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## A STUDY OF THE RISK OF COLLISION WITH POWER LINES BY COMMON TERNS AT SHOTTON STEEL WORKS, NORTH WALES


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# 1. EXECUTIVE SUMMARY


1.At Shotton Steel Works, North Wales, 200 pairs of Common Terns breed within the industrial complex and each journey from the breeding colony to the estuary means that the birds must negotiate two spans of power lines, yet their vulnerability to collisions with power lines is unknown. The construction of a new 400 kV power line close to the ternery provided an opportunity to observe this vulnerability. The study reported here therefore investigated the risk of collision with power lines in relation to the stage of the breeding season and time demands on adults, the age of birds, the significance of distance between the power lines and the breeding colony and climatic variables such as wind speed.

2.Systematic observations were made of terns journeying to and from the estuary during four phases of the breeding season (courtship, incubation, nestling and juvenile). In order to quantify the potential removal rate of bird casualties by predators, bird corpses were placed underneath the power lines and recounted after two, five and 14 days. Surveys were also made of the ground beneath the power lines in order to look for casualties.

3.There was a greater than three-fold increase in the frequency of return journeys made by terns from courtship to the nestling phase. This increase coincided with an increase in the proportion of terns which passed under or between the wires of both power lines during the nestling phase of the breeding season. Terns also flew closer, on average, to the top earth wire during the nestling and fledging phases than during the courtship or incubation phases.

4.Juvenile terns flew consistently closer to wires than adults with most juvenile crossings being less than 1 m above the top wire. Only 7% of adults were this close.

5.Only two Common Tern casualties were found beneath wires (during the nestling phase) representing only 0.4% of the colony population. The removal rate of corpses was very low, only around 6% in 14 days. Therefore mortality rate of terns due to collisions with wires was also considered to be very low.

6.The impact of the power lines on the mortality rate of Common Terns at Shotton is discussed. A review of the literature on bird collisions and transmission lines is included in the report.

## 2. LITERATURE REVIEW - BIRD MORTALITY DUE TO POWER LINES

For over 50 years there has been documented evidence of the threat that power lines may pose to birds (Borell 1939, Walkinshaw 1956). Birds have been at risk either from collision with power lines (Scott *et al.* 1972) or, in larger species, from electrocution where their wing-span can connect two parallel wires (Fielder & Wissner 1980, Orloff *et al.* 1992). In the last 27 years, many studies in both Europe and America have attempted to assess the magnitude of the problem (Ogilvie 1967, Perrins & Reynolds 1967, Cornwell & Hochbaum 1971, Krapu 1974, Anderson 1978, Avery 1978, Meyer 1978, James & Haak 1979, Benson 1980, Beaulauier 1981, Faanes 1981, Faanes 1987, McCray *et al.* 1987), but accurate quantification has always been exacerbated by the difficulties in producing true measures of casualty rate because of the problems associated with the timing (for example for migrants) and duration required for useful observations. Bird activity and observer convenience may be mutually exclusive so that most studies resort to post-event surveys of 'casualties' and calibrated estimates of true casualty rate (*e.g.* Andersen-Harild & Bloch 1973, Orloff *et al.* 1992, Alonso *et al.* 1994). Furthermore, generalisations from past studies are confounded by site specific circumstances at most study areas. These circumstance include the relative position of the power cables to features (migration routes, lakes, hill tops *etc*) (Cadbury *et al.* 1971), local weather patterns, and the local status of the species involved. Only Rose & Baillie (1989) have taken a broader perspective by using extensive ringing recovery data for all the British avifauna to look for rates of mortality through collision with wires.

