Mystery behind Hitchcock's birds

To the Editor — On 18 August 1961, a Californian newspaper reported that thousands of "crazed seabirds pelted the shores of North Monterey Bay, California" regurgitating anchovies. Soon after reading the report (Supplementary Fig. S1), local visitor Alfred Hitchcock was inspired to produce his famous thriller *The Birds*. Three decades later, in 1991, another mass poisoning occurred in the same area — this time, of fish-eating, disoriented and dying brown pelicans. But on this occasion the culprit was identified: the pelicans had ingested domoic acid, a neurotoxin that is produced by the diatom *Pseudo-nitzschia*. Large quantities of this diatom, and the associated toxin, were found in the stomachs of fish in the region. It has been suggested that diatom-generated domoic acid was also responsible for the 1961 event[1], but direct evidence has been lacking. Here we show that plankton samples from the 1961 poisoning contained toxin-producing *Pseudo-nitzschia*, supporting the contention that these toxic diatoms were responsible for the bird frenzy that motivated Hitchcock's thriller.

Algal toxins such as domoic acid are increasingly recognized as the cause of marine poisoning events. Domoic acid is a chemical analogue of glutamate and, as such, binds with high affinity to glutamate receptors in the brain[2]. When domoic acid passes through the blood–brain barrier and binds to these receptors in birds and mammals, it causes symptoms such as confusion, disorientation, scratching, seizures, coma and even death[3].

Over the past decade, Monterey Bay, a productive coastal environment in the California Current upwelling system, has been affected by recurrent blooms of *Pseudo-nitzschia* species that produce domoic acid. These blooms have led to the death or stranding of brown pelicans, Brandt's cormorants and sea-lions[4–7]. Although *Pseudo-nitzschia* has resided in the waters off California for millennia, domoic acid was only detected in diatoms in the region in 1991[8]. Prior to this, episodes of seabird mortality off the shores of California were attributed to other factors such as fog, infectious diseases, oil spills and fishing practices[9]. One such event was that involving the influx of disorientated seabirds into Monterey Bay in the summer of 1961, which entered into cinematic history.

Sooty shearwaters, *Puffinus griseus*, are common visitors to Monterey Bay. These birds travel from their breeding grounds in the south-west Pacific to the productive waters of the north-east Pacific, including the California Current, during the summer and early autumn to feed[10]. In Monterey Bay, huge flocks of sooty shearwaters feed on krill, squid and fish[11]. In the summer of 1961 the birds were found regurgitating anchovies, flying into objects and dying on the streets, capturing the attention of summer resident Alfred Hitchcock; *The Birds* was released two years later.

Here, we show that toxin-producing species of *Pseudo-nitzschia* were indeed present in high numbers at the time of the 1961 bird frenzy. In the absence of water samples, we examined archival samples of herbivorous zooplankton — which feed on diatoms, and are preyed on by sea turtles and some fish and birds — collected during ship surveys at the time[12] (Supplementary Fig. S2). By analysing the gut contents of these animals, we were able to reconstruct regional flora (Supplementary Information). Toxin-producing species of *Pseudo-nitzschia* accounted for 79% of the diatoms present in the guts of these organisms (Fig. 1a). Species included *P. turgidula* (Fig. 1b,c), *P. pseudodelicatissima* (Fig. 1d,e; Supplementary Fig.S3), *P. pungens, P. delicatissima, P. australis* and *P. multiseries* (Supplementary Table S1); the latter two dominated blooms during the 1991 poisoning of brown pelicans. The most abundant *Pseudo-nitzschia* species identified during the 1961 outbreak were *P. turgidula*, which accounted for 49% of the diatoms present and was recently shown to produce domoic acid in the subarctic Pacific[13], and *P. pseudodelicatissima*, which accounted for 38%. We suggest that domoic acid generated by these diatoms accumulated in the food chain, and led to the poisoning of

