WHEN *VIBRIOS* TAKE FLIGHT: A META-ANALYSIS OF PATHOGENIC *VIBRIOS* SPECIES IN WILD AND DOMESTIC BIRDS

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ABSTRACT

Of the over 100 species in the genus *Vibrio*, approximately twelve are associated with clinical disease, such as cholera and vibriosis. Crucially, eleven of those twelve—*V. alginolyticus*, *V. cholerae*, *V. cincinnatiensis*, *V. hollinsae*, e.g., *Grimontia hollinsae*, *V. furnissii*, *V. mimicus*, *V. parahaemolyticus*, *V. vulnificus*, *V. harveyi*, *V. scophthalmi* and *V. metschnikovi*—have also been isolated from birds. Since 1965, pathogenic *Vibrio* species have been consistently isolated from aquatic and ground-foraging bird species, which has implications for public health, as well as the One Health paradigm defined as an ecology-inspired, integrative framework for the study of health and disease, inclusive of environmental, human, and animal health. In this meta-analysis, we identified 76 studies from the primary literature which report on or examine birds as hosts for pathogenic *Vibrio* species. We found that the burden of disease in birds was most commonly associated with *V. cholerae*, followed by *V. metschnikovi* and *V. parahaemolyticus*. Meta-analysis wide prevalences of the *Vibrio* pathogens varied from 19% for *V. parahaemolyticus* to 1% for *V. mimicus*. Wild and domestic birds were both affected, which may have implications for conservation, as well as agriculturally associated avian species. As pathogenic *Vibrios* become more abundant throughout the world as a result of warming estuaries and oceans, susceptible avian species should be continually monitored as potential reservoirs for these pathogens.

Key words: *Vibrio* spp., Birds, Disease, Pathogenic, Ecology

1 Introduction

Waterborne pathogens around the globe are experiencing a period of unprecedented global change, with the Vibrionaceae categorized among the most climate-sensitive families of aquatic prokaryotes [1, 2]. Evidence continues to mount concerning the uptick in the abundance, distribution, and phenology of the Vibrionaceae, since rising temperatures, humidity, and precipitation have led to their increased survival and rates of replication [3–5]. Within this family resides the genus *Vibrio*, a genetically diverse group of gram-negative, motile, and facultatively anaerobic bacteria that are endemic to marine and estuarine waters [6]. With over 100 named species in the *Vibrio* genus, approximately twelve are known to be pathogenic to human hosts [7]. Specifically, eleven of the twelve, i.e., *V. alginolyticus*, *V. cholerae*, *V. cincinnatiensis*, *V. hollinsae*, e.g., *Grimontia hollinsae*, *V. furnissii*, *V. mimicus*, *V. parahaemolyticus*, *V. vulnificus*, *V. harveyi*, *V. scophthalmi* and *V. metschnikovii*, are the causative agents of human vibriosis, a term that incorporates a broad range of clinical signs [8–10]. These pathogenic species arguably include some of the greatest public health burdens worldwide, and over the last 40 years, the incidence of *Vibrio* infections has strikingly increased [11–13]. The continued rise of the incidence and prevalence of *Vibrio* pathogens has contributed to an unprecedented worldwide health burden of enteric, diarrheal diseases [14, 15]. Yet, the Vibrionaceae are not only expanding their breadth throughout the human population – over the last one hundred and fifty years, it also appears that the *Vibrio* genus is expanding its niche into avian hosts, with ensuing implications for the One Health paradigm, and how we contextualize ‘human’ diseases [16–19].

During the fifth pandemic of cholera (1881–1886), the bacteriologist Gamelaia reported a disease afflicting Rock Pigeons (*Columba livia*) and domestic chickens (*Gallus gallus*) in southern Russia. It was described as

“a disease of fowls”, of which the etiological agent was indistinguishable by morphological examination from *Vibrio cholerae* [20, 21]. This etiological agent would eventually be classified as *Vibrio metschnikovii*, and by the early twenty-first century, it would be considered one of twelve pathogenic *Vibrio* species that causes disease in human hosts [7, 22, 23]. The occurrence of another pathogenic *Vibrio* isolated from birds would not be reported until 1966, when individual species from the Gifu and Higashiyama Zoos (Table 2) in Japan tested positive by culture for Biotypes 1 and 2 of *Vibrio parahaemolyticus* [24]. Pathogenesis in these zoo birds was not reported [24]. Based on the literature, it is possible that the bird that had cultured positive for Biotype 2 of *Vibrio parahaemolyticus* was in fact shedding *V. alginolyticus* [25, 26].

Pathogenic *Vibrio* species can be lethal in human hosts. For example, *Vibrio vulnificus* is a causative agent of primary septicemia with a case fatality rate of up to fifty percent [27, 28]. As one of world’s leading causes of seafood-related deaths, *Vibrio vulnificus* is an opportunistic pathogen which causes high morbidity and mortality among the immunocompromised and those with liver disease [29, 30]. *Vibrio cholerae*, specifically serotypes O1 and O139, is likely the most well-known member of the *Vibrio* genus. It is a pathogen which has generated seven pandemics since 1817, and whose ecology and pathogenesis has been covered in depth [31–36]. *Vibrio parahaemolyticus* is a leading cause of seafood-borne illness, with clinicians reporting gastroenteritis and septicemia as the primary causes of morbidity among patients [37, 38]. *V. alginolyticus* and *V. fluvialis* are considered emerging pathogens and have been linked to gastroenteritis and extraintestinal infections [8, 39]. The remaining *Vibrio* species, *V. cincinnatiensis*, *V. hollinsae*, e.g., *Grimontia hollinsae*, *V. furnissii*, *V. mimicus*, *V. harveyi*, *V. scopthalmi* and *V. metschnikovii* have been linked to sporadic reports of disease in human hosts [40–45], however, that does not diminish their clinical, veterinary, or ecological importance.

The One Health paradigm is a collaborative endeavor that seeks to incorporate the health of the environment, animals and humans, given the understanding that the resilience of these individual components is integrated and intertwined [46, 47]. Thus, the emergence of pathogenic *Vibrio* species in birds is not only of public health importance [48, 49], but of significance to avian disease ecology, as little is known of the large-scale effects that members of the *Vibrio* genus may have upon species of conservation concern [50, 51]. With few exceptions [36], little is also known concerning the role that birds may play in the maintenance or potentially cyclical contamination of the brackish, aquatic reservoirs they share with other susceptible vertebrates [52–56]. Therefore, in this chapter, we build on the work of prior investigators who have identified the presence of pathogenic *Vibrio* species in avian species to a) identify the avian taxa most likely to excrete the pathogens and b) assess the prevalence of individuals in each community or sample that do so. We further examine whether pathogenic *Vibrio* species are immunogenic and/or pathogenic to birds, and the duration that they shed in experimental infection studies. We focus not just on studies that have identified the presence or absence of pathogenic *Vibrio* species in wild avian communities, but also include experimental infection and immunity studies. Our objective is to provide a baseline framework by which avian disease ecologists, wildlife management professionals, veterinarians, and One Health personnel can evaluate and/or mitigate the potential risks of emerging pathogenic *Vibrio* species within our wild birds.

2 Methods

Using Google Scholar and Web of Science [57, 58], we searched for peer-reviewed studies, pre-prints, abstracts, and graduate theses in which the antibodies against or the antigens of pathogenic *Vibrio* species were isolated from birds or from the avian environment (e.g. the isolation of *Vibrio* pathogens from avian fecal matter or their nests) [59]. In our search strategy, we used the following search terms and Boolean operators: “*Vibrio* pathogen of interest” OR “*Vibrio* pathogen and disease” and “bird*” OR “wild bird*” OR “avian” (n = 14,950). In

our search, we systematically searched for studies that examined evidence of infection by the following members of the *Vibrio* genus: *V. alginolyticus*, *V. cholerae*, *V. cincinnatiensis*, *V. furnissii*, *V. mimicus*, *V. parahaemolyticus*, *V. vulnificus*, *V. harveyi*, *V. scophthalmi* and *V. metschnikovii*. Given the relatively recent taxonomic reclassifications of *Grimontia hollinsae* [60] and *Photobacterium damsela* [61] from the genus *Vibrio*, we also included these pathogens in our analysis. We included experimental infection studies, case reports, and cross-sectional studies published between 1966 and January 1, 2022. In our analysis, we excluded sources that did not serve as primary literature involving investigations of pathogenic *Vibrio* infections in domestic or wild birds, e.g., retrospective studies and review papers (retrospective and review papers, n = 24) as well as duplicates (duplicates, n = 81). We also excluded any literature without a clear diagnostic and physiological association between domestic or wild birds as hosts of our *Vibrio* species of interest (exclusion criteria, n = 14845).

From each study, we extracted the following elements when available: avian species or taxonomic group, *Vibrio* species, country, year the study was conducted or published, the number of birds tested or infected, the number of birds from which *Vibrio* was isolated, and the method(s) by which pathogenic *Vibrio* species were identified. Where possible, we identified the prevalence of our *Vibrio* pathogens of interest, including presence and absence, to determine study-wide prevalence. We also reported serotypes and/or clinically important strains when that information was provided. We further identified whether our *Vibrio* pathogens of interest were associated with clinical signs or avian mortality events, however, unless specifically stated in the text, we could not determine whether our *Vibrio* pathogens of interest were the causative agent(s) of reported morbidity or mortality.

3 Results

3.1 Literature Review

We identified 76 studies from the primary literature that met our inclusion criteria, resulting in 425 study records of avian species or taxonomic groups from which the presence or absence of pathogenic *Vibrio* species was recorded (identified species, n = 171, identified families, n = 46). In our meta-analysis, a study record ranges from a single examined bird to 565 examined birds, which reflects the same species or taxonomic group that was tested for a single pathogenic *Vibrio* species of interest that originated from within the same study (Tables 1-5). In our meta-analysis, 29 countries were represented, constituting all continents except for Antarctica. Of the fifty-five years between 1966 and the start of 2022, studies were either published in or conducted in 41 of them. Sixteen study records did not provide sufficient information from which to identify *Vibrio* prevalence, as either the number of birds, flocks, nests, or sites were incompletely reported, or collected samples were pooled. When the *Vibrio* pathogens of interest were either not named or not classified to species, it was categorized as “*Vibrio* spp.”.