In general, the importance of mortality in birds due to collisions with power lines depends on the demography of the population (Rose & Baillie 1989). In species with high survival rates and relatively high reproductive rates (*e.g.* many geese and swans) the problem is less pronounced than for species with high survival rates but low reproductive rates (*e.g.* many large raptors). Some workers have considered that collisions with power lines can be a serious additional source of mortality in some species, that is, in addition to habitat loss, persecution and pesticide poisoning (Harrison 1963, Andersen-Harild & Bloch 1973, Fielder & Wissner 1980, Alonso *et al.* 1994). In Denmark, Andersen-Harild & Bloch (1973) found that Bitterns *Botaurus stellaris*, a declining species of wetland areas, were particularly susceptible to collisions with power lines (see also Rose & Baillie 1989). Fielder & Wissner (1980) reported that power line collision or electrocution in young White Storks *Ciconia ciconia* was an increasing source of mortality even though the White Stork population was in serious decline. They suggest that more storks die in Europe by colliding with power lines than in any other way. In Venezuela, Brown Pelicans *Pelecanus occidentalis*, an endangered species, suffered very high casualty rates due to collisions with power lines McNeil *et al.* (1985), whilst in Altamont Pass, California, large raptors are particularly vulnerable to either collisions or electrocution at power lines and the many casualties include vulnerable and protected species such as Golden Eagle *Aquiula chrysaetos* (Orloff *et al.* 1992). Amongst British ringed birds many vulnerable species were casualties of collisions with power lines, including several raptor species (Red Kite *Milvus milvus*, Marsh Harrier *Circus aeruginosus*, Montagu's Harrier *C. pygargus* and Golden Eagle (Rose & Baillie 1989).

Collision casualties are not confined to large birds and the list of species victims includes waders (Charadriiformes) (Scott *et al.* 1972, Andersen-Harild & Bloch 1973, Rose & Baillie 1989), wildfowl (Anatidae) and several small passerine species such as Starlings *Sturnus vulgaris* and thrushes (Turdidae) (Scott *et al.* 1972, Rose & Baillie 1989, Alonso *et al.* 1994).

Amongst the passerine species, most casualties were night migrants (Scott *et al.* 1972) although McNeil *et al.* (1985) considered dawn and dusk to be periods of highest risk. Poor visibility and increased bird activity increase the chance of birds colliding with power lines, but the vulnerability of so many species to collision implies that they have a limited ability to detect and avoid the magnetic field generated by high voltage cables as has been tentatively suggested by some sources (Mead pers. comm.).

Electrocution tends to be associated with the risers or connectors at pylons where birds may attempt to perch (Fielder & Wissner 1980, Orloff *et al.* 1992). Although collisions may occur anywhere along spans of wires or with pylons, most studies have found that the majority result from contact with the highest earth wire (Meyer 1978, James & Haak 1979, Beaulaurier 1981, Faanes 1981). Birds may hit the earth wire by trying to avoid the more visible groups of conducting wires below (Faanes 1987, Birch pers. comm.) and, in Spain, Alonso *et al.* (1994) were able to persuade birds to fly higher and avoid contact with the earth wire by improving the visibility of these wires with markers. In terms of mitigation, wire markers are usually considered successful in reducing casualties, at least for diurnal flying species, and may reduce collision mortality by as much as 45% (Beaulaurier 1981). It is also a cheaper alternative to placing cables underground (Fielder & Wissner 1980).

## 3. INTRODUCTION

The Common Tern *Sterna hirundo* is a medium sized (200 g) migratory species which arrives in Britain during April to breed. They forage for small, shallow water fish and in the absence of locally abundant sources of food they must travel some distance to forage, particularly where breeding colonies are inland. When provisioning young, the parents carry one, and rarely two, fish back to the colony and must make many journeys during the day in order to provide their nestlings with sufficient food (Cramp 1985).

