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Progress on updated review of pathogens described in ACAP species

Argentina

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SUMMARY

Infectious diseases have the potential to cause rapid declines and extinction in vulnerable vertebrate populations. Although they often breed far from continents and experience very little human contact, albatrosses and large petrels are not beyond the reach of pathogens. Dramatic evidence of this are the recurrent mortalities and reproductive failure from disease presently affecting three albatross species from Amsterdam Island, including the critically endangered and endemic Amsterdam albatross. Threats from disease will likely exponentially increase with globalization and climate change. Moreover, the synergistic effects of disease with other high mortality factors such as interactions with fisheries may become determinants for species extinction.

As formerly stated by Quintana (ACAP BSWG4/STWG6 Doc 07, 2011), current lack of information prevents a thorough and accurate evaluation of the overall potential threat posed by disease in albatross species, and represents an important gap for achieving conservation targets. More importantly, insufficient evidence halters effective and pro-active disease management and precludes proper analysis of effectiveness of implemented mitigation measures.

In this paper we report on progress made in an effort to fully review and compile all available information on pathogens described in ACAP species worldwide (including ACAP reports) partially addressing action item: *"Review evidence for impacts of pathogens and parasites on ACAP species and effectiveness of mitigation measures"*(Item 2.14,AC7-2013-2015 work plan).

A list of recommendations stemmed from this review are presented for consideration.

RECOMMENDATIONS

1. Develop and implement biosecurity plans for albatross breeding sites to minimize the risk of disease transmission. Check effectiveness of plans where they are practised.
2. Reinforce current investigations on diseases impacting Amsterdam Island albatrosses and consider revisiting the current biosecurity strategy. Consultation with experts is advised.
3. Implement long-term disease surveillance programs and thoroughly investigate albatross disease/mortality events when they occur.
4. Include disease risks in pre-translocation risk factor analysis.
5. Apply innovative technologies and make better use of specimens recovered from by-catch or other opportunities to improve sample sizes and species representation in albatross health assessments.

Avances en la revisión actualizada de patógenos descritos en las especies del ACAP

Las enfermedades infecciosas tienen el potencial de ocasionar una rápida disminución y extinción de poblaciones de vertebrados vulnerables. Si bien suelen reproducirse lejos de tierras continentales y tener muy poco contacto con los seres humanos, los albatros y grandes petreles no son inmunes a los patógenos. Drástica prueba de ello son las tasas de mortalidad recurrente y los fracasos en la reproducción a causa de enfermedades que actualmente afectan a tres especies de albatros de la isla de Ámsterdam, incluido el albatros de Ámsterdam endémico de esta isla, en peligro crítico de extinción. Es probable que las amenazas que presentan las enfermedades aumenten exponencialmente con la globalización y el cambio global. Además, los efectos sinérgicos de las enfermedades con otros altos factores de mortalidad, tales como la interacción con las pesquerías, pueden ser causas determinantes para la extinción de la especie.

Tal como lo indicó Quintana (durante la GdTCS4 del ACAP/GdTCS Doc 07 de 2011), la actual falta de información impide la realización de una evaluación exhaustiva y precisa de la amenaza global potencial que presentan las enfermedades en las especies de albatros y constituye un importante vacío de información que obstaculiza la consecución de los objetivos de conservación. Más significativamente, la falta de pruebas limita el manejo efectivo y proactivo de enfermedades e imposibilita el análisis adecuado de la efectividad de las medidas de mitigación implementadas.

En el presente documento, se informan los avances logrados en el esfuerzo de revisar en su totalidad y compilar toda la información disponible sobre patógenos descritos en las especies del ACAP a nivel mundial (incluidos los informes del ACAP), en parcial cumplimiento con el punto de acción: "*Examinar las pruebas de los efectos de patógenos y*

parásitos sobre las especies del ACAP y la efectividad de las medidas de mitigación" (punto 2.14, del plan de trabajo para 2013-2015, CA7).

Se presenta para su consideración una lista de recomendaciones elaboradas a raíz de esta revisión.