3.1.1 *Vibrio cholerae*

A total of 41 studies in the primary literature examined the role of *Vibrio cholerae* in wild or domestic birds [49, 53, 62–101]. One hundred and fifty-six study records investigated the presence or absence of *Vibrio cholerae*, with the most common technique utilized being culture alone, followed by culture and PCR, or PCR coupled with sequencing. Twenty-five study records reported multiple serotypes from the same species, in the same study. Five of those 25 study records dealt with individual birds who either excreted or displayed multiple serotypes within the same fecal or blood sample or were sampled longitudinally and subsequently cultured

positive for different serotypes at different times [53, 91]. Four study records reported the detection of *Vibrio cholerae* O1 from within one or a flock of birds, with Inaba and Ogawa each reported at least once [53, 84, 87, 88]. Serotype distribution across species or taxonomic groups was not analyzed, since the number of birds positive for each serotype was usually not provided in the primary literature. We do, however, report the available data in Table 1. The most common ‘type’ of *Vibrio cholerae* reported from birds was non-O1/O139, however, many study records did not identify or report the serotype of *Vibrio cholerae* that was isolated. *Vibrio cholerae* O139 was not reported from any study.

One-hundred and seven (n = 107) species were examined for the presence of *Vibrio cholerae* antigens or antibodies. An additional sixteen records were extracted from the literature, but we were not able to identify those study records to species. The Anatidae (waterfowl) represented 49 study records, Laridae (gulls and terns) represented 20 study records, and the Ardeidae (shorebirds) represented 10 study records. Within our meta-analysis, 5492 reported birds were tested for *Vibrio cholerae*, and 864 reported birds tested positive, for an overall meta-analysis prevalence of 16%. Study prevalences ranged from 100% in case reports to zero, for example, this often represented rarely captured species that did not yield evidence of exposure to the pathogen. Mallards (*Anas platyrhynchos*) (n = 381) [53, 73, 90, 94, 99] appeared to be the most captured and examined wild species, while domestic chickens (n = 552), both backyard and experimentally inoculated, were the most commonly examined domestic species [65, 76, 87, 88, 91, 97]. Wilson’s Plover (*Charadrius wilsonia*), a species of shorebird that was examined in Venezuela (n = 16/16), had the highest cross-sectional study prevalence for any wild bird captured, with a prevalence of 100% [80]. This was followed by Greater Yellowlegs (*Tringa melanoleuca*), also in Venezuela (n = 6/6), with a prevalence of 100% [80], and Killdeer (*Charadrius vociferus*) in the western United States (n = 13/15), with a prevalence of 86.7% [53].

Clinical signs were reported from 20 study records and were most often associated with *V. cholerae* non-O1/O139 [63, 66, 75, 77, 87, 89, 93, 96, 98, 100, 101]. One study reported clinical signs, primarily edema and cellulitis of the gastrointestinal tract, with an experimental inoculation of O1 Ogawa in domestic chickens [87]. Clinical signs from the literature ranged from respiratory signs to lethargy and sepsis; most infections were associated with other pathogens. However, in a mortality study of American Flamingoes (*Phoenicopterus ruber*), *V. cholerae* infection was associated with lead toxicity [63]. The largest cross-sectional study to examine wild birds who had exhibited clinical signs in the wild was performed in China, whereby Ruddy Shelducks (*Tadorna ferruginea*) (n = 25/55) tested positive for *V. cholerae* non-O1 [101]. This study also examined other taxa of birds, such as waterfowl, gulls, shorebirds, and Great Cormorants (*Phalacrocorax carbo*) for the presence of *Vibrio cholerae*, however, study-wide prevalences were generally low when associated with clinical signs (Table 1).

3.1.2 *Vibrio parahaemolyticus*

We identified 20 studies in the literature that examined the role of wild birds as hosts for *V. parahaemolyticus* [24, 68–73, 82, 85, 95, 102–109]. We extracted seventy-three study records from these papers that examined the prevalence of the pathogen, however, in an additional two study records, we were unable to determine the number of birds infected and/or the number of birds tested [85, 105]. One paper examined the immunogenicity of *V. parahaemolyticus* and *V. vulnificus* in Japanese Quail eggs (*Coturnix coturnix*), and found that birds elicited a high humoral response to the antigens, as measured by ELISA and Western Blots [105]. Most studies utilized culture to determine the presence of *V. parahaemolyticus*, or suckling mice coupled with culture, however, PCR and sequencing was more commonly utilized in more recent works. The Anatidae were represented by 21 study records, the Phasianidae (turkeys, chickens, and pheasants) represented nine study records, and the Laridae represented six study records. We were able to identify 60 species that had been examined for *V. parahaemolyticus*, representing 22 families. For eleven study records, we were unable the species or family

of the birds involved in the study [68, 71, 82, 85, 95, 100, 104]. Common Loons (*Gavia immer*) were the most common species tested for *V. parahaemolyticus*, after a multi-year mortality event in Florida [102], however the prevalence was only 0.23% (1/434).

Similar to *V. cholerae*, prevalences for *V. parahaemolyticus* ranged from 100% in the cases of individual study records that were examined, or zero when relatively cryptic and/or scarce species were assessed. Out of the seventy-five study records that we extracted, only 44 reported study records contained birds that tested positive for the pathogen. The highest prevalence for wild birds captured in a cross-sectional study was 68%, involving three species of gulls: Herring Gulls (*Larus argentatus*), Laughing Gulls (*Leucophaeus atricilla*), and Ring-billed Gulls (*Larus delawarensis*) captured off the coast of Florida [69]. This was followed by Herring Gulls and Black-tailed Gulls (*Larus crassirostris*) captured off the coast of Japan, with a prevalence of 67% [106]. Across our study records, we found that 3996 birds had been tested for the presence of the pathogen or for antibodies against the pathogen. A total of 761 birds were positive for *V. parahaemolyticus*, for a meta-analysis prevalence of 19%. Clinical signs were only reported for two studies, in both, co-infection with other organisms was noted [102, 108]. Four studies were associated with other *Vibrio spp.* that were not identified to species [69, 73, 107, 109]. Few studies overlapped between reporting both *V. cholerae* and *V. parahaemolyticus* in birds [69, 73, 85].

3.1.3 *Vibrio vulnificus*

Eight studies reported examining wild or domestic birds for the presence of *V. vulnificus* or *V. vulnificus* antibodies in the literature, from which we were able to extract 21 study records [71, 83, 85, 105, 106, 109–111]. At least 17 species were represented in this dataset, categorized into 10 families. We were unable to determine within-study prevalences for five of those 21 study records, however, due to the pooling of samples [85, 105, 111]. The most commonly utilized method of determining exposure to *V. vulnificus* in birds was the use of a biochemical panel coupled with culture [83, 110]; similar to *V. parahaemolyticus*, PCR and sequencing were more commonly used in later papers [109, 111]. Study prevalences ranged from zero for rarely captured and/or examined species, to 50%, which was attributed to one of two Black-tailed Godwits (*Limosa limosa*) captured in China that was positive by PCR and sequencing [109]. This was followed by a prevalence of 26% for Herring Gulls and Black-tailed Gulls sampled off the coast of Japan [106]. The largest cross-sectional study was performed in Ogun State, Nigeria, from which multiple farms, representing 565 domestic chickens, were sampled for the presence of exposure to *V. vulnificus* [110]. The study wide prevalence was 0.7%.

No clinical signs or mortality events were reported from any study. In a cross-sectional sampling of urban birds in Houston, Texas, Zhao et al. 2020 reported [111] that Muscovy Ducks (*Cairina moschata*) and Laughing Gulls excreted more *V. vulnificus* (vvh) than American Crows in the winter as compared to the summer. The greatest diversity of pathogenic *Vibrio* species was reported from a study of stranded seabirds (n = 17/69, *Vibrio spp.*, prevalence of 25%) in Brazil, from which *V. vulnificus* was isolated along with *V. cholerae*, *V. parahaemolyticus*, *V. cincinnatiensis*, *V. fluvialis*, *V. harveyi*, and *V. mimicus* [85]. The individual prevalence of *V. vulnificus*, or the species afflicted in this study was not reported, however a follow-up study reported a *V. vulnificus* prevalence of 1.7% in Brazilian seabirds [71]. Overall, 1231 birds were examined for evidence of exposure to *V. vulnificus*, and 94 were positive, for a meta-analysis wide prevalence of 8%.

3.1.4 *Vibrio alginolyticus*

In the literature, we recovered 15 studies in which the role of domestic and wild birds as hosts for *V. alginolyticus* was examined, providing us with 49 study records [68–73, 83, 90, 102, 105, 110, 112–115]. Two study records, involving seabirds off the coast of Brazil, did not identify the sampled birds to species [71, 85].

Forty-seven species were represented in this data subset, categorized into 18 families. Nineteen study records were attributed to the Anatidae, five study records to the Laridae, and three study records were represented by the Falconidae family, known for its small falcons and hawks. Culture, followed by biochemical panels, were the most commonly utilized methods to identify the pathogen. PCR was rarely utilized. The highest prevalence of *V. alginolyticus* recovered from a cross-sectional study of wild birds involved Herring Gulls, Laughing Gulls, and Ring-billed Gulls captured off the coast of Florida, with a prevalence of 68% [69]. The next highest prevalence of the pathogen was 55%, originating from Herring Gulls and Great Black-backed Gulls captured along coastal Connecticut [69]. Across the board, prevalences ranged from zero to 68%, no study record reached a prevalence of 100%. In a study performed in Ogun State, Nigeria, *V. alginolyticus* was isolated from 2% of domestic chickens [110].

Clinical signs and mortality were recorded by two studies, one involving a multi-year mortality event of Common Loons in Florida, and the second involved a mortality event off the coast of Oahu, Hawaii, of Wedge-tailed Shearwaters (*Ardenna pacifica*), which demonstrated prevalence of 10% [102, 115]. Clinical signs ranged from emaciation and lethargy to toxemia and sepsis; bacteremia in the case of the Wedge-tailed Shearwaters was strongly suspected [102, 115]. In a diagnostic examination of critically endangered Mauritius Kestrels (*Falco punctatus*), a captive individual (1/6) was positive by culture for *V. alginolyticus*, yet no clinical signs were noted [113]. In general, waterfowl demonstrated the lowest prevalences for any group of birds, besides passerines, for the pathogen [73, 83]. Throughout our dataset, 258 birds of 2,967 sampled birds tested positive for *V. alginolyticus*, for a meta-analysis prevalence of 9%.