At Shotton Steel Works, North Wales, Common Terns breed within the industrial complex and each journey from the breeding colony to the estuary means that the birds must negotiate two spans of power lines, yet their vulnerability to collisions with power lines is unknown. They are an agile species and small, agile and diurnal birds are probably considered less vulnerable to collisions with power lines than large birds or nocturnally migrating species. However, small gulls such as the Black-headed Gull *Larus ridibundus* and Laughing Gull *Larus atricalla*, and terns such as the Common Tern *Sterna hirundo*, Little Tern *Sterna albifrons* and Royal Tern *Sterna maxima* have all been recorded as victims of such collisions (Scott *et al.* 1972, McNeil *et al.* 1985, Alonso *et al.* 1994). At Shotton, casual observers have also recorded the occasional Common Tern casualty (Birch pers. comm.).

In the present study, our aim was to determine how the risk of collision with power lines would vary in relation to the activity of the birds during the breeding season (that is, in view of the time constraints placed upon adults), the age of birds, the significance of distance between the power lines and the breeding colony and climatic variables such as wind speed. One might, for example, predict that birds would be more vulnerable to collision in windier weather when they are less able to control their flight and that juveniles too would be more prone to collision than adults by being naive of the problem and by being less proficient in flight and so at negotiating the wires (cf. Fielder & Wissner 1980).

In some ways the Common Tern is a convenient study species in which to observe the responses of birds to power lines, due to their being diurnal and because of the high frequency of their foraging journeys. This meant that continuous observations, carried out over long time spans and usually in good visibility, were possible, resulting in large sample sizes and an accurate assessment of collision frequency or collision risk. In the study below this assessment is supported by ground surveys of casualties and the removal rate of casualties by predators.

# 4. METHODS

## 4.1 Study site

The Common Tern colony of around 200 pairs is situated within the industrial complex of Shotton Steelworks, on Deeside, North Wales (OS 296 707). The artificially constructed nesting islands are immediately surrounded by water-filled lagoons and then wasteland which gives way to saltmarsh to the north and west (Fig. 1). Terns flying to and from the estuary need not cross any industrial construction, except for power lines. Two sets of power lines run west of the ternery towards the River Dee and in doing so act as potential obstacles which the terns must cross on their journeys to and from the estuary (Fig. 2). The estuary is approximately 5 km to the north-west of the tern colony, or approximately 10 minutes flight time.

The nearest power line to the tern colony (line 1) is approximately 100 m from the nesting islands at its closest point. Line 1 carries 132 kV on cables between 6.7 m and 26 m high (the height of the pylon). Line 1 comprises six groups of four closely held cables plus an earth cable running from the top of each pylon. The groups of cables are 2.8 m apart.

Line 2 was erected in late 1993 and carries 400 kV and is approximately 200 m away from the nesting island at its nearest point. It is almost twice as high as line 1 but carries fewer cables (three groups of two, plus an earth line) with 5.7 m distance between cable groups. The pylons rise to 46 m and at their lowest point the power cables are 7.6 m above the ground.

## 4.2 Data collection

Systematic observations (described below) were made of terns journeying to and from the estuary during four phases of the breeding season. The phases are as follows, with expectations included as to the likely relevant activity of the birds:

1. Courtship:lower expected rate of journeying to and from the estuary with adults prospecting for nest sites after their arrival at the nesting colony.
2. Incubation:lower expected rate of journeying to and from the estuary by the non-incubating partner.
3. Nestling:higher expected rate of journeying to and from the estuary by provisioning parents.
4. Juvenile:naive and less skilled flying individuals present with a higher potential for colliding with power lines.

Initial observations were carried out from dawn until dusk in order to assess the diurnal activity of the terns, the flock size patterns and frequency of journeys to and from the estuary. These observations were completed for the first two phases only. However, during each phase a minimum of two 11 hour periods of observation were completed (over five days), between 0600 h to 1659 h inclusive. During this time period variance in tern flock size was at its lowest between the dawn exodus and before the dusk influx of birds. In other words, birds had settled down into a routine and which made measures of journey rate, flock size and frequency between phases more comparable. In total we effectively completed two 'days' (available hours of daylight used by the terns) of observations per breeding phase.