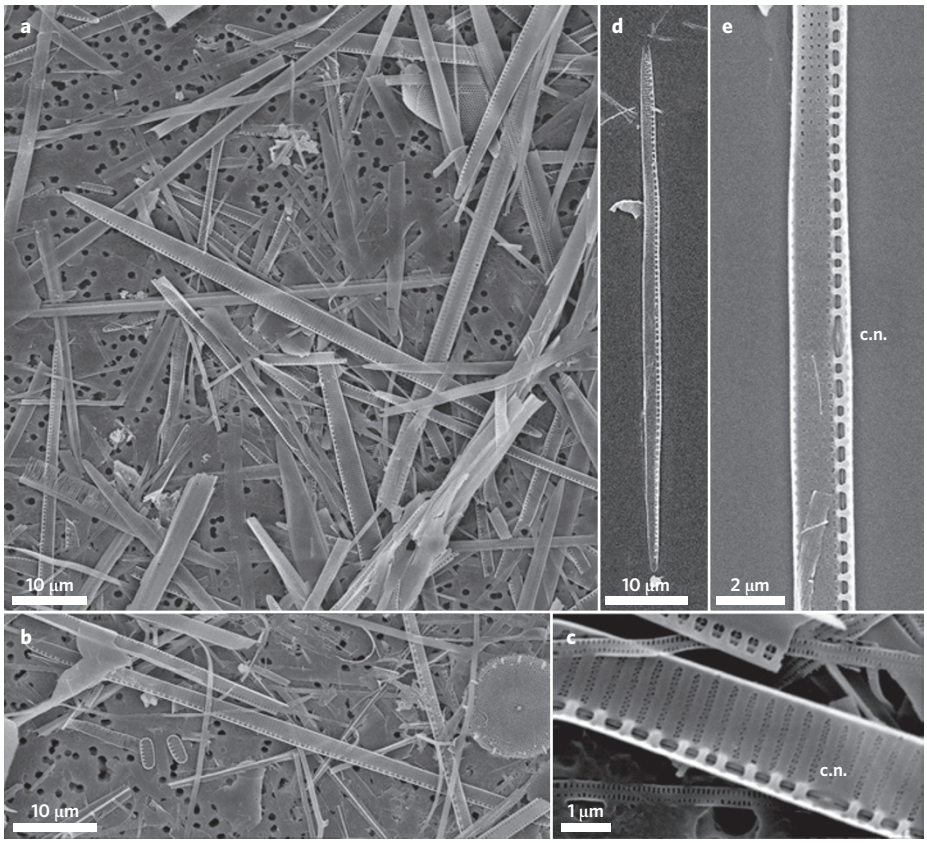

Figure 1 | Toxic *Pseudo-nitzschia* and Hitchcock's bird frenzy. Scanning electron microscopy images of zooplankton gut contents collected in July–August 1961 from Monterey Bay, California. **a**, Overview image showing the relative abundance of *Pseudo-nitzschia*. **b**,**c**, *P. turgidula* and **d**,**e**, *P. pseudodelicatissima* – the two most abundant *Pseudo-nitzschia* species found in the zooplankton. Notice the presence of poroid rows within the striae of the latter two species; a central nodulus (c.n.) is also present in both. Both features were used to help identify the species.

migratory flocks of shearwater that foraged in these waters.

We show that *Pseudo-nitzschia* abundance during the summer of 1961 was of the same order of magnitude as that observed during more recent animal stranding events related to domoic acid poisoning[14]. The upwelling of bottom waters declined at the time, and the inflow of oceanic surface waters increased, probably leading to the development of warm-water, low-wind conditions[15]. We suggest that this, in turn, promoted *Pseudo-nitzschia* growth and prolonged the residence time of the visiting seabirds. Similar conditions led to the mass poisoning event in 1991[4].

Given the similarities between events in 1961 and the domoic acid-induced poisoning of 1991, we suggest that toxic *Pseudo-nitzschia* were probably responsible for the odd behaviour and death of Sooty shearwaters in August 1961. This brief study therefore supports the contention that domoic acid caused the seabird frenzy that eventually led Hitchcock to make his film[1], and strongly suggests that domoic-acid-producing phytoplankton have been an agent of marine animal mortality in the California Current system for at least the past fifty years. ❐

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Author Contributions

S.B., M.W.S. and D.L.G. designed the overall project; S.B., M.W.S., M.D.O. and C.R.B.-N performed research; S.B., M.W.S. and M.D.O. analysed data. All authors participated in discussions, contributed ideas along the way and edited the manuscript.

Additional information

Supplementary information accompanies this paper on www.nature.com/naturegeoscience.

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