"Vocal behaviour and information coding in a pelagic Arctic seabird, the little auk (*Alle alle*)"

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Vocal communication is fundamental for many animal species. Vocalisations can carry information on the sender's identity, sex, size or quality, but also about the behavioural and emotional context they find themselves in. As a result, vocal signals facilitate many social interactions, from identifying a potential mate to performing parental care, or from de-escalation of aggression to predator avoidance. Not surprisingly, vocal communication systems become particularly complex in species maintaining stable and complex social bonds.

In this work, I attempted to provide a comprehensive introduction to the acoustic world of the little auk (*Alle alle*). Little auks are long-lived, monogamous seabirds of high fidelity to both nest and partner, indicating the importance and stability of their social bonds. They are also very vocally active. Yet seabird colonies are crowded, noisy places, where acoustic communication may encounter special difficulties. So how can – and do – little auks exchange socially important information vocally?

To answer this question, I used available and newly collected passive acoustic recordings of little auks in undisturbed situations, including passive monitoring at the colony scale, as well as focal recordings of known, sexed and measured individuals. I have supplemented this material with recordings of hand-held birds collected during standard ornithological procedures – this included both young chicks and adult individuals. This allowed me to have an overview of the vocalisation types commonly produced by the species over the breeding season, as well as their related behavioural – and thus affective – contexts. All the data obtained for this work were collected at the little auk breeding colony in Hornsund, SW Svalbard, Norwegian High Arctic.

As a result, this work answers the following questions: What is the vocal repertoire of the species, i.e. the vocalisations those birds produce? In what contexts do they produce those vocalisations, and do vocal signals reflect the behavioural and emotional contexts of production? If yes – is such dynamic information already present in young chicks? Do vocalisations carry static information about the sender, such as their size, sex, or identity? Finally, how well does this information travel through their environment?

Chapter I provides a description of little auk vocal repertoire over the mating and incubation periods. Using passive acoustic monitoring of the colony over breeding seasons 2019-2021, I have identified and described eight distinct call types, as well as their associated production contexts. Wherever it was possible, I assigned the calls with a putative affective valence – i.e., positive/elicited approach vs. negative/elicited avoidance. The putative contextual valence significantly affected the acoustic properties of the calls: these assigned positive valence had higher fundamental frequency and spectral centre of gravity as well as shorter sound duration than calls assigned negative valence. This indicates that the little auk's vocal communication system may allow expression of complex behavioural and emotional contexts.

Chapter II revisits the question of vocal expression of affect in young chicks. Using focal recordings of chicks during interactions with their parents (positive/approach context) and during handling for standard ornithological procedures (negative/avoidance context), I have shown that affective expression is already present in this species early in ontogeny (5-8 days after hatching). Calls could be reliably classified to their production context, with over 97% accuracy. Calls produced during handling had higher mean entropy, fundamental frequency, as well as lower spectral centre of gravity and a less steep spectral slope compared to calls produced during interactions with a parent. Additionally, I assessed the information content of the calls produced in the two contexts, showing that the distress calls had a lower carrying capacity than those uttered in a positive context. These findings suggest that seabird chicks can effectively express behavioural/affective contexts through calls, conveying socially important messages early in development.

Chapter III investigates vocal cues to sex, size, and partnership in two important social calls: a short, one-syllable call, and a complex, multi-syllable call with an apparent formant structure. While the short call carried information on the body size of the emitter, this was not true for the complex call. Neither call type carried cues to sex, which is in line with descriptions of other seabird species. In both call types, certain parameters of the calls tended to match between partners. This indicates that vocal cues are at best weak indicators of size, and that social bonds likely influence the vocal output of individual birds.

Chapter IV provides a detailed description of vocal individuality coding within and across five call types of the little auk. Calls could be reliably assigned to an individual both within and across call types, and all call types showed information content allowing to distinguish across at least 11,

and up to at least 41 individuals. Vocal cues to individuality were based mostly on the peak fundamental frequency, frequency value at the upper limit of the second and first quartiles of energy, sound duration, and amplitude modulation rate, but also temporal patterning within the call. This strong individuality coding likely plays a role in maintaining long-term social bonds in the species.

Finally, chapter V provides a theoretical model of information transmission over distance, using two common social call types of the little auk, produced both inside the nest and in flight. I calculated the sound pressure levels of the vocalisations recorded inside the nest by known individuals. Then, using a spherical spreading model based on the local meteorological data from 1983-2021, I simulated the propagation of those calls up the putative hearing threshold. Calls could be correctly classified to individuals independently of the distance up to and over the putative physiological hearing threshold. The carrying capacity of the signal did not decrease with propagation. This shows that little auk signals can travel extreme distances with minimum information loss, which suggests that they can recognise calls of the members of social groups as far as those calls are actually audible, and support the hypothesis that vocalisations could play a role in long-distance communication in this species.

Together, these chapters provide a comprehensive guide to little auk vocal communication, exploring behaviourally important questions is a way intended to be as comparable as possible across species. As such, I hope this work will prove to be an important contribution to our understanding not only of seabird acoustics, but also of the overall expression patterns and the importance of acoustic communication in animals.