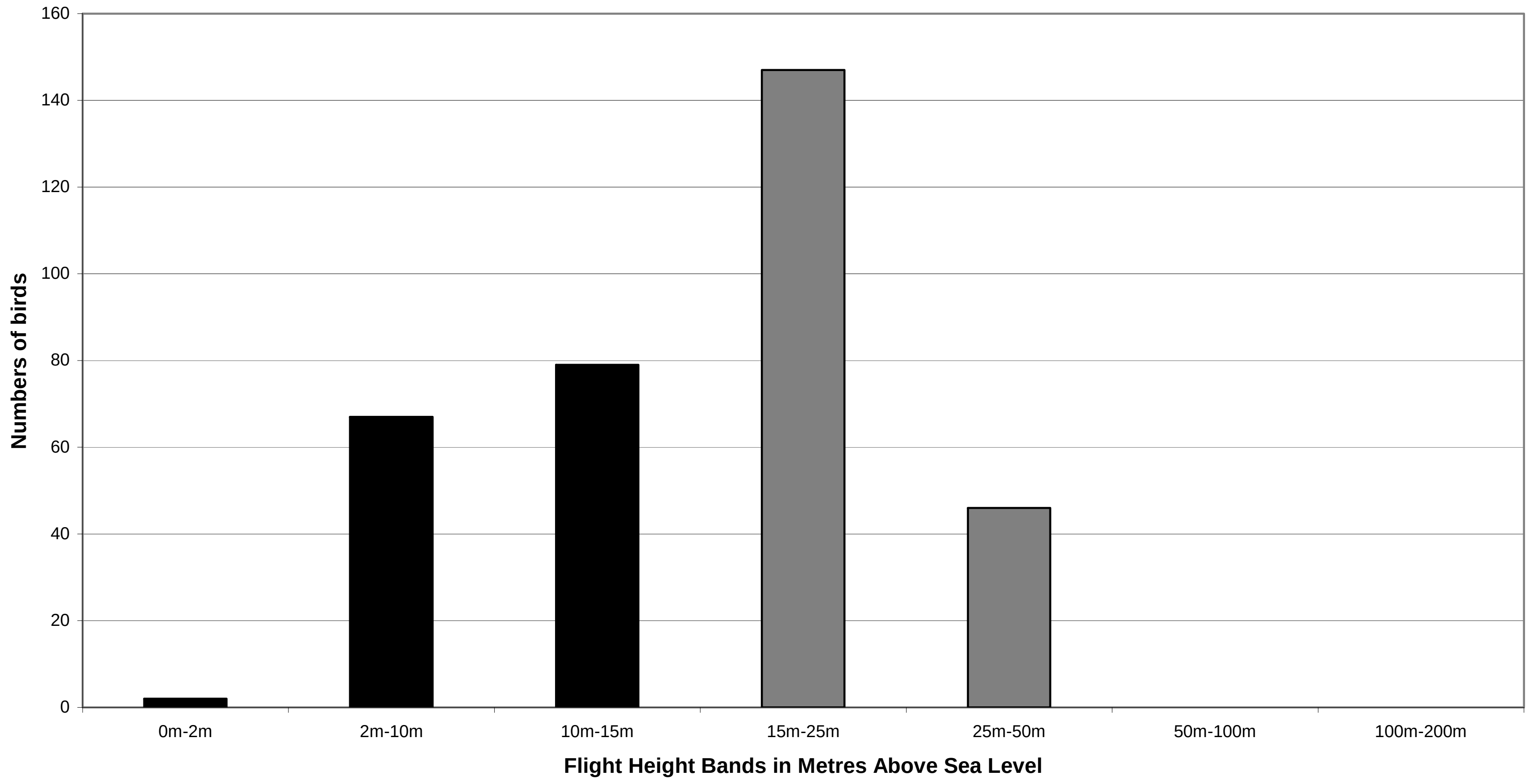
Appendix 3.4: Arctic Skua Flight Heights (the grey shading represents birds flying within the rotor sweep)



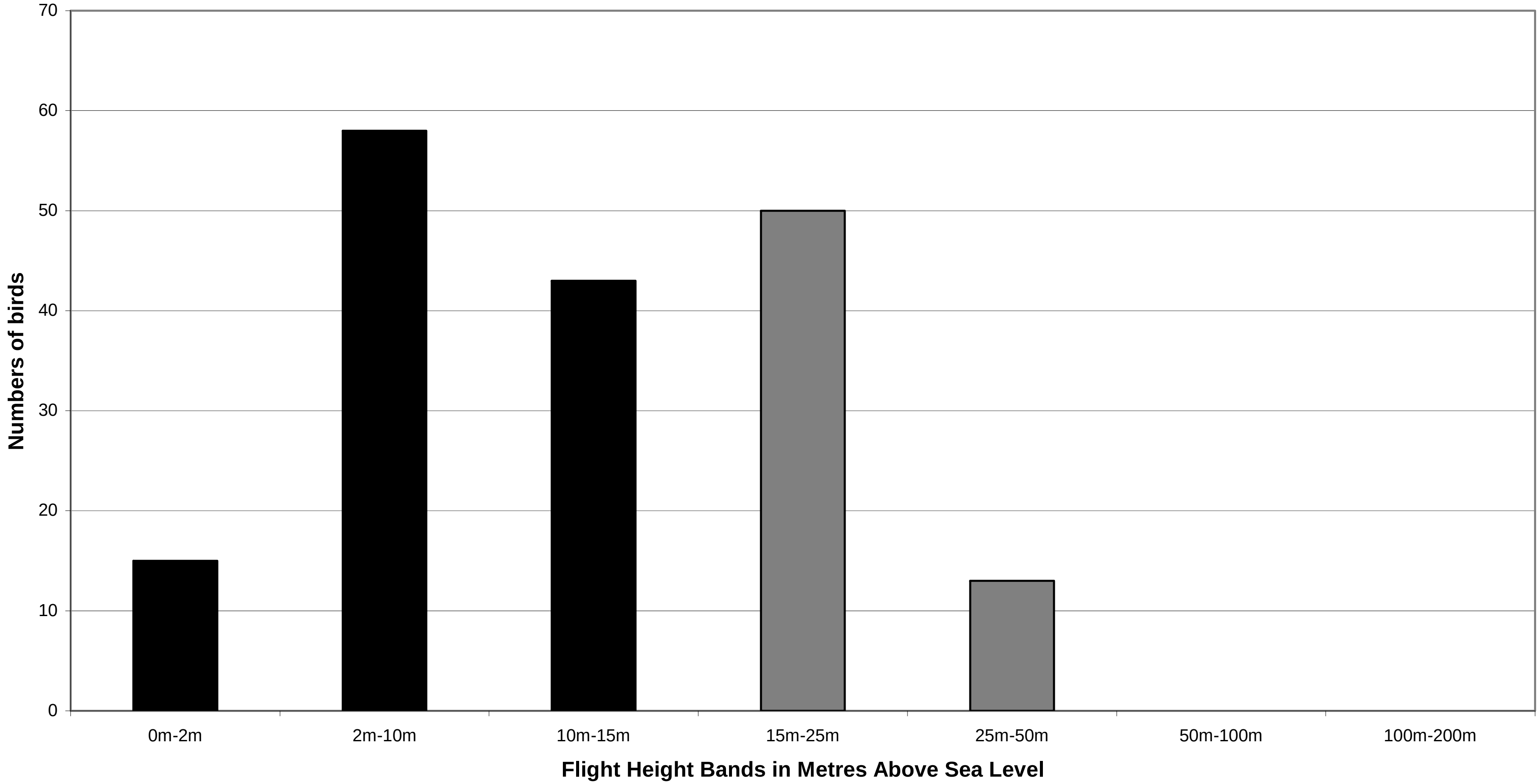
Appendix 3.5: Little Gull Flight Heights (the grey shading represents birds flying within the rotor sweep)



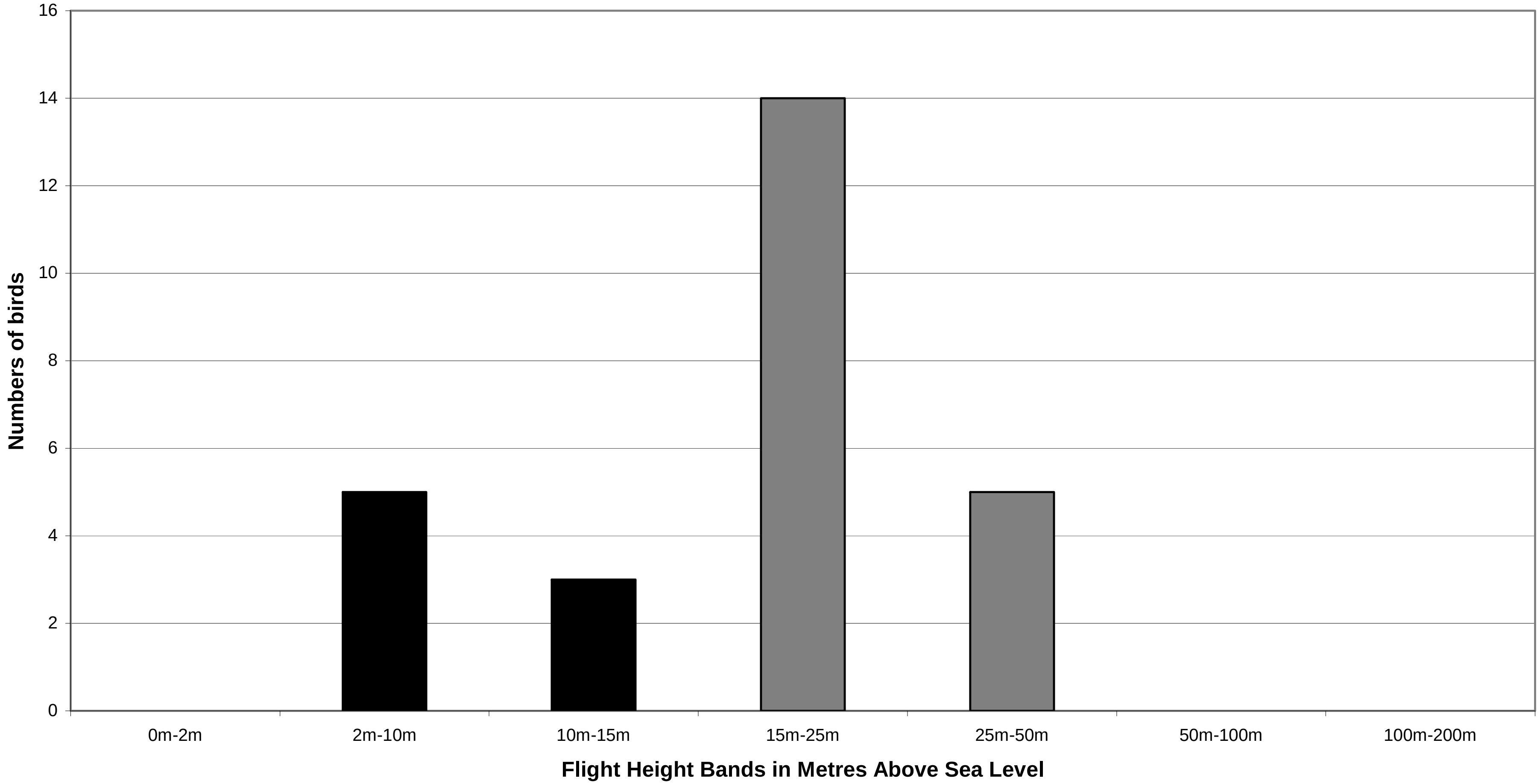
Appendix 3.6: Black-headed Gull Flight Heights (the grey shading represents birds flying within the rotor sweep)