3.1.5 *Vibrio fluvialis*

From the literature, we found 15 studies that reported examining wild or domestic birds for the presence of *V. fluvialis* or *V. fluvialis* antibodies, from which we were able to extract 26 study records [68, 69, 71, 71, 80, 82, 83, 85, 105, 114, 116–121]. At least 20 species were reported in this dataset, representing 15 families. Four records did not provide sufficient data from which to identify birds to species or family. Culture was the most commonly utilized method to identify *V. fluvialis*, followed by a biochemistry panel. The largest cross-sectional study examining the prevalence of *V. fluvialis* in wild birds was performed on Canada Geese in Germany, however, only one of 289 birds cultured positive for the pathogen [116]. *V. fluvialis* was associated with one mortality event – a die-off of overwintering Mallards in Canada which was attributed to a Vitamin A deficiency [121]. The reported prevalence of the pathogen for these birds was 8%. In a study of captive study of Great Egrets (*Ardea alba*) captured from the Mississippi Delta, control birds shed *V. fluvialis* for four of seven days in captivity [117]. The highest prevalence was associated with a study performed in Connecticut involving Herring Gulls and Great Black-backed Gulls, with 55% culturing positive for *V. fluvialis*. Studies with a prevalence of 100% involved two experiments, one involving of avian-sourced strains, and a mitogenicity study on domestic chickens [119, 120]. Overall, the meta-analysis prevalence, including experimental infection studies (88/834) was 11% percent (85/834).

3.1.6 Other Pathogenic *Vibrio* spp.: *V. cincinnatiensis*, *V. hollinsae*, e.g., *Grimontia hollinsae*, *V. furnissii*, *V. mimicus*, *V. harveyi*, *V. scophthalmi*, *V. metschnikovi*, and *Photobacterium damsela*

The abundance of studies that reported on other pathogenic *Vibrio* species that were isolated from wild or domestic birds varied (Table 6). *V. cincinnatiensis* was examined by five studies and provided five study records [42, 70, 71, 85, 114]. Unspecified seabirds were the taxa that were examined most frequently [71, 85], however overall prevalences were low across all studies for a mean prevalence of 3%. The presence or absence of *Photobac-*

terium damsela was examined by three studies [69, 102, 122], and yielded three study records from the United Kingdom and the United States. Two studies involved mortality events, one of Common Loons in Florida, and the second of British passerines [102, 122]. Across these cross-sectional studies, the overall meta-analysis prevalence was approximately 5%. Our literature search of *V. furnissii* yielded four study records from three cross-sectional studies [71, 81, 114], two of those study records did not identify the number of birds positive or the number of individuals examined. The Laridae were the most prevalent species identified in association with *V. furnissii*, specifically Kelp Gulls (*Larus dominicanus*), Laughing Gulls, and Brown Boobys (*Sula leucogaster*). The overall meta-analysis prevalence for this *Vibrio* pathogen was approximately 2%.

The search for studies involving *V. harveyi* and avian species yielded four cross-sectional studies and four study records [70, 71, 85, 109], involving seabirds and Manx Shearwaters (*Puffinus puffinus*). A single study involving a coastal sandpiper, the Common Greenshank (*Tringa nebularia*), had a prevalence of 0% out of five birds that were tested by PCR [109]. From the two studies that provided individual birds positive in contrast to individual birds examined, we were able to calculate a *V. harveyi* prevalence of approximately 13%. No study that tested for this pathogen reported clinical signs or a mortality event. *Grimontia hollisae* was rarely detected in birds, as we found only two studies, resulting in three study records, that searched for the pathogen in avian hosts [123, 124]. One study examined the shared microbiota between wild Hooded Cranes (*Grus monacha*) and domestic geese (*Anser anser*) using Miseq – *Grimontia hollisae* was identified as a potential pathogen, but the total number of birds colonized was not reported [123]. A longitudinal microbiome study involving shorebirds off the coast of Cork, Ireland discovered *Grimontia hollisae* in fecal samples, however, the number of samples positive/examined was not enumerated [124]. Clinical signs or mortality were not reported from either study.

Vibrio metschnikovii was reported from three studies, resulting in 10 study records [83, 101, 125]. Approximately half the study records examined passerines of Romania as hosts [83], including members of the Laniidae, Sylviidae, and Paridae families, all of which were negative for the pathogen by biochemical panels. The highest prevalence was reported from sites in Inner Mongolia, China, by Black-headed Gulls (*Chroicocephalus ridibundus*), from which an overall study prevalence of 38% was reported [101]. Clinical signs and a mortality event that spanned multiple waterfowl and waterbird species were documented in the study by Zheng et al. 2021 [101]. The number of total tested birds were not available for analysis in the latter study; thus, we could not report a meta-analysis prevalence of *V. metschnikovi* with confidence. *Vibrio mimicus* was examined by six studies, yielding 18 study records [71, 83, 85, 110, 126]. Biochemical panels were the most common diagnostic tool used to identify the pathogen, however, overall prevalences were very low across studies. In a study of wading birds and songbirds performed along the Danube Delta of Romania, all sampled birds (n = 38) were negative for *V. mimicus* [83]. On the other hand, wading birds and seabirds sampled in China, Brazil, and Italy demonstrated evidence of shedding the pathogen [71, 103, 126]. The only study to examine the role of domestic birds as hosts was performed in Ogun State, Nigeria – this study yielded a prevalence of approximately 1% [101]. Across studies, 806 birds were examined for the presence of the pathogen, with 21 testing positive, resulting in a meta-analysis prevalence of 2%. No clinical signs or mortality events were reported from any study that examined the role of birds as hosts for *V. mimicus*.

Vibrio scophthalmi was only reported from one study, resulting in a single study record [103]. A Common Greenshank (1/26) that was sampled using whole genome sequencing was positive for the pathogen [103]. This study was not associated with clinical signs or a mortality event. Uncategorized *Vibrio* spp. were reported from 14 studies [68, 69, 71, 73, 74, 80, 83, 95, 100, 109, 124, 127–129]. Two studies were associated with clinical signs and/or mortality events, however, these outbreaks were attributed to other causal pathogens [100, 127]. Culture, followed by biochemical panels, were the most commonly utilized methods of identifying *Vibrio* spp. Given that many studies did not identify these *Vibrio* spp. to species or identify the number of birds excreting them, we were unable to calculate a meta-analysis wide prevalence.

4 Discussion

The question of pathogenic *Vibrio* spp. as the etiological agents of disease in birds remains only partially answered. Of the 76 studies that surveyed birds for pathogenic *Vibrio* species, 19 reported disease or death from individuals, scaling up to community level events [63, 66, 75, 77, 87, 89, 93, 96, 98, 100, 101, 108, 115, 118, 121, 125, 127]. Yet, it remains uncertain whether these pathogenic *Vibrio* species are opportunistic pathogens that contribute to morbidity and/or mortality in already stressed individuals, or whether they can be the primary arbiters of disease [111]. Experimental inoculation studies reported contrasting results, if they reported clinical signs at all [49, 87, 99, 120]. In addition, avian susceptibility to pathogenic *Vibrio* species may also be conflated by host species, natural history, and prior exposure, resulting in an as yet-understood degree of immunity [130, 131]. In our meta-analysis, disease was most commonly associated with *V. cholerae*, followed by *V. metschnikovi* and *V. parahaemolyticus* – notably, 11 of 39 study records were associated with domestic ducks (*Anas platyrhynchos* or *Anser anser*) or domestic chickens [66, 67, 75, 77, 87, 96]. This may have implications for agriculturally associated species in areas of the world where backyard birds are the primary protein source for pastoral families [132–134].

Of the 425 study records we extracted from the literature, interestingly, the Anatidae represented 105 of them, including wild and domesticated Mallards, which represented 16 study records. The Laridae represented 39 study records, prominently represented by Laughing Gulls, Herring Gulls, and Ring-billed Gulls. Shorebirds and waders, categorized into the Ardeidae family, represented 16 study records, primarily of egrets and herons. These bird species are often highly associated with coastal estuarine and marine environments [135–137], which are also inhabited by autochthonous and halophilic *Vibrio* species. These results are congruent with what is known of avian foraging ecology and *Vibrio* habitat specificity [6, 36, 55, 138–140]. What was unexpected were the number of ground-foraging birds that tested positive for pathogenic *Vibrio* species that are often not strictly associated with aquatic environments, such as Great Tits (*Parus major*), Garden Warblers (*Sylvia borin*), and Hooded Crows (*Corvus cornix*) [81, 83].

For example, in a study of Egyptian backyard poultry (chickens, turkeys, and waterfowl), 36% of examined birds were positive for *V. cholerae*, including chickens and turkeys [76]. Domestic chickens accounted for 13 total study records, across geographical areas as varied as the United States, Bangladesh, Egypt, Ghana, Nigeria, Iraq, and India, and reported as early as 1972 [65, 76, 87, 88, 91, 97, 110, 112, 120, 125]. On the other hand, another surprising result was the low prevalence of pathogenic *Vibrio* species cultured from seabirds that were sampled from the New England region of the United States, with only one of 192 birds testing positive for *Vibrio cholerae*, non-O1 [68]. This result may be due to several reasons, many of which are not mutually exclusive [137]. For one, as seabirds tend to spend more time in marine versus coastal habitats, they may be less susceptible to exposure from pathogenic *Vibrio* species that tend to congregate in lower salinity, brackish habitats [141]. In addition, the northern Atlantic may harbor a lower abundance of pathogenic *Vibrios* during the cooler months as a result of low sea surface temperatures [13] [12, 142]. Lastly, it may be possible that although pathogenic *Vibrio* spp. may cause disease in seabirds, that the recovery of carcasses or diseased individuals may be reduced due to minimal mortality, low carcass persistence, and increased distances from urbanized centers [143–145].

Meta-analysis prevalences varied across pathogenic *Vibrio* species, but all were below 20% (e.g., 19% for *V. parahaemolyticus*, 16% for *V. cholerae*, 13% for *V. harveyi*, 11% for *V. fluvialis*, 9% for *V. alginolyticus*, 8% for *V. vulnificus*, 5% for *P. damsela*, 2% for *V. furnissi*, and 1% for *V. mimicus*). Given that we utilized experimental inoculation studies coupled with cross-sectional studies, there is likely a degree of reporting bias in our meta-analysis prevalences [146], however, we speculate that this reporting bias is likely offset by the reportedly few studies that have targeted these pathogens for investigation in wild and domestic birds. To determine true ‘prevalence’, and avian susceptibility under ecological conditions, longitudinal studies that sought to recover these pathogens from a community of birds would be more informative [147, 148]. In addition, these studies

would need to utilize large sample sizes, as well as represent various ecological foraging guilds, in geographic locations with both low and high recovery rates of these pathogens from their aquatic, environmental reservoir [149–152].