For each tern crossing either line 1 or line 2 we recorded the following criteria:

1. Direction of journey.

2. Whether the bird passed over, under or between the wires.

3. The estimated height in metres of the bird when crossing above the top earth wire.

4.Whether a bird approached a group of power lines either level with, above (the top wire) or below (the lowest wire) the cables at a distance of 6 m away from them. If a bird was still level with the wires at less than 6 m out then some form of late avoidance action was necessary in order to prevent collision, that is, the bird either climbed over the wires or sometimes flew between them (per. obs.). This variable showed whether birds avoided wires later or took greater risks at different phases of the breeding season or perhaps in windier or wetter weather.

5. Weather estimations: Wind speed (Beaufort estimate) and direction, visibility (metres), percentage cloud cover and rain (1 - barely raining, 2 - light rain, 3 - steady rain, 4 - heavy rain, 5 - storm).

During the juvenile phase of the breeding season birds travelling towards the estuary were easily aged on their flight pattern (juveniles have a much quicker wing beat than adults) and on plumage features (Cramp 1985) and juveniles were subsequently separated from adults in the following analyses.

### 4.3 Effect of wire avoidance on flight time

To evaluate part of the potential cost to terns of having to negotiate power lines on foraging journeys, the flight times of terns which had to climb and avoid the wires late in their approach by altering the course of their flight level, were compared to those individuals which travelled a more direct, unobstructed course to or from the colony by gaining height early on the approach and flying straight over the power lines, or by flying under the power lines. The time taken (in seconds) for terns, on the outward journey, to cross the distance from 10 m outside span 2 to 10 m beyond span 5 (and vise-versa on inward journeys) was recorded over two one-hour periods during the nestling phase.

### 4.4 Ground survey of casualties

The ground beneath power lines 1 and 2 was walked on two occasions during each breeding phase (that is twice in five days) in order to look for corpses and casualties which might have struck the power cables. As much of the ground as possible was covered to within 30 m either side of the outside wire using a zig-zag path through the grass or undergrowth. Not all of the ground was either accessible or visible but in total, 1.2 km of power line was searched. Each survey took approximately 1 h to complete.

## 4.5 Placement of dead birds

In order to quantify the potential removal rate of bird casualties by predators (*e.g.* Foxes *Vulpes vulpes*, Stoats *Mustela erminea* and Ravens *Corax corax*), and in the absence of tern corpses, bird corpses of other species were placed underneath the power lines and recounted after two, five and 14 days. This was to coincide with the latency between ground surveys for corpses, *i.e.* two surveys in each five-day observation period and a minimum of 14 days between observation periods. At the beginning of the provisioning phase, 15 fresh road-killed bird corpses (six magpies *Pica pica*, three blackbirds *Turdus merula*, three wood pigeons *Columba palumbus* and two young pheasants *Phasianus cholchicus* and one Starling *Sturna vulgaris*, each less than 3 days old) were placed beneath the power lines in a pseudo-random fashion. This was done to reduce the chance of predators learning the position of successive corpses so that each corpse would represent an independent sample. Thus, seven birds were consigned to line 1 and eight corpses to line 2. The ground beneath the two power lines was divided into six sections (or spans (see Fig. 1)). Each dead bird was placed beneath span 1, 2, 3 or 4 according to the throw of a dice. Within a given section, a corpse was either placed to the left (1 or 2), right (3 or 4) or middle (5 or 6) according to the throw of a dice, but no two corpses were placed closer together than six metres. Most of spans 3 and 6 were inacessible and were not used in this experiment.

The experiment above was repeated at the end of the 14 day period using five fresh corpses (two magpies, two blackbirds and one wood pigeon), monitored after two and five days respectively. Three corpses were placed under line 2 and two under line 1 using the method above.