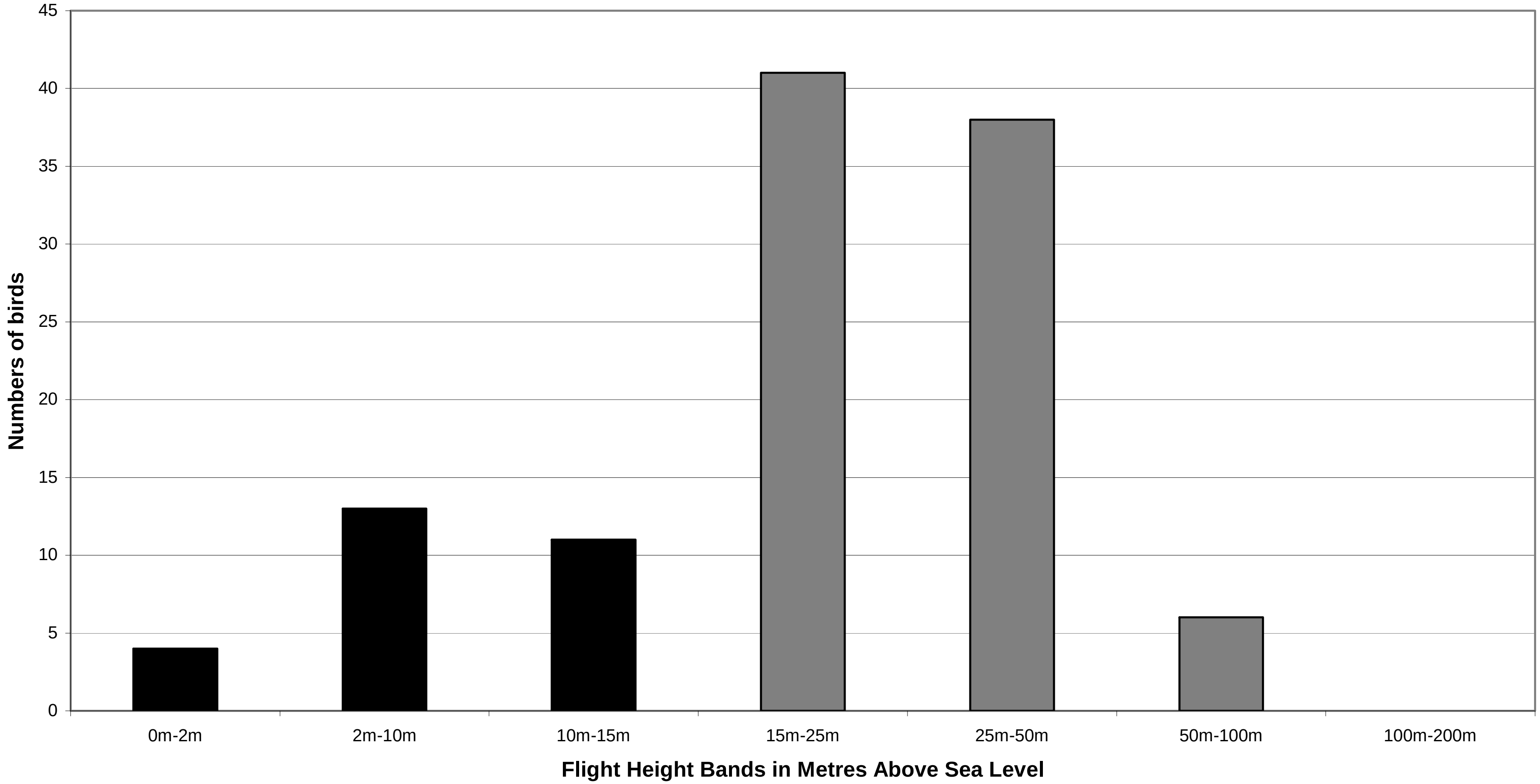
Appendix 3.7: Mew Gull Flight Heights (the grey shading represents birds flying within the rotor sweep)



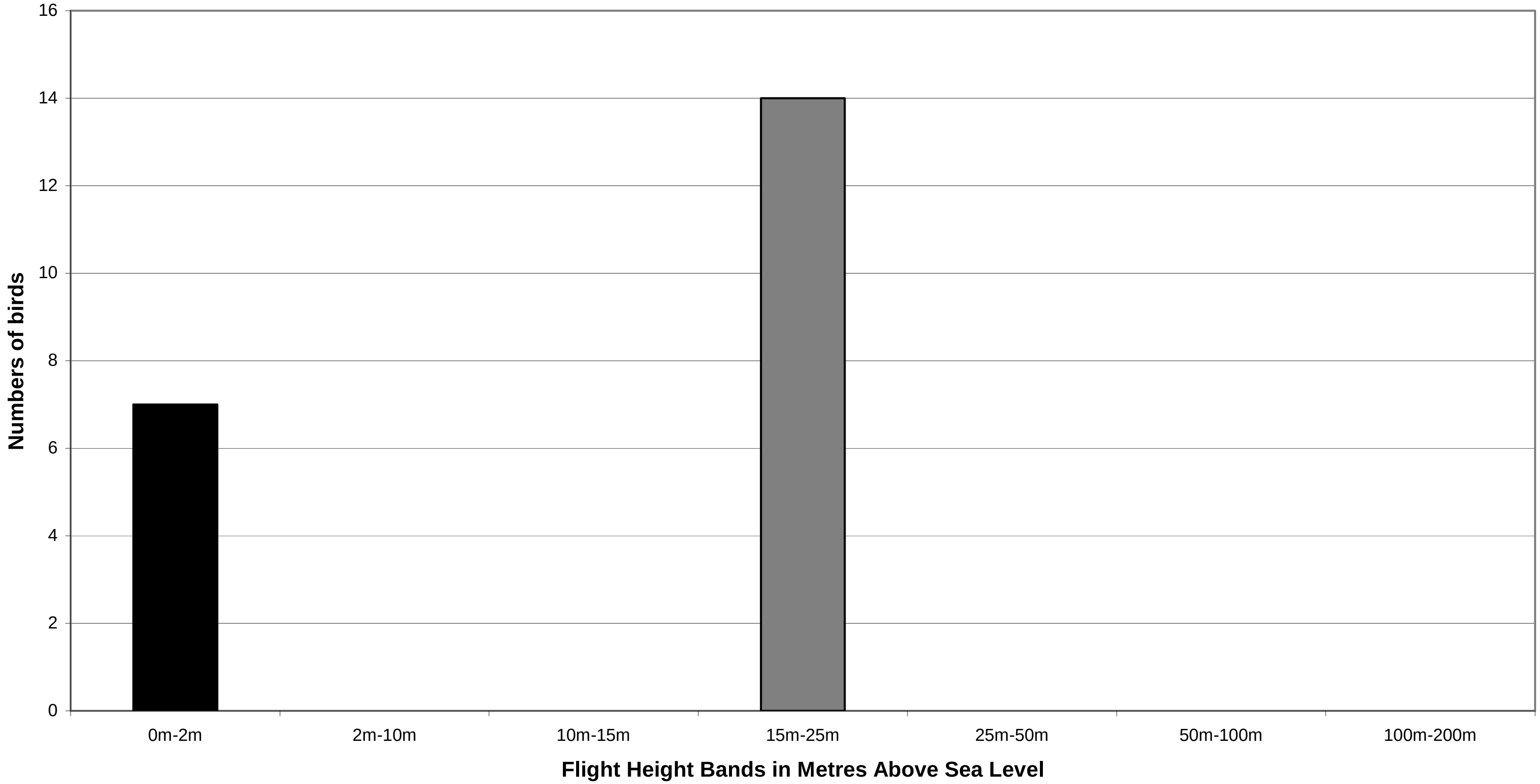
Appendix 3.8: Black-legged Kittiwake Flight Heights (the