RECOMENDACIONES

1. Diseñar e implementar planes de bioseguridad para sitios de reproducción de albatros con el objetivo de minimizar el riesgo de transmisión de enfermedades. Revisar la efectividad de los planes donde se hubieran puesto en práctica.
2. Reforzar las investigaciones en curso sobre las enfermedades que afectan a los albatros de la isla de Ámsterdam y considerar la posibilidad de revisar la estrategia actual de bioseguridad. Se recomienda efectuar una consulta con expertos.
3. Implementar programas de vigilancia de enfermedades a largo plazo e investigar con exhaustividad los acontecimientos de morbimortalidad en albatros, cuando estos ocurran.
4. Incluir el estudio de riesgos de enfermedades en los análisis de factores de riesgo efectuados antes de las reubicaciones.
5. Implementar tecnologías innovadoras y aprovechar mejor los especímenes recuperados de la captura secundaria y de otras oportunidades para aumentar el tamaño de las muestras y la representación de especies en las evaluaciones de la salud de albatros.

Progrès relatifs à la mise à jour du passage en revue des pathogènes décrits chez les espèces de l'ACAP

Les maladies infectieuses peuvent entraîner le déclin et l'extinction rapide de populations vertébrées vulnérables. Bien qu'ils se reproduisent loin des continents et ont peu de contacts avec les hommes, les albatros et les grands pétrels restent vulnérables aux pathogènes. Les morts par maladie récurrentes et les échecs de reproduction répétés au sein de trois espèces d'albatros de l'île Amsterdam, dont l'espèce endémique d'albatros d'Amsterdam gravement en danger, en est le triste exemple. Les menaces présentées par les maladies risquent d'augmenter de façon exponentielle en raison de la mondialisation et du changement climatique. En outre, la synergie entre les maladies et d'autres facteurs importants de mortalité, tels que les interactions avec les pêcheries, pourraient jouer un rôle déterminant dans l'extinction de certaines espèces.

Comme l'a précédemment déclaré Quintana (ACAP BSWG4/STWG6 Doc 07, 2011), l'absence actuelle d'informations ne permet pas de mener une évaluation précise et minutieuse de l'ensemble de la menace potentielle que présentent les maladies touchant les espèces d'albatros et constitue par conséquent une lacune dans la réalisation des objectifs de conservation. Plus important encore, l'absence d'informations ne permet pas de gérer les maladies de façon efficace et pro-active et ne permet pas d'analyser l'efficacité des mesures d'atténuation mise en œuvre.

Dans le présent document, il est fait rapport des progrès accomplis dans le passage en revue et la compilation de toutes les informations relatives aux pathogènes décrites chez les espèces de l'ACAP du monde entier (y compris celles contenues dans les rapports de l'ACAP) et abordant partiellement le point d'action suivant: *«Passage en revue des preuves d'impacts des pathogènes et des parasites sur les espèces inscrites à l'ACAP et de l'efficacité des mesures d'atténuation»*(Point 2.14,AC7- Plan de travail 2013-2015).

Une liste de recommandations découlant de ce passage en revue sont présentées pour examen.

RECOMMANDATIONS

1. Il est recommandé d'élaborer et de mettre en œuvre des plans de biosécurité sur les sites de reproduction des albatros afin de limiter les risques de transmission de maladies. Il est recommandé de vérifier l'efficacité des plans une fois ceux-ci mis en œuvre.
2. Il est recommandé d'intensifier les recherches actuelles relatives aux impacts des maladies sur les albatros de l'île d'Amsterdam et d'envisager la révision de la stratégie de biosécurité actuelle. Il est conseillé de consulter des experts.
3. Il est recommandé de mettre en œuvre des programmes à long terme de surveillance des maladies et d'analyser minutieusement les cas de maladie/mort survenant au sein des populations d'albatros.
4. Il est recommandé d'inclure les risques liés aux maladies dans l'analyse des facteurs de risques du pré-transfert d'espèces.
5. Il est recommandé d'appliquer des technologies novatrices et de mieux utiliser les spécimens retrouvés lors de capture accessoire ou à d'autres occasions pour agrandir la taille des échantillons et la représentation des espèces dans les évaluations de l'état de santé des albatros.