With a meta-analysis *Vibrio* prevalence of 16% coupled with the reports of clinical signs, there is a possibility that pathogenic *Vibrio* species—specifically *V. parahaemolyticus*, *V. cholerae*, and *V. metschnikovi*—may be emerging pathogens of wild and domestic aquatic or wetland birds [153, 154]. Gire et al. 2012 [155] defined emerging pathogens as falling into two categories: introduced microbes, and existing microbes that rapidly increase in prevalence and/or incidence in a population. Given that so little is known of non-cholera *Vibrio* species in human hosts, however, it is difficult to distinguish between the two categories in our avian hosts given the currently available data. Speculation suggests that these *Vibrio* pathogens may have a long-standing relationship with aquatic birds. However, as climate change alters and influences the abundance and distribution of pathogenic *Vibrio* species in marine and estuarine environments, so too may the incidence of these pathogens in wild and domestic birds [156].

In summary, we have offered a rigorous meta-analysis that examines the prevalences of *Vibrio* spp. across bird species. In doing so, we reveal both a plethora of data that fortify the notion that birds are an underappreciated object of study and are potential reservoirs for pathogenic bacterial species. In the context of a dynamic ecology defined by climate change, and human-associated activities, we suggest that bird reservoirs should be the focus of more rigorous study, as they may be an actor in *Vibrio* emergence events. Transcending the case of birds, our species propose that more attention should be paid to other animal species that may harbor pathogens of interest to human health.

Table 1: This table details the study records extracted from the 41 studies that investigated birds as hosts for *Vibrio cholerae*, both O1 El tor and Non-O1. In the table are provided the common name, the scientific name, the family, the number of birds that tested positive for *Vibrio cholerae*, the total number of birds examined for *V. cholerae*, and the prevalence for that record. We also provide the country that the study was performed in, as well as the year the study was conducted or published. For studies that reported clinical signs or mortality, we placed a “Yes” in that column. For serotypes or strains, there were several primary categories, for Non-O1, this involves any *Vibrio cholerae* that was tested for the properties specific to *V. cholerae* O1. The designation O999 was used when no typing was utilized beyond species, e.g., the serotype of *V. cholerae* was not reported or investigated further. NA was provided when the prevalence was zero, and no serotype was applicable. When multiple serotypes were reported, but not tied to records, we specified that in the column, and when serotypes were provided and could be tied to a record, we noted that in the column as well.

Avian Species	Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
American Coot	Fulica americana	Rallidae	0	13	0	United States	1990	None reported	NA	[73]
American Coot	Fulica americana	Rallidae	44	117	0.38	United States	1989	None reported	O11, O14, O22, O23, O44, O106, O148, O176, O359, O999	[53]
American Coot	Fulica americana	Rallidae	1	2	0.5	United States	1989	None reported	Non-O1	[90]
American Flamingo	Phoenicopterus ruber	Phoenicopteridae	2	34	0.06	Venezuela	2012	None reported	Non-O1	[74]
American Flamingo	Phoenicopterus ruber	Phoenicopteridae	3	9	0.33	Mexico	1991	None reported	Non-O1	[63]
American Oystercatcher	Haematopus palliatus	Haematopodidae	4	15	0.27	Peru	2021	None reported	Non-O1	[80]
American Robin	Turdus americana	Turdidae	0	13	0	United States	2007	Unknown	NA	[90]
American White Pelican	Pelecanus erythrorhynchos	Pelecanidae	10	51	0.2	United States	1989	None reported	O17, O19, O22, O999	[53]

Avian Species	Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
American Widgeon	Mareca americana	Anatidae	0	41	0	United States	1990	No	NA	[73]
Anas spp.	Unknown	Anatidae	14	30	0.47	Egypt	2020	None reported	Non-O1	[76]
Aves spp.	Unknown	Unknown	3	23	0.13	Venezuela	2012	None reported	Non-O1	[74]
Aves spp.	Unknown	Unknown	54	343	0.16	Japan	2000	None reported	Non-O1	[95]
Aves spp.	Unknown	Unknown	2	7	0.29	Denmark	1977	None reported	Non-O1	[92]
Aves spp.	Unknown	Unknown	61	123	0.5	China	1994	None reported	Non-O1	[92]
Aves spp.	Unknown	Unknown	7	8	0.88	Australia	1989	None reported	Non-O1	[82]
Black Skimmer	Rynchops niger	Laridae	0	1	0	Venezuela	2012	None reported	NA	[74]
Black-and-white Magpie	Pica hudsonia	Corvidae	2	5	0.4	Romania	2021	No	O999	[83]
Black-bellied Whistling Duck	Dendrocygna autumnalis	Anatidae	3	110	0.03	Mexico	1992	No	Non-O1	[64]
Black-crowned Night Heron	Nycticorax nycticorax	Ardeidae	3	19	0.16	United States	1989	None reported	O60, O999	[53]
Black-crowned Night Heron	Nycticorax nycticorax	Ardeidae	4	16	0.25	United States	2007	None reported	Non-O1	[90]
Black-crowned Night Heron	Nycticorax nycticorax	Ardeidae	7	8	0.88	Israel	2018	None reported	O94	[78]
Black-headed Gull	Chroicocephalus ridibundus	Laridae	0	5	0	Israel	2018	None reported	NA	[78]
Black-headed Gull	Chroicocephalus ridibundus	Laridae	7	142	0.05	United Kingdom	1979	None reported	Multiple, not reported	[79]

Avian Species	Scientific Name	Family	Number Tested	Total Ex- amined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Black-headed Gull	Chroicocephalus ridibundus	Laridae	4	55	0.07	China	2018	Yes	Non-O1	[101]
Black-necked Stilt	Himantopus mexicanus	Charadriidae	0	55	0	China	2018	Yes	NA	[101]
Black-winged Stilt	Himantopus himantopus	Charadriidae	1	55	0.02	China	2018	Yes	Non-O1	[101]
Blue-winged Teal	Anas discors	Anatidae	1	80	0.01	United States	1990	No	O999	[73]
Blue-winged Teal	Anas discors	Anatidae	12	39	0.31	United States	1989	None reported	O19, O22, O23, O106, O355, O360, O999	[53]
Brown Pelican	Pelecanus occi- dentalis	Pelecanidae	1	6	0.17	United States	2007	None reported	Non-O1	[90]
Bufflehead	Bucephala albe- ola	Anatidae	2	12	0.17	United States	1990	No	O999	[73]
California Gull	Larus californi- cus	Laridae	1	93	1%	United States	1989	None reported	O22, O31, O340, O999	[53]
Canada Goose	Branta canaden- sis	Anatidae	2	4	50%	Canada	1985	Yes	Non-O1	[98]
Cattle Egret	Bubulcus ibis	Ardeidae	1	6	17%	United States	1989	None reported	O312, O359	[53]
Charadriiformes spp.	Unknown	Unknown	1	7	14%	Venezuela	2012	None reported	Non-O1	[74]
Cinnamon Teal	Spatula cyanoptera	Anatidae	1	2	50%	United States	1989	None reported	O106, O999	[53]

Avian Species	Scientific Name	Family	Number Tested	Total Ex- amined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Coal Tit	Periparus ater	Paridae	0	4	0%	Germany	1988	None reported	NA	[81]
Mourning Dove and Band-tailed Pigeon	Zenaida macroura and Patagioenas fasciata	Columbidae	0	16	0%	United States	2007	None reported	NA	[90]
Common Black- bird	Turdus merula	Turdidae	0	1	0%	Germany	1988	None reported	NA	[81]
Common Chaffinch	Fringilla coelebs	Fringillidae	0	3	0%	Romania	2021	None reported	NA	[83]
Common Gold- eneeye	Bucephala clan- gula	Anatidae	0	1	0%	United States	1990	No	NA	[73]
Common Gold- eneeye	Bucephala clan- gula	Anatidae	1	1	100%	United States	2007	Unknown	Non-O1	[90]
Common Green- shank	Tringa nebularia	Scolopacidae	0	2	0%	Romania	2021	No	NA	[83]
Common King- fisher	Alcedo atthis	Alcedinidae	0	1	0%	Romania	2021	No	NA	[83]
Common Moorhen	Gallinula chloro- pus	Rallidae	0	6	0%	United States	1990	No	NA	[73]
Common Murre	Uria aalge	Alcidae	3	31	10%	United States	2007	None reported	Non-O1	[90]
Common Pochard	Aythya ferina	Anatidae	1	55	2%	China	2018	Yes	Non-O1	[101]
Common Snipe	Gallinago galli- nago	Scolopacidae	2	3	67%	Romania	2021	None reported	O999	[83]

Avian Species	Scientific Name	Family	Number Tested	Total Ex- amined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Common Tern	Sterna hirundo	Laridae	2	2	100%	Germany	2019	Yes	Non-O1	[93]
Domestic chicken	Gallus gallus	Phasianidae	24	250	10%	Bangladesh	2008	None reported	O999	[65]
Domestic chicken	Gallus gallus	Phasianidae	4	22	18%	India	1973	None reported	O1 El tor Ogawa, Non-O1	[88]
Domestic chicken	Gallus gallus	Phasianidae	2	7	29%	Unknown	1977	None reported	Non-O1	[97]
Domestic chicken	Gallus gallus	Phasianidae	27	60	45%	Egypt	2020	None reported	Non-O1	[76]
Domestic chicken	Gallus gallus	Phasianidae	134	212	63%	Ghana	1973	Yes	O1 El tor Ogawa	[87]
Domestic chicken	Gallus gallus	Phasianidae	1	1	100%	India	1975	None reported	O999	[91]
Domestic Duck	Unknown	Anatidae	3	17	18%	Denmark	1975	Yes	Non-O1	[66]
Domestic Duck	Unknown	Anatidae	51	80	64%	Denmark	1978	None reported	O34, O60, O34, O54, O2,O57	[67]
Domestic Duck	Anas platyrhynchos	Anatidae	1	1	100%	Germany	2017	Yes	Non-O1	[75]
Domestic Duck	Anas platyrhynchos	Anatidae	1	1	100%	Germany	2016	Yes	Non-O1	[75]
Domestic Duck	Anas platyrhynchos	Anatidae	1	1	100%	Germany	2011	Yes	Non-O1	[75]