grey shading represents birds flying within the rotor sweep)



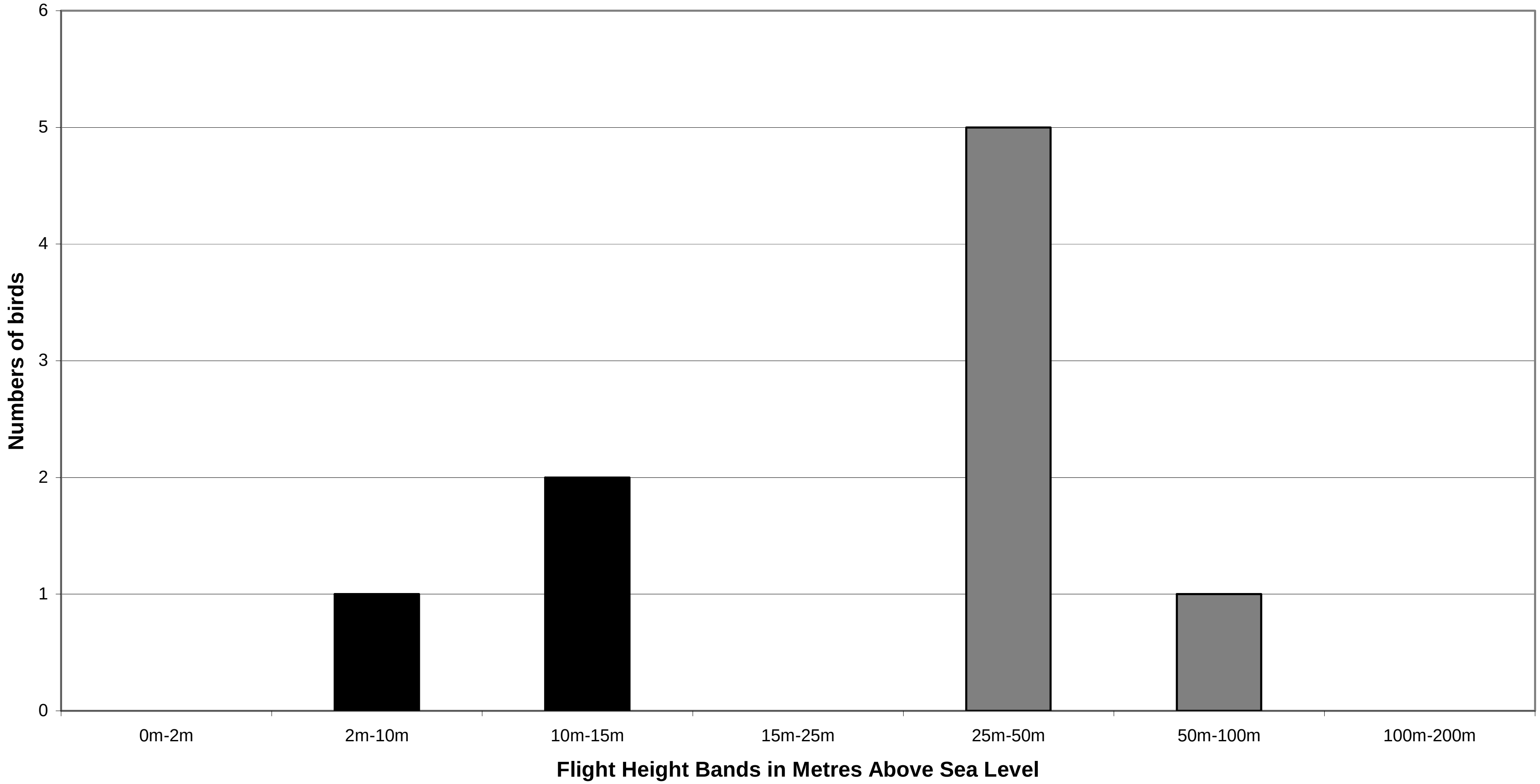
Appendix 3.9: Herring Gull Flight Heights (the grey shading represents birds flying within the rotor sweep)