# 5. RESULTS

## 5.1 Diurnal activity

Larger flocks of adult terns (to a maximum of 61 birds per flock) departed from the breeding colony just after dawn and returned towards the evening in similar sized groups (Fig. 3 and 4). The first returning birds appeared around one hour after the main flocks had left. From this point onwards the size of flocks leaving and returning to the colony showed relatively little variation (Fig. 3 and 4), and consisted typically of groups of two or three birds. This pattern of activity was similar between breeding phases.

Throughout the breeding season 95.8% (n = 5131) of outgoing terns travelled in a north-westerly direction towards the estuary and 96.4% (n = 4529) of incoming terns travelled from the north-west on returning from foraging. In doing so, almost all individual journeys required the bird to negotiate the power lines.

## 5.2 Crossing height in relation to breeding phase and power line height

There was a greater than three-fold increase in the frequency of combined outward and incoming journeys made by terns from courtship to the nestling phase (ANOVA: $F_{3,22} = 14.2$, $P < 0.0001$; Fig. 5). This increase in journey rate coincided with an increase in the proportion of terns which passed under or between the wires of both power lines 1 and 2 during the nestling phase of the breeding season (Fig. 6). This was true of both the outward (chi-squared: $\chi^2$ under wires = 663.1, df= 5, $P < 0.0001$; between wires = 1524.5, df= 5, $P < 0.0001$) and inward journeys ($\chi^2$ under wires = 1199.6, df= 5, $P < 0.0001$; between wires = 1088.5, df= 5, $P < 0.0001$).

The proportion of adult terns flying close to wires before having to avoid them (that is, approaching within 6 m) increased by approximately 60% for outgoing terns, and by approximately 40% for incoming terns between the courtship and nestling phases (for outgoing terns: $\chi^2$ = 302.5 and = 321.0 (line 1 and 2 respectively, both: df = 3, $P < 0.0001$); for incoming terns: $\chi^2$ = 162.6 and 245.1 (line 1 and line 2 respectively, both: df = 3, $P < 0.001$; Fig. 7). The height at which terns crossed wires was negatively correlated to breeding phase, that is terns flew lower on average during the later nestling and fledging phases (Table 1 (3 & 4)), although this effect was weaker on the inward journey (Table 1 (4)).

On average, 39.9% of birds took late avoidance action at power line 1 as opposed to 57.1% at line 2 ($\chi^2$ = 66.8, df = 1, $P < 0.001$). A higher percentage of terns passed under or between line 2 than line 1 ($\chi^2$ (inward journey) = 591.4, (outward journey) = 280.1; df = 3, $P < 0.0001$ both values). Therefore birds tended to either react later or pass between the higher, more widely spaced wires of line 2, than they did line 1.

At line 2 a higher percentage of birds took late avoidance action on the outward journey (60.5%, n = 574) than the inward journey (53.6%, n = 332; $\chi^2$ = 23.3, df = 1, $P < 0.01$), but there was no significant difference at line 1. Also a higher proportion of birds passed under or between wires on the outward journey than inward journey ($\chi^2$ = 15.0, df = 1, $P < 0.01$). Therefore birds tended to get closer to or pass between wires on the outward journey than on the inward journey.

### 5.3 Crossing height in relation to tern age

Juvenile terns flew consistently closer to the wire when crossing than adults (t-test: $t_{line\ 1}$ = 12.7, P < 0.001; $t_{line\ 2}$ = 23.5, P < 0.001; Fig. 8) with the combined mean height above the earth wires of lines 1 and 2 for juveniles being just 2.5 m (SE = 0.2), but 10.4 m (SE = 0.3) for adults. For juvenile terns, almost half of all wire crossings were less than 1 m above the earth wire, whereas for adults less than 7% of crossings were this close ($\chi^2$ = 196.2, and 323.8 for lines 1 and 2 respectively; for both df = 1, P < 0.0001; Fig. 8).