1. INTRODUCTION

Infectious diseases have the potential to cause rapid declines and extinction in vulnerable vertebrate populations (Smith *et al*. 2009, Heard *et al.*2013). The main drivers of wildlife disease emergence, anthropogenic introduction of pathogens into new areas and spill-over from domestic animals, are directly derived from human activities and often act jointly (Daszak *et al*. 2001). Favoured by human transport, remoteness is no longer a valid barrier to pathogen movement (Tatem *et al*. 2006). Therefore, although they often breed far from continents and experience very little human contact, albatrosses and large petrels (hereafter albatrosses) are not beyond the reach of pathogens. Dramatic evidence of this are the recurrent mortalities and reproductive failure from disease presently affecting three albatross species from Amsterdam Island, including the critically endangered and endemic Amsterdam albatross (Weimerskirch 2004, Rolland *et al*. 2009, Jaeger *et al.* 2013). Furthermore, the identified culprit, *Pasteurella multocida*, is a pathogen closely linked to poultry and human dispersion, and has caused the most significant epizootics in locations as isolated as Antarctica (Woods *et al*. 2009).

It is likely that most albatrosses are immunologically naïve to infectious diseases due to evolutionary geographic isolation, rendering them susceptible to opportunistic pathogens. As pathogen transmission dynamics evolve rapidly with globalization and climate change (Morse 1995, Altizer *et al*. 2013), threats from disease will likely exponentially increase. Moreover, the synergistic effects of disease with other high impact factors such as interactions with fisheries may become determinants for species extinction and further accelerate this irrevocable process (Rolland *et al*. 2009, Demay *et al.* 2013).

As formerly stated by Quintana (ACAP BSWG4/STWG6 Doc 07, 2011), current lack of information prevents a thorough and accurate evaluation of the overall potential threat posed by disease in albatross species, and represents an important gap for achieving conservation targets. More importantly, insufficient evidence halters effective and pro-active disease management, including prevention where disease has yet to occur, as well as mitigation and control where it is known to be a problem. It also precludes proper analysis of effectiveness of implemented mitigation measures, limiting capacity to adequately adapt, improve and reinforce biosecurity.

Commendably, and as evidence mounts, ACAP has reinvigorated actions to further investigate and address management of diseases of concern. Likewise, ACAP has urged the development and implementation of biosecurity plans for albatross breeding sites to minimize the risk of disease transmission (ACAP AC7, 2013 Report).Yet in light of ongoing events (ie. Amsterdam albatross now also affected by *P. multocida,* plus unrelenting mortalities in *Thalassarche carteri* which go back as far as 1996),these steps may have to be re-energized, and would significantly benefit from consultation with experts.

In this paper we report on progress made in an effort to fully review and compile all available information on pathogens described in ACAP species worldwide (including ACAP reports) partially addressing action item: *"Review evidence for impacts of pathogens and parasites on ACAP species and effectiveness of mitigation measures"*(Item 2.14,AC7- 2013-2015 work plan). This document contains data previously summarized and reported in ACAP BSWG4/STWG6 Doc 07 (2011) after checking the original sources for accuracy, as well as new information from recent publications and omitted earlier references. In addition, we have aimed to expand the utility of information by providing context significant for data interpretation such as location of studies, whether they report isolation of pathogens or indirect evidence of exposure (ie. antibodies), and, when available, whether studies were conducted on apparently healthy animals or on individuals with signs of disease. We have also noted author comments or hypothesis on potential reservoirs, vectors or modes of transmission for reported pathogens. Due to unavailability of information, this document does not include an analysis of effectiveness of mitigation measures implemented, the second aspect of the action item referred to above.

2. MATERIALS AND METHODS

We used Google Scholar and Pubmed databases to conduct an extensive search of published studies on any type of pathogens and/or clinical disease reported in albatrosses and large petrels. We also included health assessments reporting exposure (as evidenced by blood antibodies) and, when available, added unpublished data reporting on any of the above. Finally, disease information available in ACAP reports and documents was likewise collated.

3. RESULTS

3.1. Publications and species covered

We were able to expand the previous review with 19 additional published papers and ACAP reports (27 references quoted in this document were cited in ACAP BSWG4/STWG6 Doc 07, 2011). The revised database now contains a total 46 papers reporting on pathogen or pathogen-specific antibody searches in ACAP species, including those which yielded negative results.