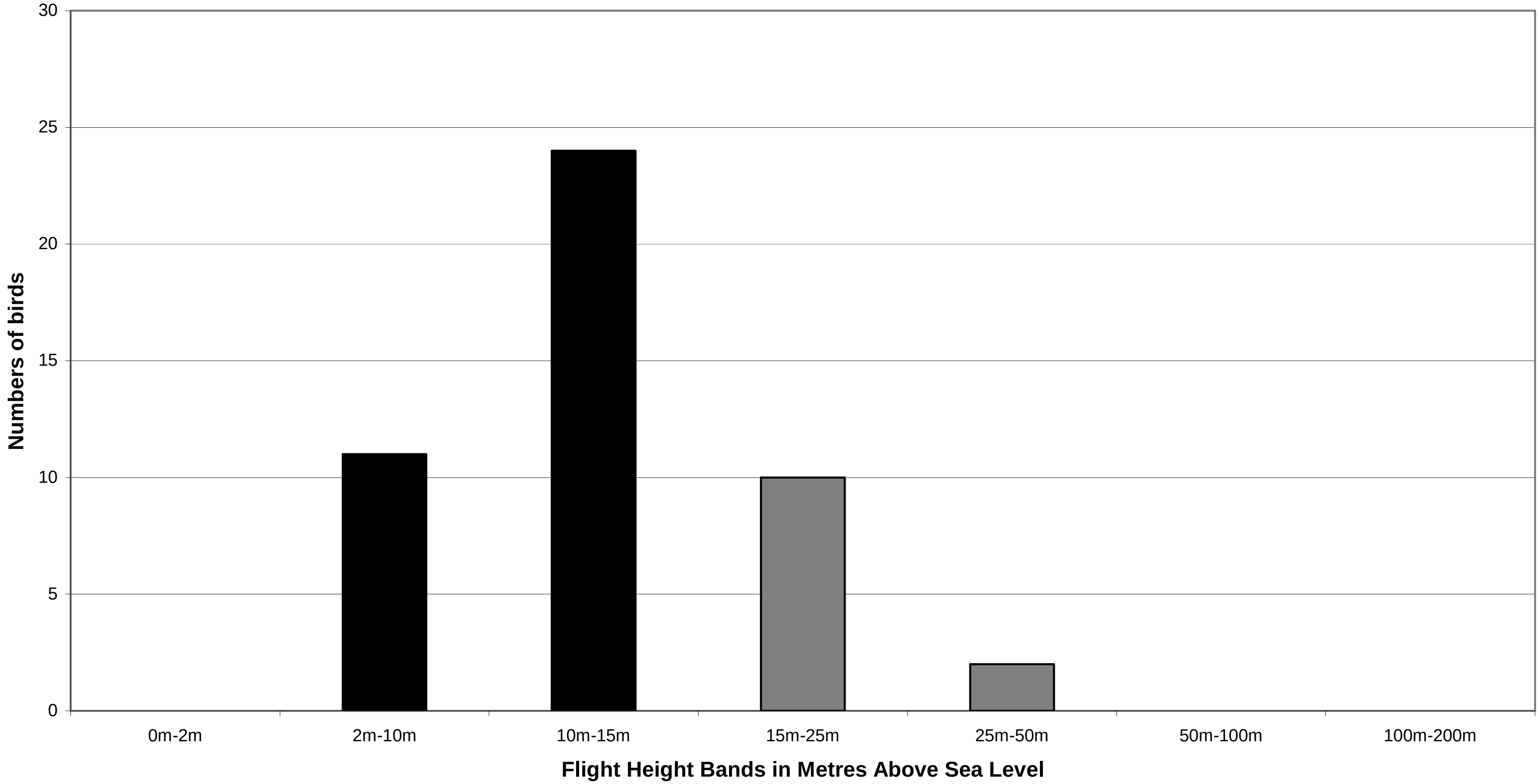
Appendix 3.10: Great Black-backed Gull Flight Heights (the grey shading represents birds flying within the rotor sweep)



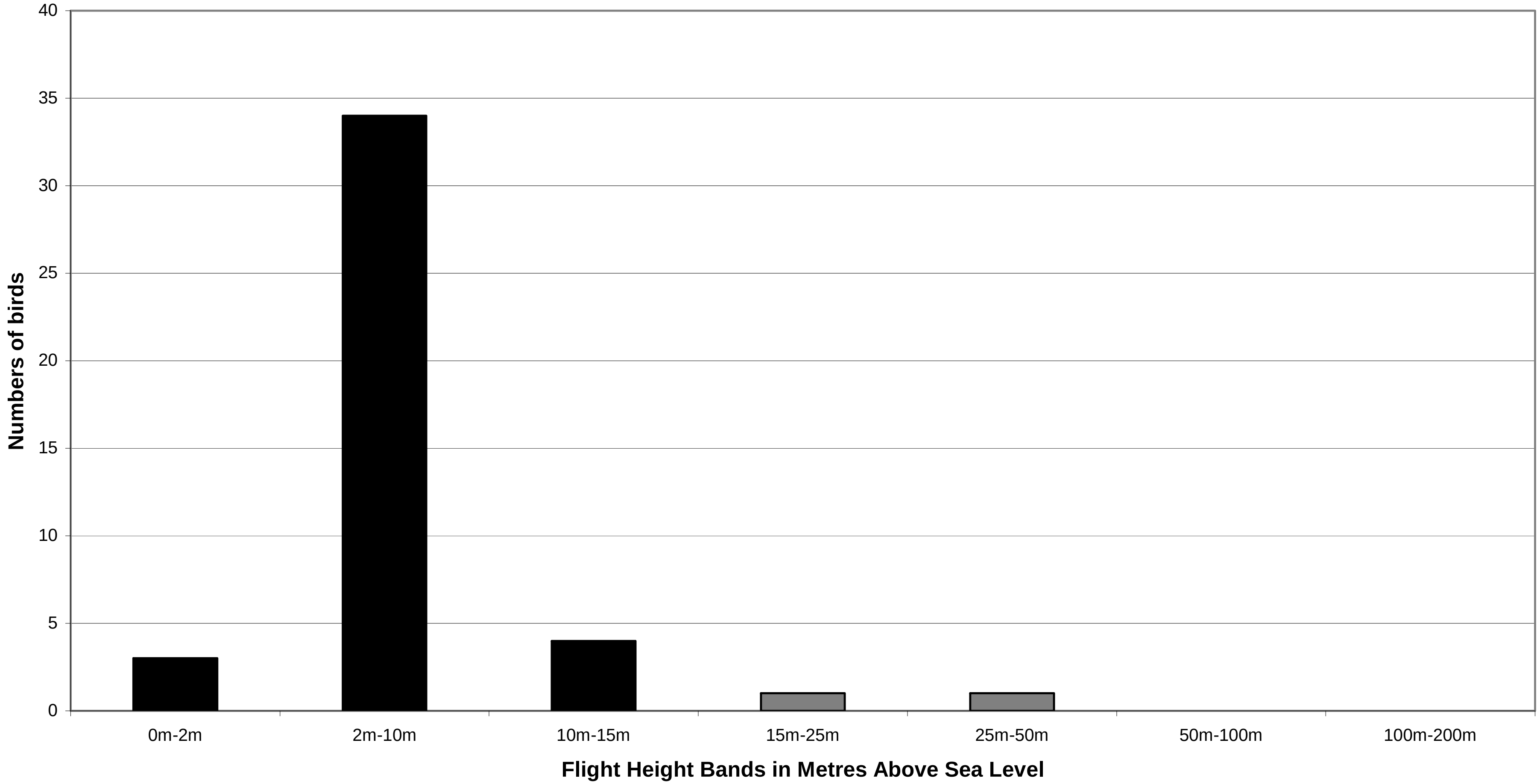
Appendix 3.11: Lesser Black-backed Gull Flight