Avian Species	Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Domestic Duck	Anas platyrhynchos	Anatidae	1	1	100%	Germany	1996	Yes	Non-O1	[75]
Domestic Goose	Anser anser	Anatidae	1	2	50%	United States	1980	Yes	Non-O1	[89]
Domestic Turkey	Meleagris gallopavo	Meleagrididae	0	20	0%	Egypt	2020	None reported	NA	[76]
Domestic Turkey	Meleagris gallopavo	Meleagrididae	1	23	4%	Germany	2012	Yes	Non-O1	[77]
Double-crested Cormorant	Phalacrocorax auritus	Phalacrocoracidae	32	84	38%	United States	1989	None reported	O12, O22, O23, O106, O360, O999	[53]
Eared Grebe	Podiceps nigricollis	Podicipedidae	1	2	50%	United States	2007	Unknown	Non-O1	[90]
Eastern Spot-billed Duck	Anas zonorhyncha	Anatidae	3	55	5%	China	2018	Unknown	Non-O1	[101]
Elegant Tern	Thalasseus elegans	Laridae	0	51	0%	Mexico	2012	None reported	NA	[72]
Eurasian Blue Tit	Cyanistes caeruleus	Paridae	0	5	0%	Germany	1988	None reported	NA	[81]
Eurasian Hobby	Falco subbuteo	Falconidae	2	2	100%	Romania	2021	No	O999	[83]
Eurasian Nuthatch	Sitta europaea	Paridae	1	5	20%	Germany	1988	None reported	Non-O1	[81]
Eurasian Sparrowhawk	Accipiter nisus	Accipitridae	1	2	50%	Romania	2021	No	O999	[83]

Avian Species		Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Eurasian Sparrow	Tree	Passer montanus	Passeridae	0	1	0%	Germany	1988	None reported	NA	[81]
Eurasian Sparrow	Tree	Passer montanus	Passeridae	2	2	100%	Romania	2021	No	O999	[83]
Eurasian Whim-brel		Numenius phaeopus	Scolopacidae	0	9	0%	Peru	2021	None reported	NA	[80]
Herring Gull		Larus argentatus	Laridae	1	55	2%	China	2018	Yes	Non-O1	[101]
Herring Gull		Larus argentatus	Laridae	5	88	6%	United Kingdom	1979	None reported	Multiple, not reported	[79]
Franklin's Gull		Leucophaeus pipixcan	Laridae	8	41	20%	United States	1989	None reported	O11, O22, O43, O999	[53]
Gadwall		Mareca strepera	Anatidae	10	200	5%	United States	1990	No	O999	[73]
Gadwall		Mareca strepera	Anatidae	2	3	67%	United States	1990	None reported	O22	[53]
Great Black-backed Gull and Herring Gull		Larus marinus and Larus argentatus	Laridae	23	45	56%	United States	1990	None reported	Non-O1	[69]
Great Blue Heron		Ardea herodias	Ardeidae	11	24	46%	United States	1989	None reported	O22, O1 El tor Ogawa	[53]
Great Cormorant		Phalacrocorax carbo	Phalacrocoracidae	1	55	2%	China	2017	Unknown	Non-O1	[101]
Great Cormorant		Phalacrocorax carbo	Phalacrocoracidae	9	11	82%	Israel	2017	None reported	Non-O1	[49]
Great Spotted Woodpecker		Dendrocopus major	Picidae	0	1	0%	Germany	1988	None reported	Non-O1	[81]

Avian Species	Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Great Tit	Parus major	Paridae	4	12	33%	Germany	1988	None reported	Non-O1	[81]
Greater Black-backed Gull	Larus marinus	Laridae	3	15	20%	United Kingdom	1979	None reported	Multiple, not reported	[79]
Greater Scaup	Aythya marila	Anatidae	0	1	0%	United States	1990	None reported	NA	[73]
Greater Scaup	Aythya marila	Anatidae	2	3	67%	United States	2007	Unknown	NA	[90]
Greater Yellowlegs	Tringa melanoleuca	Scolopacidae	6	6	100%	Venezuela	2006	None reported	O1 El tor Inaba	[84]
Green Heron	Butorides virescens	Ardeidae	2	8	25%	United States	2007	Unknown	Non-O1	[90]
Green-winged Teal	Anas carolinensis	Anatidae	2	35	6%	United States	1989	None reported	O22, O106, O999	[53]
Green-winged Teal	Anas carolinensis	Anatidae	15	255	6%	United States	1990	No	O999	[90]
Grey Gull	Leucophaeus modestus	Laridae	0	5	0%	Peru	2021	None reported	NA	[80]
Guanay Cormorant	Leucocarbo bougainvillorum	Phalacrocoracidae	0	1	0%	Peru	2021	None reported	NA	[80]
Heerman's Gull	Larus heermanni	Laridae	0	44	0%	Mexico	2012	None reported	NA	[72]
Heron spp.	Unknown	Ardeidae	1	6	17%	Venezuela	2012	None reported	Non-O1	[74]
Hooded Merganser	Lophodytes cucullatus	Anatidae	0	3	0%	United States	1990	No	O999	[73]
House Crow	Corvus splendens	Corvidae	3	3	100%	India	1970	None reported	O17, O23, O308	[86]

Avian Species	Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Ibis spp.	Unknown	Threskiornithidae	0	3	0%	Venezuela	2012	None reported	NA	[74]
Indian Spot-billed Duck	Anas poe-cilorhyncha	Anatidae	0	55	0%	China	2018	Yes	Non-O1	[101]
Indian Spot-billed Duck	Anas poe-cilorhyncha	Anatidae	2	2	100%	China	1996	Yes	Multiple, not reported	[99]
Kelp Gull	Larus dominicanus	Laridae	5	11	45%	Brazil	2009	None reported	Non-O1	[71]
Killdeer	Charadrius vociferus	Charadriidae	0	2	0%	Peru	2021	None reported	NA	[80]
Killdeer	Charadrius vociferus	Charadriidae	13	15	87%	United States	1989	None reported	O22, O106, O999	[53]
Large-billed Tern	Phaetusa simplex	Laridae	1	1	100%	Venezuela	2012	None reported	Non-O1	[74]
Laughing Gull	Leucophaeus atricilla	Laridae	1	7	14%	Peru	2021	None reported	Non-O1	[80]
Least Sandpiper	Calidris minutilla	Scolopacidae	0	1	0%	Venezuela	2012	None reported	NA	[74]
Lesser Scaup	Aythya affinis	Anatidae	0	8	0%	United States	1990	No	NA	[73]
Little Egret	Egretta garzetta	Ardeidae	5	11	45%	Israel	2018	None reported	O13, O36, O171, O6, O123, O36, O16, O128, O40, O21, O193, O36	[78]
Magnificent Frigatebird	Fregata magnificens	Fregatidae	0	1	0%	Venezuela	2012	None reported	NA	[74]

Avian Species	Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Mallard	Anas platyrhynchos	Anatidae	0	32	0%	United States	1990	None reported	NA	[73]
Mallard	Anas platyrhynchos	Anatidae	27	306	9%	United States	1989	None reported	O22, O48, O999	[53]
Mallard	Anas platyrhynchos	Anatidae	2	12	17%	United States	2007	Unknown	Non-O1	[90]
Mallard	Anas platyrhynchos	Anatidae	17	29	59%	Hungary	1979	None reported	Non-O1	[94]
Mallard	Anas platyrhynchos	Anatidae	2	2	100%	China	1996	None reported	Multiple, not reported	[99]
Manx Shearwater	Puffinus puffinus	Procellariidae	1	35	3%	Brazil	2014	None reported	Non-O1	[70]
Mottled Duck	Anas fulvigula	Anatidae	2	123	2%	United States	1990	None reported	O999	[73]
Mute Swan	Cygnus olor	Anatidae	2	2	100%	United Kingdom	1979	None reported	O2	[79]
Neotropic Cormorant	Phalacrocorax brasilianus	Phalacrocoracidae	0	3	0%	Venezuela	2012	None reported	NA	[74]
Northern Pintail	Anas acuta	Anatidae	0	53	0%	United States	1990	No	NA	[73]
Northern Pintail	Anas acuta	Anatidae	5	56	9%	United States	1989	None reported	O22, O360, O999	[53]
Northern Shoveler	Spatula clypeata	Anatidae	3	37	8%	United States	1990	No	O999	[73]
Parus spp.	Unknown	Paridae	4	22	18%	Germany	1988	None reported	Non-O1	[81]

Avian Species	Scientific Name	Family	Number Tested	Total Ex- amined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Passerine spp.	Unknown	Unknown	Not re- ported	Not re- ported	NA	Germany	1988	None reported	Non-O1	[81]
Passerines	Unknown	Unknown	0	24	0%	United States	2007	Unknown	NA	[90]
Peruvian Booby	<i>Sula variegata</i>	Sulidae	1	1	100%	Peru	2021	None reported	Non-O1	[80]
Peruvian Pelican	<i>Pelecanus thagus</i>	Pelecanidae	1	1	100%	Peru	2021	None reported	Non-O1	[80]
Red-footed Falcon	<i>Falco vespertinus</i>	Falconidae	2	2	100%	Romania	2021	None reported	Non-O1	[83]
Redhead	<i>Aythya ameri- cana</i>	Anatidae	0	1	0%	United States	1990	None reported	O999	[73]
Redhead	<i>Aythya ameri- cana</i>	Anatidae	1	17	6%	United States	1989	None reported	O999	[53]
Rhinoceros auk- let	<i>Cerorhinca monocerata</i>	Alcidae	1	1	100%	United States	2007	Unknown	Non-O1	[90]
Ring-billed Gull	<i>Larus delawarensis</i>	Laridae	17	112	15%	United States	1989	None reported	O1 (not dis- tinguished to Ogawa or Inaba), O16, O22, O102, O106, O999	[53]
Ring-necked Duck	<i>Aythya collaris</i>	Anatidae	4	37	11%	United States	1990	No	O999	[73]
Rook	<i>Corvus frugile- gus</i>	Corvidae	1	28	4%	United King- dom	1989	None reported	Multiple, not reported	[79]