Summarized information comprises references for 18 (62%) of the 29 species listed under ACAP. Publications cover 5 genuses, namely *Diomedea* (4 species): *exulans, nigripes, amsterdamensis, albatrus; Macronectes* (2 species): *giganteus, halli; Thalassarche* (5 species): *melanophrys, chrysostoma, cauta, carteri, chlororynchos; Phoebastria* (4 species): *immutabilis, irrorata, fusca, palpebrata*; and *Procellaria* (3 species): *aequinoctalis, cinerea, parkinsoni.*

3.2. Main findings: pathogens and antibodies

Updated counts on pathogens found in ACAP species (including isolation, recovery and molecular characterization of DNA or RNA) contain bacteria in 7 species (24%), viruses in 5 (17%), protozoa in 4 (14%), gastrointestinal parasites in 3 (10%), ectoparasites in 13 (49%) and fungus in 1 species (3%). Bacteria and virus-specific antibodies were reported in 2 (7%), and 4 (14%) of ACAP species, respectively. Only ectoparasites are reported for 4 ACAP species (*T.chlororynchos, M. halli, P. cinerea* and *P. aequinoctalis*), and pathogen descriptions are limited to protozoa plus ectoparasites in *D. exulans* and solely gastro-intestinal parasites in *D. albatrus*. We were unable to verify gastrointestinal parasites described by Mawson 1953, and thus refer readers to Barbosa and Palacios (2009) for that information.

Detailed results separated by pathogen group (bacteria and fungi, viruses, protozoa, gastrointestinal parasites and ectoparasites) and host species are provided in tables 1-5. In addition, for positive viral, bacterial and fungal reports we present data on tissues tested and tests performed, as well as location of studies in table 6.

Seventeen different bacteria were reported, most commonly *Pasteurella multocida*(4 reports in 4 different species) (Weimerskirch 2004, Leotta *et al.*2003, Rolland *et al.*2009, Jaeger *et al.*2013) and *Salmonella sp*. (4 strains in 2 different species) (Work *et al.*1998, Palmgrem *et al.*2000). Only 2 viruses were isolated from ACAP species, namely pox viruses (5 cases in 5 different species) (Young and Vanden Werf 2008, Shearn-Boschler *et al.*2008, Woods 2004, Bell *et al.*2007, Kane *et al.*2012) and a newly discovered Phlebovirus (HIGV) in ticks collected from shy albatrosses from the Hunter Island Group in Tasmania (Wang *et al.* 2014).

3.3. Species studied

The Black Browed Albatross (BBA) with 16 papers and the Southern Giant Petrel (SGP) with 15, are the two ACAP species with higher number of health or pathogen-related publications. Yet the only allegedly significant pathogens isolated from these species are *P. multocida* in SGP (Leotta *et al.* 2003) and avian poxvirus in both (Shearn-Boschler *et al.* 2008, Kane *et al.* 2012). Interestingly, both SGP isolates are from Antarctica.

3.4. Type of study

Most papers reporting on pathogens or pathogen-specific antibodies in ACAP species resulted from disease/mortality investigations (n=14), 9 from baseline studies, 4 investigated the role of albatrosses and petrels as vectors or dispersers of pathogens of human origin, 2 were associated to specific pathogen searches (eg. *Borrelia* sp. and *Edwardsiella sp.*), and information on type of study was not inferable in 4 cases.

3.5. Temporal and spatial distribution of reports

The number of papers reporting on pathogens or health assessments in ACAP species has increased over time. Referenced publications go as far back as 1970 (Clay and Moreby 1970, Wilson 1970). Two papers referenced in Quintana (2011), one from 1953 (Mawson 1953) and one from 1967 (Murray and Vestjens 1967) were unavailable for revision and therefore not included in this summary. Up to 1980 there were 7 publications; 14 were added from 1981-2000, and 25 between 2001 and 2014.

The location of studies surveying pathogens in ACAP species is diverse, and covers Antarctic, Sub-Antarctic and other locations ("other" locations are those not included in the two previous categories), with fewer studies in Antarctica. Details on number of studies by location and pathogen type are shown in the table below (some papers report on more than one pathogen group). Distribution of reports is likely reflective of albatross and petrel reproductive sites location (Birdlife International 2004), as this is where most sampling has occurred for all species.