Heights (the grey shading represents birds flying within the rotor sweep)



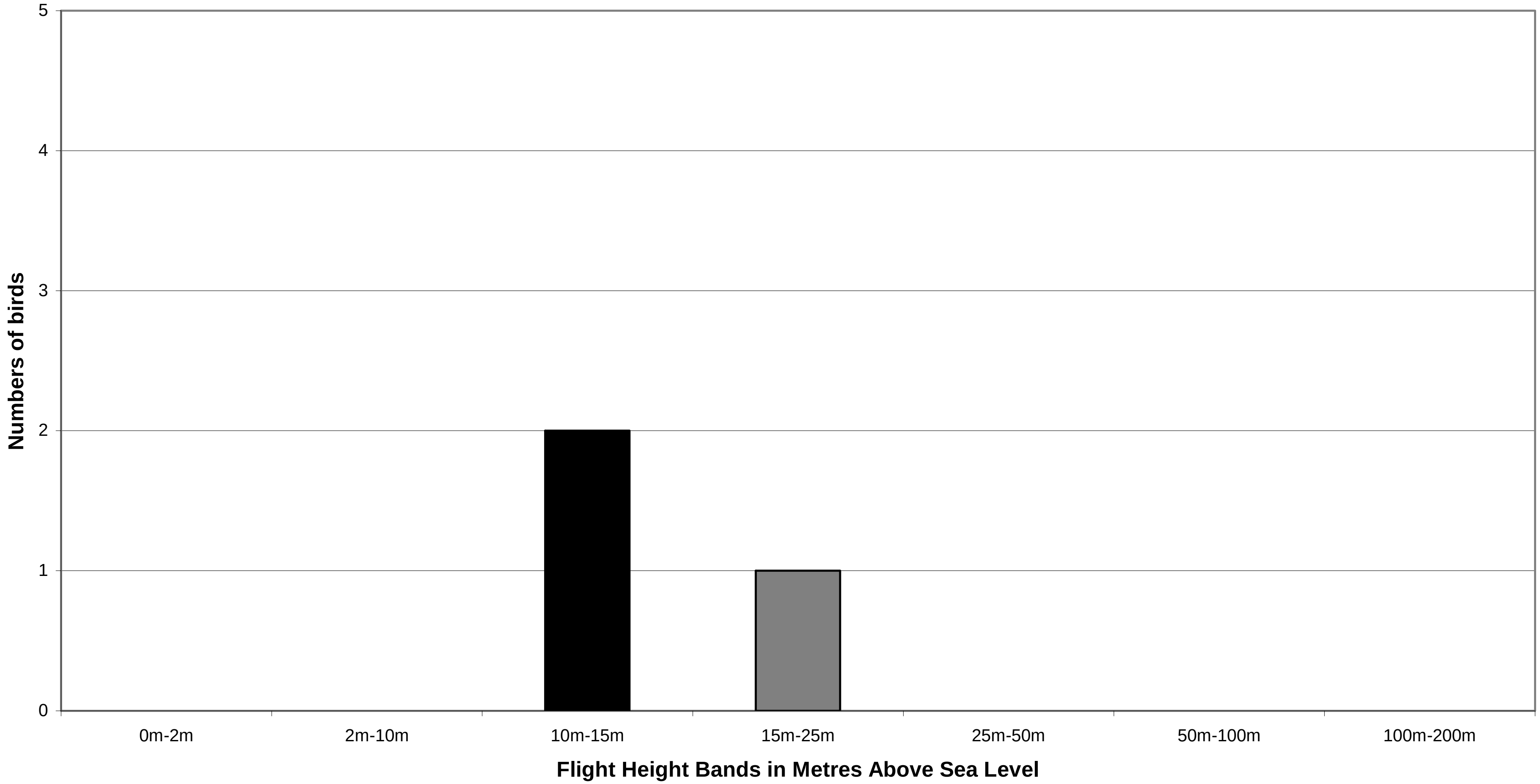
Appendix 3.12: Gull spp. Flight Heights (the grey shading represents birds flying within the rotor sweep)