Avian Species	Scientific Name		Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Ruddy Shelduck	Tadorna	fer-	Anatidae	2	5	40%	United States	2007	Unknown	Non-O1	[90]
Ruddy Shelduck	Tadorna	fer-	Anatidae	25	55	45%	China	2018	Yes	Non-O1	[101]
Seabirds	Unknown		Unknown	1	192	0.50%	United States	2008	None reported	Non-O1	[68]
Seabirds	Unknown		Unknown	4	116	3%	Brazil	2010	None reported	Non-O1	[71]
Seabirds	Unknown		Unknown	Unknown	69	NA	Brazil	2010	None reported	O999	[85]
Semipalmated Plover	Charadrius	semi-	Scolopacidae	0	1	0%	Venezuela	2012	None reported	NA	[74]
Semipalmated Sandpiper	Charadrius		Scolopacidae	1	2	50%	Venezuela	2012	None reported	Non-O1	[74]
Snow Goose	Chen		Anatidae	0	22	0%	United States	1990	No	NA	[73]
Snowy Egret	Egretta	thula	Ardeidae	1	13	8%	United States	1989	None reported	O14, O340, O999	[53]
Song Thrush	Turdus	philome-	Turdidae	1	2	50%	Romania	2021	No	Non-O1	[83]
Squacco Heron	Ardeola	ralloides	Ardeidae	1	2	50%	Romania	2021	No	Non-O1	[83]
Surf Scoter	Melanitta	perspi-	Anatidae	6	11	54%	United States	2007	Unknown	Non-O1	[90]
Wading bird spp.	Unknown		Unknown	2	2	100%	United States	2007	Unknown	Non-O1	[90]
Wattled Jacana	Jacana	jacana	Jacanidae	2	6	33%	Venezuela	2012	None reported	Non-O1	[74]

Avian Species	Scientific Name	Family	Number Tested	Total Ex- amined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Western Grebe	Aechmophorus occidentalis	Podicipedidae	2	12	17%	United States	2007	Unknown	Non-O1	[90]
Western Gull	Larus occidentalis	Laridae	1	7	14%	United States	2007	Unknown	Non-O1	[90]
Western Jackdaw	Coloeus monedula	Corvidae	0	4	0%	Romania	2021	None reported	NA	[83]
Western Scrub-Jay	Aphlecoma californica	Corvidae	0	12	0%	United States	2007	Unknown	NA	[90]
White Pekin Duck	Anas platyrhynchos domesticus	Anatidae	2	187	1%	United States	1993	Yes	O999	[96]
White-faced Ibis	Plegadis chihi	Threskiornithidae	1	30	3%	United States	1989	None reported	O14	[53]
Wilson's Phalarope	Phalaropus tricolor	Scolopacidae	6	11	55%	United States	1989	None reported	O999	[53]
Wilson's Plover	Charadrius wilsonia	Charadriidae	16	16	100%	Venezuela	2006	None reported	Non-O1	[84]
Wood Duck	Aix sponsa	Anatidae	0	3	0%	United States	1990	None reported	NA	[73]
Wood Duck	Aix sponsa	Anatidae	0	55	0%	China	2018	Yes	NA	[101]
Yellow-legged Gull	Larus michahellis	Laridae	1	93	1%	France	2013	None reported	Non-O1	[62]

Table 2: This table details the study records extracted from the 20 studies that investigated birds as hosts for *Vibrio parahaemolyticus*. In the table are provided the common name, the scientific name, the family, the number of birds that tested positive for *Vibrio parahaemolyticus*, the total number of birds examined for *V. parahaemolyticus*, and the prevalence for that record. We also provide the country that the study was performed in, as well as the year the study was conducted or published. For studies that reported clinical signs or mortality, we placed a “Yes” in that column. For serotypes or strains, we identified the strain when it was available. NA was provided when the prevalence was zero, and no strain was applicable.

Avian Species	Scientific Name	Family	Number Posi- tive	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
American Coot	Fulica americana	Rallidae	0	13	0%	United States	1990	None reported	Not specified	[73]
American Wid- geon	Mareca americana	Anatidae	3	41	7%	United States	1990	None reported	Not specified	[73]
Anas spp.	Unknown	Anatidae	57	171	33%	Japan	2005	None reported	Not specified	[106]
Aves spp.	Unknown	Unknown	0	298	0%	China	2019	None reported	Not specified	[100]
Aves spp.	Unknown	Unknown	29	343	8%	Japan	2000	None reported	Not specified	[95]
Aves spp.	Unknown	Unknown	1	8	13%	India	1986	None reported	Not specified	[104]
Aves spp.	Unknown	Unknown	4	8	50%	Australia	1989	None reported	Not specified	[82]
Black-and-White Magpie	Pica hudsonia	Corvidae	0	5	0%	Romania	2021	None reported	NA	[83]
Black-crowned Crane	Balearica pavonine	Gruidae	1	1	100%	Japan	1965	None reported	Biotype 1	[24]
Black-crowned Night Heron	Nycticorax nyctico- rax	Ardeidae	0	2	0%	Romania	1989	None reported	NA	[83]
Black-headed Gull	Chroicocephalus ridibundus	Laridae	68	125	54%	Japan	2005	None reported	NA	[106]
Black-tailed God- wit	Limosa limosa	Scolopacidae	1	2	50%	China	2005	None reported	Not specified	[109]

Avian Species	Scientific Name	Family	Number Posi- tive	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Blue-winged Teal	Anas discors	Anatidae	0	80	0%	United States	1990	No	NA	[73]
Brown Pelican	Pelecanus occiden- talis	Pelecanidae	20	42	48%	United States	1990	None reported	Not specified	[69]
Bufflehead	Bucephala albeola	Anatidae	1	12	8%	United States	1990	No	Not specified	[73]
Charadriiformes spp.	Unknown	Unknown	71	112	64%	China	2019	None reported	Not specified	[100]
Chinese Bamboo Partridge	Bambusicola tho- racicus	Phasianidae	1	1	100%	Japan	1966	None reported	Biotype 2	[24]
Common Gold- eneye	Bucephala clangula	Anatidae	0	1	0%	United States	1990	No	NA	[73]
Common Green- shank	Tringa nebularia	Scolopacidae	6	26	23%	China	2017	None reported	Not specified	[103]
Common Green- shank	Tringa nebularia	Scolopacidae	2	5	40%	China	2015	None reported	Not specified	[109]
Common Loon	Gavia immer	Gaviidae	1	434	0.20%	United States	1994	Yes	Not specified	[102]
Common Moorhen	Gallinula chloropus	Rallidae	0	6	0%	United States	1990	No	NA	[73]
Common Teal	Anas crecca	Anatidae	1	1	100%	Japan	2005	None reported	Not specified	[106]
Cormorant spp.	Unknown	Phalacrocoracidae	0	23	0%	China	2018	None reported	NA	[100]
Crested Fireback	Lophura ignita	Phasianidae	1	1	100%	Japan	1965	None reported	Biotype 1	[24]
Crested Ibis	Nipponia nippon	Threskiornithidae	1	1	100%	Japan	1965	None reported	Biotype 1	[24]

Avian Species	Scientific Name	Family	Number Posi- tive	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Demoiselle Crane	<i>Grus virgo</i>	Gruidae	0	125	0%	China	2019	None reported	NA	[100]
Elegant Tern	<i>Thalasseus elegans</i>	Laridae	1	51	2%	Mexico	2012	None reported	Not specified	[72]
Eurasian Black- cap	<i>Sylvia atricapilla</i>	Sylviidae	0	1	0%	Romania	2021	None reported	NA	[83]
Eurasian Blue Tit	<i>Cyanistes caeruleus</i>	Paridae	0	2	0%	Romania	2021	None reported	NA	[83]
Eurasian Curlew	<i>Numenius arquata</i>	Scolopacidae	1	2	50%	China	2015	None reported	NA	[109]
Eurasian Spar- rowhawk	<i>Accipiter nisus</i>	Falconidae	0	2	0%	Romania	2021	None reported	NA	[83]
Gadwall	<i>Mareca streptera</i>	Anatidae	16	200	8%	United States	1990	No	Not specified	[73]
Garden Warbler	<i>Sylvia borin</i>	Sylviidae	0	4	0%	Romania	2021	No	NA	[83]
Great Argus	<i>Argusianus argus</i>	Phasianidae	1	1	100%	Japan	1965	None reported	Biotype 1	[24]
Great Black- backed Gull and Herring Gull	<i>Larus marinus</i> and <i>Larus argentatus</i>	Laridae	23	45	56%	United States	1990	None reported	Not specified	[69]
Greater Scaup	<i>Aythya marila</i>	Anatidae	0	1	0%	United States	1990	None reported	NA	[73]
Green Pheasant	<i>Phasianus versicolor</i>	Phasianidae	1	1	100%	Japan	1965	No	Not specified	[24]
Green-winged Teal	<i>Anas carolinensis</i>	Anatidae	18	255	7%	United States	1990	No	Not specified	[90]
Grey-hooded Parakeet	<i>Psilopsiagon mara</i>	Ay- Psittacidae	0	1	0%	Germany	2020	Yes	NA	[108]

Avian Species	Scientific Name	Family	Number Posi- tive	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Helmeted Guineafowl	Numida meleagris	Numididae	1	1	100%	Japan	1965	None reported	Biotype 1	[24]
Heron spp.	Unknown	Ardeidae	26	89	29%	China	2018	None reported	Not specified	[100]
Herring Gull, Laughing Gull, Ring-billed Gull	Larus argenta- tus, Leucophaeus atricilla, Larus delawarensis	Laridae	29	42	69%	United States	1990	None reported	Not specified	[69]
Herring Gull and Ring-billed Gull	Larus argentatus and Larus delawarensis	Laridae	23	45	56%	United States	1990	None reported	Not specified	[69]
Herring Gull and Black-backed	Larus argentatus and Larus crassirostris	Laridae	216	320	68%	Japan	2005	None reported	Not specified	[106]
Hooded Crow	Corvus cornix	Corvidae	0	7	0%	Romania	2021	None reported	NA	[83]
Hooded Mer- ganser	Lophodytes cuculla- tus	Anatidae	0	3	0%	United States	1990	None reported	NA	[73]
Icterine Warbler	Hippolais icterina	Acrocephalidae	0	1	0%	Romania	2021	None reported	NA	[83]
Japanese Quail	Coturnix coturnix	Phasianidae	Unknown	Unknown	Unknown	Korea	2011	None reported	ATCC 17802	[105]
Lady Amherst's Pheasant	Chrysolophus amherstiae	Phasianidae	1	1	100%	Japan	1965	None reported	Not specified	[24]
Lesser Scaup	Aythya affinis	Anatidae	0	8	0%	United States	1990	None reported	NA	[73]
Mallard	Anas platyrhynchos	Anatidae	2	32	6%	United States	1990	None reported	Not specified	[73]
Mallard	Anas platyrhynchos	Anatidae	72	267	27%	China	2018	None reported	Not specified	[100]
Mallard	Anas platyrhynchos	Anatidae	33	73	45%	Japan	2005	None reported	Not specified	[106]