### 5.4 Crossing height and wind speed

There was a significant positive increase in the proportion of adult terns avoiding wires late (coming within 6 m of) in relation to wind speed on both outward ($\chi^2$ line 1 = 679.1, df= 5, P < 0.0001; $\chi^2$ line 2 = 479.0, df= 5, P < 0.0001) and inward journeys ($\chi^2$ line 1 = 370.6, df= 5, P < 0.0001; $\chi^2$ line 2 = 169.5, df= 5, P < 0.0001; Fig. 9). There was also a significant negative correlation between wind speed and the height at which adult terns crossed the wires (Table 1 (1)). This relationship was much weaker on the inward journey (Table 1 (2)). Because wind speed was negatively correlated with breeding phase (that is, the wind was lighter during the later nestling and fledging phases), the relationship between tern height above the wires and wind speed was not confounded by breeding phase (Table 1 (3 & 4)).

### 5.5 Effect of wire avoidance on flight time

There was a highly significant difference between terns which had to alter their flight course to avoid either lines 1 (span 2) or 2 (span 5) on their foraging journeys and terns which took a direct flight line (z-test: $z_{(inward)}$ = 25.9, P< 0.001, n = 144; $z_{(outward)}$ = 30.4, P < 0.001, n = 139). Terns which needed to avoid the power line took on average 32.1 s to pass between spans 2 and 5 (outward and inward journeys combined) whereas birds using direct flight paths took on average 19.6 s. Both of these times represented a relatively small proportion of the total journey time of approximately 600 seconds to the estuary, between 3% and 5%. This difference also represents only 0.35% of the total journey, including foraging time, of approximately 3,600 seconds.

### 5.6 Measures of casualty rate

Two adult corpses (Common Terns) were found during the systematic surveys of the ground beneath the power lines. Both casualties occurred during the nestling phase and were found directly beneath the 132 kV wires at their closest point to the tern colony (they were approximately one week old when found). Remains of these corpses were present for up to 19 days later.

Of the 15 corpses placed beneath the power lines during the first experiment only one blackbird, from line 2, could not be found after 14 days (none were missing after two and five days respectively) and one other corpse, a magpie from line 1, was moved by approximately 15 m but subsequently found again. During the second experiment, involving five corpses over five days, none were missing after two days, but one magpie was moved after five days, from below line 1, but found approximately 5 m away. This equates to a possible removal rate of 6.7% over 14 days, or possibly 2 % of birds moved over five days (*i.e.* the period during which two surveys were conducted per breeding phase).

## 6. DISCUSSION

Extensive observations resulted in just under 10,000 individual cases of terns crossing power lines. However, there were only two probable casualties (approximately 0.5% of the colony population) and during the course of the study no birds were actually seen to strike the wires.

Throughout the study period visibility was good and therefore the ability of terns to negotiate the power lines during periods of reduced visibility could not be tested. In the morning, terns did not depart from the colony before sun-rise (being visual feeders) so that again there was no opportunity to investigate the effects of reduced visibility in the form of 'half-light' on collision frequency. Heavy rain storms were always preceded by an influx of Common Terns from the estuary back to the colony so that there were few birds actually crossing wires in heavy rain.

The risk of collision is otherwise governed by three factors: the demands associated with breeding phase, the age of the birds and to a lesser extent wind velocity.

On their arrival at the colony, early in the season, terns tended to fly high in order to avoid the power lines. At this time, during courtship there were fewer demands on the adults and the return journeys to the estuary were relatively few. During incubation the incubating bird was sometimes supported by its partner, although usually the two birds of a pair changed duties after one to two hours. During the nestling phase, however, both parents repeatedly made return journeys to the estuary, throughout the daylight hours, in order to collect food for their chicks. This period of the breeding season is exceptionally demanding of parent birds, and led them to reduce their journey time by flying a more direct line to and from the colony. This meant that they flew more frequently under or between the power cables and in doing so may have increased the risk of collision. Adults were not simply learning to fly between the wires but were apparently conserving energy, since parents again resorted to flying over wires immediately after their young had become independent.