Location / Pathogen type	Antarctic	Sub-Antarctic	Other
Bacteria and fungi	6	9	9
Virus	2	1	7
Protozoa	1	1	0
GI parasites	3	0	1
Ectoparasites	1	11	7
TOTAL	13	23	24

The location of bacterial and viral isolates, including host species and tissues from which they were recovered, is provided in table 6. In summary, poxviruses were isolated in all but one case from locations in the "other" category. The remaining isolate was recovered from a SGP in Antarctica (Shearn-Boschler *et al.* 2008). No viruses are reported for sub-Antarctic locations. Bacteria on the other hand, were recovered in all geographical sites. In addition, the single fungal isolate was recovered in an "other" type location, from *T. chrysostoma (Tham et al. 1974).* Parasites of all classes were found in Sub-Antarctic, "other" and Antarctic locations in decreasing order.

4. SIGNIFICANCE OF FINDINGS

4.1. Viral isolates

All avian poxvirus reports relate to findings in clinically ill or dead animals, mostly chicks or fledglings, and were often associated with mortality or low reproductive success. In some cases the immediate cause of death was not poxvirus, but a secondary bacterial infection (ie. *Cl. perfringens* (Shearn-Boschler *et al.* 2008). Poxvirus outbreaks seem to be recurrent in some locations and species (ie. Laysan albatross in Oahu (Young and Vanden Werf 2008), and in many cases morbidity seems to exceed mortality –at least while chicks are under parental care (Young and Vanden Werf 2008, Sileo *et al.* 1990)). Adults appear to be rarely and not too severely affected, with some exceptions. Recovery from disease has been reported in sick chicks (Young and Vanden Werf 2008) and adults (Shearn-Boschler *et al.*2008, Young and Vanden Werf 2008). Most reported cases refer to cutaneous pox (Young and Vanden Werf 2008, Sileo *et al.* 1990). The more severe form of the disease, diphtheritic pox, was only described in a SGP chick which died during an outbreak in Antarctica (Shearn-Boschler *et al.* 2008). All these characteristics agree with what is observed in many avian species infected with pox viruses (Kane *et al*. 2012), and luckily differs from what has occurred in some island birds for which avian pox has been a major driver of extinction (Van Riper *et al.*2002). Notwithstanding, because the virus is transmitted mechanically by insects or by contact with pox-infected particles, it is highly contagious. This implies that outbreaks often occur in clusters within colonies, but also that it can be spread to remote locations through bird travels and migration, human visitors, and as importantly, reintroduction programs (Gyuranecz *et al.* 2013). Therefore, strict biosecurity is recommended during outbreaks and poxvirus-specific screening should be included in translocation and reintroductions risk assessments.

The only other virus isolated from ACAP species is a novel tick-borne phlebovirus, HIGV (Wang *et al*. 2014). It was described recently in samples collected during the investigation of a disease outbreak in shy albatrosses from Tasmania which occurred in 2002, as advanced technology for viral discovery (next-generation sequencing) became available at the lab. The HIGVvirus is closely related to two newly discovered tick-borne zoonotic phleboviruses (SFTSV and HRTV) that were responsible for severe disease and death in humans in four countries in Asia and North America (Wang *et al.* 2014). However, and as reported by the authors, this is probably an incidental finding and not particularly related to the disease event in the shy albatrosses.

4.2. Bacterial isolates

Due to their capacity to produce acute systemic disease followed by death, the most significant bacterial pathogens isolated from albatrosses are *P. multocida* and *Erysipelothrix rhusopathiae*. *P. multocida* is a contagious avian pathogen which is known to infect over 180 species of birds and causes major and recurrent epizootics of avian cholera in waterfowl in North America (Samuel *et al.* 2007). Transmission occurs from contact between birds and by ingestion or inhalation of bacteria within a contaminated environment. Diseased birds and rotting carcasses are important sources of contamination and the bacteria can be carried between infected sites by migrating or carrion scavenger birds (Friend1999). *E. rhusopathiae* on the other hand typically appears to be a secondary pathogen affecting individuals, not populations (Wolcott 2007). It can be acquired by ingestion, and fish eating habits may be a predisposing condition (Wolcott 2007).