Avian Species	Scientific Name	Family	Number Posi- tive	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Manx Shearwater	<i>Puffinus puffinus</i>	Procellariidae	7	35	20%	Brazil	2014	None reported	Not specified	[70]
Budgerigar	<i>Melopsittacus undulatus</i>	Psittaculidae	1	2	50%	Germany	2020	Yes	Not specified	[108]
Mottled Duck	<i>Anas fulvigula</i>	Anatidae	5	123	4%	United States	1990	None reported	NA	[73]
Northern Pintail	<i>Anas acuta</i>	Anatidae	4	53	8%	United States	1990	None reported	Not specified	[73]
Northern Shoveler	<i>Spatula clypeata</i>	Anatidae	3	37	8%	United States	1990	None reported	Not specified	[73]
Red-backed Shrike	<i>Lanius collurio</i>	Laniidae	0	1	0%	Romania	2021	None reported	NA	[83]
Red-crowned Crane	<i>Grus japonensis</i>	Gruidae	0	26	0%	China	2018	None reported	NA	[100]
Redhead	<i>Aythya americana</i>	Anatidae	0	1	0%	United States	1990	None reported	NA	[73]
Reeve's Pheasant	<i>Syrnaticus reevesii</i>	Phasianidae	1	1	100%	Japan	1965	None reported	Not specified	[24]
Ring-necked Duck	<i>Aythya collaris</i>	Anatidae	0	37	0%	United States	1990	None reported	NA	[73]
Seabirds	Unknown	Unknown	0	192	0%	United States	2008	None reported	NA	[68]

Avian Species	Scientific Name	Family	Number Posi- tive	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Seabirds	Unknown	Unknown	4	116	3%	Brazil	2010	None reported	Not specified	[71]
Seabirds	Unknown	Unknown	Unknown	69	NA	Brazil	2010	None reported	Not specified	[85]
Snow Goose	<i>Chen caerulescens</i>	Anatidae	0	22	0%	United States	1990	None reported	NA	[73]
Snowy Egret	<i>Egretta thula</i>	Ardeidae	1	2	50%	United States	1990	None reported	Not specified	[69]
Squacco Heron	<i>Ardeola raloides</i>	Ardeidae	1	2	50%	Romania	2021	None reported	Not specified	[83]
Swinhoe's Pheasant	<i>Lophura swinhoii</i>	Phasianidae	1	1	100%	Japan	1965	None reported	Biotype 1	[24]
Wood Duck	<i>Aix sponsa</i>	Anatidae	0	3	0%	United States	1990	None reported	Not specified	[73]

Table 3: This table details the records extracted from the eight studies that investigated birds as hosts for *Vibrio vulnificus*. In the table are provided the common name, the scientific name, the family, the number of birds that tested positive for *Vibrio vulnificus*, the total number of birds examined for the pathogen, and the prevalence for that record. We also provide the country that the study was performed in, as well as the year the study was conducted or published. For studies that reported clinical signs or mortality, we placed a “Yes” in that column. For serotypes or strains that were reported, we reported those as well, otherwise we designated the column as not specified.

Avian Species	Scientific Name	Family	Tested Number	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
American Crow	Corvus brachyrhynchos	Corvidae	Unknown	Unknown	Unknown	United States	2019	None reported	NA	[111]
Barred Warbler	Curruca nisoria	Sylviidae	0	3	0%	Romania	2021	None reported	NA	[83]
Black-crowned Night Heron	Nycticorax nycticorax	Ardeidae	0	2	0%	Romania	2021	None reported	NA	[83]
Black-headed Gull	Chroicocephalus ridibundus	Laridae	1	125	1%	Japan	2005	None reported	Not specified	[106]
Black-tailed Godwit	Limosa limosa	Scolopacidae	1	2	50%	China	2015	None reported	Not specified	[109]
Common Green-shank	Tringa nebularia	Scolopacidae	0	5	0%	China	2015	None reported	Not specified	[109]
Common Teal	Anas crecca	Anatidae	0	1	0%	Japan	2005	None reported	NA	[106]
Domestic chicken	Gallus gallus	Phasianidae	4	565	0.70%	Nigeria	2017	None reported	Not specified	[110]
Eurasian Blue Tit	Cyanistes caeruleus	Paridae	0	2	0%	Romania	2021	None reported	NA	[83]
Common Teal	Anas crecca	Anatidae	0	2	0%	Romania	2021	None reported	NA	[83]
Garden Warbler	Sylvia borin	Sylviidae	0	4	0%	Romania	2021	None reported	NA	[83]
Herring Gull and Black-tailed Gull	Larus argentatus and Larus crassirostris	Laridae	86	320	27%	Japan	2005	None reported	NA	[106]
Hooded Crow	Corvus cornix	Corvidae	0	7	0%	Romania	2021	None reported	NA	[83]

Avian Species	Scientific Name	Family	Tested Number	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Japanese Quail	Coturnix coturnix	Phasianidae	Unknown	Unknown	Unknown	Korea	2011	None reported	KCTC 2959	[105]
Laughing Gull	Leucophaeus atricilla	Laridae	Unknown	Unknown	Unknown	United States	2021	None reported	Not specified	[111]
Lesser Whitethroat	Sylvia curruca	Sylviidae	0	2	0%	Romania	2021	Not reported	NA	[83]
Mallard	Anas platyrhynchos	Anatidae	0	73	0%	Japan	2005	None reported	NA	[106]
Muscovy Duck	Cairina moschata	Anatidae	Unknown	Unknown	Unknown	United States	2019	None reported	Not specified	[111]
Seabirds	Unknown	Unknown	2	116	2%	Brazil	2010	None reported	Not specified	[71]
Seabirds	Unknown	Unknown	Unknown	69	NA	Brazil	2010	None reported	Not specified	[85]
Wood Sandpiper	Tringa glareola	Scolopacidae	0	2	0%	Romania	2021	Not reported	NA	[83]

Table 4: This table details the records extracted from the 15 studies that investigated birds as hosts for *Vibrio alginolyticus*. In the table are provided the common name, the scientific name, the family, the number of birds that tested positive for *Vibrio cholerae*, the total number of birds examined for *Vibrio alginolyticus*, and the prevalence for that record. We also provide the country that the study was performed in, as well as the year the study was conducted or published. For studies that reported clinical signs or mortality, we placed a “Yes” in that column.

Avian Species	Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Kelp Gull	<i>Larus dominicanus</i>	Laridae	Unknown	Unknown	Unknown	Brazil	2011	None reported	Not specified	[114]
Lesser Scaup	<i>Aythya affinis</i>	Anatidae	0	8	0%	United States	1990	None reported	NA	[73]
Magellanic Penguin	<i>Spheniscus magellanicus</i>	Spheniscidae	Unknown	Unknown	Unknown	Brazil	2011	None reported	Not specified	[114]
Mallard	<i>Anas platyrhynchos</i>	Anatidae	0	32	0%	United States	1990	None reported	NA	[73]
Manx Shearwater	<i>Puffinus puffinus</i>	Procellariidae	1	35	3%	Brazil	2014	None reported	Not specified	[70]
Mauritius Kestrel	<i>Falco punctatus</i>	Falconidae	1	6	17%	Mauritania	1986	None reported	Not specified	[113]
Mottled Duck	<i>Anas fulvigula</i>	Anatidae	0	123	0%	United States	1990	None reported	NA	[73]
Mute Swan	<i>Cygnus olor</i>	Anatidae	2	3	67%	United States	1990	None reported	Not specified	[69]
Northern Pintail	<i>Anas acuta</i>	Anatidae	0	53	0%	United States	1990	None reported	NA	[73]
Northern Shoveler	<i>Spatula clypeata</i>	Anatidae	1	37	3%	United States	1990	None reported	Not specified	[73]
Red-backed Shrike	<i>Lanius collurio</i>	Laniidae	0	1	0%	Romania	2021	None reported	NA	[83]

Avian Species	Scientific Name	Family	Tested Number	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Red-footed Falcon	Falco vespertinus	Falconidae	0	2	0%	Romania	2021	None reported	NA	[83]
Redhead	Aythya americana	Anatidae	0	1	0%	United States	1990	None reported	NA	[73]
Ring-necked Duck	Aythya collaris	Anatidae	1	37	3%	United States	1990	None reported	Not specified	[73]
Seabirds	Unknown	Unknown	8	192	4%	United States	2008	None reported	Not specified	[68]
Seabirds	Unknown	Unknown	30	116	26%	Brazil	2010	None reported	Not specified	[71]
Seabirds	Unknown	Unknown	19	69	28%	Brazil	2010	None reported	Not specified	[85]
Snow Goose	Chen caerulescens	Anatidae	0	22	0%	United States	1990	No	NA	[73]
Song Thrush	Turdus philomelos	Turdidae	0	2	0%	Romania	2021	No	NA	[83]
Squacco Heron	Ardeola ralloides	Ardeidae	1	2	50%	Romania	2021	No	Not specified	[83]
Wedge-tailed Shearwater	Ardenna pacifica	Procellariidae	24	246	10%	United States	1994	Yes	Not specified	[115]
Wood Duck	Aix sponsa	Anatidae	0	3	0%	United States	1990	None reported	NA	[73]

Table 5: This table details the records extracted from the 15 studies that investigated birds as hosts for *Vibrio alginolyticus*. In the table are provided the common name, the scientific name, the family, the number of birds that tested positive for *Vibrio cholerae*, the total number of birds examined for *Vibrio alginolyticus*, and the prevalence for that record. We also provide the country that the study was performed in, as well as the year the study was conducted or published. For studies that reported clinical signs or mortality, we placed a “Yes” in that column.