Juvenile Common Terns are easily distinguished from adults by their weak and 'fluttery' flight (apart from plumage features). Although the great majority of juveniles seen tended to follow their parents out on journeys to the estuary, and although the adults tended to fly higher above the wires when escorting young, still almost 50% of all juveniles crossed the earth wires with less than 1 m to spare. Usually these individuals saw the wires late, and many needed a second attempt to clear them. Clearly the juveniles were at much greater risk from collision than adults, because of their naivety and because of their poorer flying skills. Nevertheless, no juvenile corpses were found underneath wires during the study. However, the weather conditions were always good and so it was not possible to test the effects of poor visibility.

Terns flying out towards the estuary had to climb more quickly in order to cross over the power lines and this resulted in there being a greater tendency amongst outward going terns to take late avoidance action or risk passing between wires. This was a result of the close proximity of the power lines to the nesting colony. A higher proportion of terns passed between the wires of power line 2, than line 1, but the wires of line 2 were twice as widely spaced than those of line 1, so this in fact was probably less of a risk. Likewise terns readily passed under the wires of line 2 but were reluctant to do so at line 1. Consequently, in some ways the higher pylon created less of an obstacle to terns than the nearer, lower pylon because the risk of collision was greater where the distance between wire groups was only 2.8 meters. Almost all near misses and late avoidances of wires were of the top, single earth wire (Meyer 1978, James & Haak 1979, Beaulaurier 1981, Faanes 1981).

Extremes of wind speed had a significant effect on the height at which terns flew over wires and increased their vulnerability to collision. Despite this, no casualties were found immediately after periods of high winds, though these never occurred during the nestling or juvenile phases of the breeding season.

Two probable casualties in a colony of approximately 500 birds (including juveniles) represents less than 0.5% mortality rate caused by the power lines. Although this may be an underestimate, the error involved is unlikely to be great since the removal rate of corpses by predators was low. Even when birds were moved, feathers tended to remain at the original site for several days, so that the likelihood of missing these signs of casualties, given the frequency of ground surveys, was also low. In all probability the ground surveys were giving a fairly accurate representation of casualty rate in the regions that could be surveyed. A much more likely source of error is through birds falling into the reed bed or other areas which could not be checked. Nevertheless, virtually all of the ground beneath the 400 kV power line was surveyed. This was true also of section 1 of the 132 kV power line which through its proximity to the tern colony, presented the greatest potential hazard to terns. It is worth noting, however, that reduced visibility such as in fog, or poor conditions such as high winds occurring during the nestling or particularly the juvenile phases of the breeding season, could have very different consequences for casualty rate.

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Table 1. Kendall correlation coefficients summarizing the relationship between the height at which Common Terns crossed power lines on foraging journeys, estimated wind speed (Beaufort scale) and breeding phase (which were ranked as follows: Courtship = 1, Incubation = 2, Nestling = 3 and Juvenile = 4).

| | Power line 1 (132 kV) | | Power line 2 (400 kV) | |
|---|---|---|---|---|
| Relationship | Kendall's *Tau* | n | Kendall's *Tau* | n |
| (1) Wind speed and tern height - outward journey: | -0.10*** | 1345 | -0.11*** | 1128 |
| (2) Wind speed and tern height - inward journey: | 0.01 ns | 1630 | -0.06** | 1189 |
| (3) Breeding phase and tern height - outward journey: | -0.28*** | 1345 | -0.24*** | 1128 |
| (4) Breeding phase and tern height - inward journey: | -0.18*** | 1630 | -0.05* | 1189 |
| (5) Wind speed and breeding phase - outward journey: | -0.22*** | 1478 | | |
| (6) Wind speed and breeding phase - inward journey: | -0.28*** | 1745 | | |

* $P < 0.05$, ** $P < 0.001$, *** $P < 0.0001$, ns = non significant.