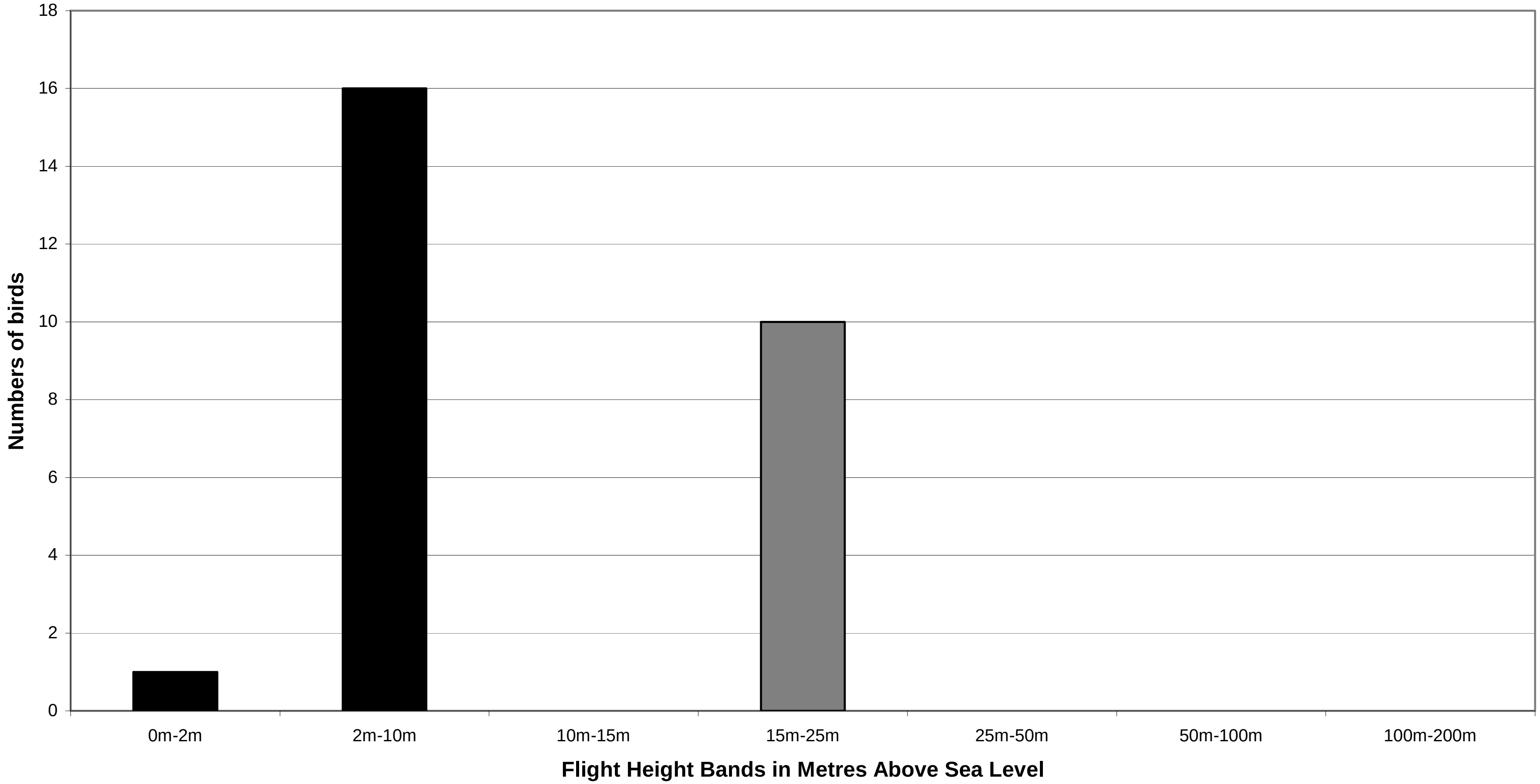
Appendix 3.13: Sandwich Tern Flight Heights (the grey shading represents birds flying within the rotor sweep)



Appendix 3.14: Common Tern Flight Heights (the grey shading represents birds flying within the rotor sweep)



Appendix 3.15: Arctic Tern Flight Heights (the grey shading represents birds flying within the rotor sweep)



Appendix 3.16: Commic Tern Flight Heights (the grey shading represents birds flying within the rotor sweep)