Avian Species	Scientific Name	Family	Number Positive	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
American Oystercatcher	Haematopus palli-ates	Haematopodidae	2	15	13%	Peru	2021	None reported	Not specified	[80]
Aves spp.	Unknown	Unknown	4	8	50%	Australia	1989	None reported	Not specified	[82]
Aves spp.	Unknown	Unknown	4	4	100%	Unknown	1983	None reported	Not specified	[119]
Brown Booby	Sula leucogaster	Sulidae	Unknown	Unknown	Unknown	Brazil	2011	None reported	Not specified	[114]
Brown Pelican	Pelecanus occiden-talis	Pelecanidae	20	42	48%	United States	1990	None reported	Not specified	[69]
Canada Goose	Branta canadensis	Anatidae	1	289	0.30%	Germany	2003	None reported	Not specified	[116]
Common King-fisher	Alcedo atthis	Alcedinidae	0	1	0%	Romania	2021	None reported	NA	[83]
Domestic chicken	Gallus gallus	Phasianidae	10	10	100%	Iraq	2014	None reported	Not specified	[120]
Domestic Duck	Unknown	Anatidae	5	Unknown	Unknown	Botswana	2010	Yes	Not specified	[118]
Eurasian Hobby	Falco subbuteo	Falconidae	0	2	0%	Romania	2021	None reported	NA	[83]
Eurasian Tree Sparrow	Passer montanus	Passeridae	0	2	0%	Romania	2021	None reported	NA	[83]
Great Black-backed Gull and Herring Gull	Larus marinus and Larus argentatus	Laridae	23	45	56%	United States	1990	None reported	Not specified	[69]
Great Egret	Ardea alba	Ardeidae	3	11	27%	United States	2012	None reported	Not specified	[117]

Avian Species	Scientific Name	Family	Number Positive	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Great Tit	Parus major	Paridae	0	2	0%	Romania	2021	None reported	NA	[83]
Laughing Gull	Leucophaeus atricilla	Laridae	2	15	13%	Peru	2021	None reported	Not specified	[80]
Magellanic Penguin	Spheniscus magellanicus	Anatidae	Unknown	Unknown	Unknown	Brazil	2011	None reported	Not specified	[114]
Mallard	Anas platyrhynchos	Anatidae	3	38	8%	Canada	1991	Yes	Not specified	[121]
Manx Shearwater	Puffinus puffinus	Procellariidae	2	35	6%	Brazil	2014	None reported	Not specified	[70]
Red-backed Shrike	Lanius collurio	Laniidae	0	1	0%	Romania	2021	None reported	NA	[83]
Red-footed Falcon	Falco vespertinus	Falconidae	0	2	0%	Romania	2021	None reported	NA	[83]
Seabirds	Unknown	Unknown	0	192	0%	United States	2008	None reported	NA	[68]
Seabirds	Unknown	Unknown	9	116	3%	Brazil	2010	None reported	Not specified	[71]
Seabirds	Unknown	Unknown	Unknown	69	NA	Brazil	2010	None reported	Not specified	[85]
Western Jackdaw	Coleus monedula	Corvidae	0	4	0%	Romania	2021	None reported	NA	[83]

Table 6: This table details the records extracted from the 18 studies that investigated birds as hosts for other pathogenic *Vibrios*, including *V.metschnikovii*, *V. mimicus*, *V. cincinnatiensis*, *V. scophtalmi*, *Grimontia hollisae*, formerly *V. hollisae*, *Photobacterium damsela*, formerly *V. damsela*, *V. furnissii*, and *V. harveyi*. In the table are provided the common name, the scientific name, the family, the number of birds that tested positive for the respective pathogen, the total number of birds examined, and the prevalence for that record. We also provide the country that the study was performed in, as well as the year the study was conducted or published. For studies that reported clinical signs or mortality, we placed a “Yes” in that column.

Avian Species	Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Barred Warbler	Curruca nisoria	Sylviidae	1	1	100%	Romania	2021	None reported	Vibrio metschnikovii	[83]
Bearded Warbler	Panurus biamicus	Paridae	0	3	0%	Romania	2021	None reported	Vibrio metschnikovii	[83]
Black-and-White Magpie	Pica hudsonia	Corvidae	0	2	0%	Romania	2021	None reported	Vibrio metschnikovii	[83]
Black-headed Gull	Chroicocephalus ridibundus	Laridae	13	34	38%	China	2018	Yes	Vibrio metschnikovii	[100]
Black-necked Stilt	Himantopus mexicanus	Charadriidae	1	34	3%	China	2018	Yes	Vibrio metschnikovii	[100]
Black-winged Stilt	Himantopus himantopus	Charadriidae	0	34	0%	China	2018	Yes	Vibrio metschnikovii	[100]
Common Kingfisher	Alcedo atthis	Alcedinidae	0	1	0%	Romania	2021	None reported	Vibrio metschnikovii	[83]
Common Pochard	Aythya ferina	Anatidae	1	34	3%	China	2018	Yes	Vibrio metschnikovii	[100]
Common Whitethroat	Curruca communis	Sylviidae	0	5	0%	Romania	2021	None reported	Vibrio metschnikovii	[83]
Domestic Chicken	Gallus gallus	Phasianidae	1	1	100%	Unknown	1978	None reported	Vibrio metschnikovii	[125]

Avian Species	Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Domestic Goose	Anser anser	Anatidae	1	1	100%	Germany	2001	None reported	Vibrio cincinnatiensis	[42]
Kelp Gull	Larus dominicanus	Laridae	Unknown	Unknown	Unknown	Brazil	2011	None reported	Vibrio cincinnatiensis	[114]
Manx Shearwater	Puffinus puffinus	Procellariidae	2	35	6%	Brazil	2014	None reported	Vibrio cincinnatiensis	[70]
Seabirds	Unknown	Unknown	Unknown	69	Unknown	Brazil	2010	None reported	Vibrio cincinnatiensis	[85]
Seabirds	Unknown	Unknown	2	116	2%	Brazil	2010	None reported	Vibrio cincinnatiensis	[71]
Brown Pelican	Pelecanus occidentalis	Pelecanidae	20	42	48%	United States	1990	None reported	Photobacterium damsela	[69]
Common Loon	Gavia immer	Gaviidae	1	434	0.20%	United States	1994	Yes	Photobacterium damsela	[102]
Great Tit	Parus major	Paridae	1	5	20%	United Kingdom	2011	Yes	Photobacterium damsela	[122]
Kelp Gull	Larus dominicanus	Laridae	Unknown	Unknown	Unknown	Brazil	2011	None reported	Vibrio furnissii	[114]
Brown Booby	Sula leucogaster	Sulidae	Unknown	Unknown	Unknown	Brazil	2011	None reported	Vibrio furnissii	[114]

Avian Species	Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Laughing Gull	Leucophaeus atricilla	Laridae	1	7	14%	Peru	2021	None reported	Vibrio furnissi	[80]
Seabirds	Unknown	Unknown	1	116	1%	Brazil	2010	None reported	Vibrio furnissi	[71]
Seabirds	Unknown	Unknown	Unavailable	69	Unknown	Brazil	2010	None reported	Vibrio Harveyi	[85]
Common Green-shank	Tringa nebularia	Scolopacidae	0	5	0%	China	2015	None reported	Vibrio Harveyi	[109]
Manx Shearwater	Puffinus puffinus	Procellariidae	7	35	20%	Brazil	2014	None reported	Vibrio Harveyi	[70]
Seabirds	Unknown	Unknown	14	116	13%	Brazil	2010	None reported	Vibrio Harveyi	[71]
Aves	Unknown	Unknown	Unknown	204	Unknown	Ireland	2019	None reported	Grimontia hollisae	[124]
Domestic Goose	Anser anser	Anatidae	Unknown	20	Unknown	China	2017	None reported	Grimontia hollisae	[123]
Hooded Crane	Grus monacha	Gruidae	Unknown	20	Unknown	China	2017	None reported	Grimontia hollisae	[123]
Seabirds	Unknown	Unknown	Unknown	69	Unknown	Brazil	2010	None reported	Vibrio mimicus	[85]
Bearded Reedling	Panarus biarmicus	Paridae	0	2	0%	Romania	2021	None reported	Vibrio mimicus	[83]
Black-tailed Godwit	Limosa limosa	Scolopacidae	3	26	12%	China	2018	None reported	Vibrio mimicus	[103]

Avian Species	Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Common Chaffinch	Fringilla coelebs	Fringillidae	0	5	0%	Romania	2021	None reported	Vibrio mimicus	[83]
Common Kingfisher	Alcedo atthis	Alcedinidae	0	1	0%	Romania	2021	None reported	Vibrio mimicus	[83]
Common Snipe	Gallinago gallinago	Scolopacidae	0	3	0%	Romania	2021	None reported	Vibrio mimicus	[83]
Domestic Chicken	Gallus gallus	Phasianidae	8	565	1%	Nigeria	2017	None reported	Vibrio mimicus	[110]
Eurasian Blue Tit	Cyanistes caeruleus	Paridae	0	2	0%	Romania	2021	None reported	Vibrio mimicus	[83]
Eurasian Hobby	Falco subbuteo	Falconidae	0	2	0%	Romania	2021	None reported	Vibrio mimicus	[83]
Eurasian Stone Curlew	Burhinus oedicnemus	Burhinidae	1	61	2%	Italy	2018	None reported	Vibrio mimicus	[126]
Great Tit	Parus major	Paridae	0	2	0%	Romania	2021	None reported	Vibrio mimicus	[83]
Hawfinch	Coccothraustes coccothraustes	Fringillidae	0	8	0%	Romania	2021	None reported	Vibrio mimicus	[83]
Hooded Crow	Corvus cornix	Corvidae	0	7	0%	Romania	2021	None reported	Vibrio mimicus	[83]

Avian Species	Scientific Name	Family	Number Tested	Total Examined	Prevalence	Country	Year	Clinical Signs or Mortality	Serotypes or Strains	Citation
Lesser Whitethroat	<i>Sylvia curruca</i>	Sylviidae	0	2	0%	Romania	2021	None reported	<i>Vibrio mimicus</i>	[83]
Seabirds	Unknown	Unknown	8	116	7%	Brazil	2010	None reported	<i>Vibrio mimicus</i>	[71]
Song Thrush	<i>Turdus philomelos</i>	Turdidae	0	2	0%	Romania	2021	None reported	<i>Vibrio mimicus</i>	[83]
Wood Sandpiper	<i>Tringa glareola</i>	Scolopacidae	0	2	0%	Romania	2021	None reported	<i>Vibrio mimicus</i>	[83]
Common Green-shank	<i>Tringa nebularia</i>	Scolopacidae	1	26	4%	Romania	2021	None reported	<i>Vibrio scophthalmi</i>	[83]

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