At least two mortality events from *P. multocida* infections have affected several seabird species in Antarctica (Leotta *et al.* 2006) in addition to an isolated case in an adult SGP (Leotta *et al.* 2003). Both *P. multocida* and *E. rhusopathiae* have been reported in all albatrosses breeding in Amsterdam Island, namely the Yellow-nosed, Sooty and Amsterdam albatross (Weimerskirch 2004, Rolland *et al.* 2009, Jaeger *et al.* 2014), the latter being particularly important given its critical conservation status. While mortality attributed to disease in these species extends to the 1980s, the first bacterial isolates were obtained from dead yellow-nosed albatrosses in 1995-96 (*E. rhusiopathiae)* and 1999-2000 (*P. multocida*) (Weimerskirch 2004). The extended time lag between the suspected onset of disease-induced mortality and investigations highlights the need for implementing early warning systems via disease surveillance programs, including thorough investigations whenever disease is suspected. It also emphasizes that characterizing disease agents early on may allow for interventions to limit disease spread (ie. strict biosecurity) at the onset of the problem, when they are likely to be more impactful.

Several factors make the behavior of *P. multocida* unusual in albatrosses from Amsterdam Island, including its biased impact on recently hatched chicks, its apparent self-limitation, its somewhat erratic recurrence (ie. years with high and very low mortality), and the fact that only albatrosses seem to be affected even though potentially susceptible waterfowl are also present at the site (Friend 1999, Weimerskirch 2004, Demay *et al*. 2013, RAMSAR 2014,). As has been indicated by Jaeger *et al.* (2013), the situation in Amsterdam Island requires urgent and detailed investigation of the epizootiology of *P. multocida* infections to better understand the ecology of the disease and accordingly define mitigation and prevention methods.

A number of additional bacterial infections were implicated in albatross and large petrel chick mortalities, but do not seem to be extend or sustained problems. Three strains of *Salmonella sp*. and compatible histopathological lesions were described in Laysan albatross chicks dying from necrotizing enteritis (Work *et al.* 1998). The authors suggest a similar problem may have caused earlier mortality in this species (Sileo *et al.* 1990). In both cases death was associated with dehydration, and potentially linked to lead poisoning. Infections with *Nocardia asteriodes* were reported in dead Laysan albatross chicks with mild fibrinous airsacculitis (Sileo *et al.* 1990). Nocardiosis is uncommon in birds and was suggested by the authors to deserve further study. However, no follow up studies have been published to date. Enterotoxemia from *Cl. Perfringens* toxins was the ultimate cause of death in a SGP nestling with cutaneous and diphtheritic pox (Shearn-Boschler *et al.* 2008). Pox infections in this case were considered significant stressors triggering clostridial overgrowth in the gut. Finally, *Escherichia coli* was cultured from a single adult SGP dying from *P. multocida* infection in Antarctica, but was considered a secondary finding (Leotta *et al.* 2003).

All other bacterial isolates were recovered from rectal swabs of apparently healthy SGP adults (Jorge *et al.* 2002, Leotta *et al.* 2009) or BBA chicks (Palmgrem *et al.* 2000) during surveys and are likely of little clinical significance. In any case, these reports show that albatrosses regularly shed bacteria and can therefore act as carriers to distant locations. This might be particularly more relevant in carrion-eating species such as the SGP.

4.3. Fungal isolates

Fungal nephritis caused by *Aspergillus flavus-oryzae group*was reported in a moribund and later euthanizedGrey-headed albatross (Tham *et al.* 1974). Based on the chronicity of

histological lesions however, it was considered more likely that the isolated *Proteus sp*., a common urinary tract bacteria (Guentzel 1996), was responsible for the debilitated condition of the animal. Of note, *Aspergillus* genus consists of several hundred species undergoing taxonomical changes with the advent of genome sequencing (Bennet 2010). Therefore, the classification of the fungus in this study might be presently inaccurate.

4.4. Parasites

Only infestations with ticks *Ixodes uriae*in BBA (Bergstrom *et al.* 1999b) and mites *Myialges nudus* (Gilardi *et al.* 2001) *and Womersia midwayensis* (Sileo *et al.* 1990) in Laysan albatross have been linked to disease or death in ACAP species, while mosquitoes *Aedes taeniorhynchus* (Anderson and Fortner 1988) were considered responsible for nest abandonment in the Waved albatross (WA). With the exception of ticks which have been described in numerous seabird species in Sub-Antarctic and even Antarctic locations, most ectoparasite infestation problems seem to be restricted to “other” type locations, presumably due to warmer climate conditions at lower latitudes.

4.5 Pathogen-specific antibodies

Few studies report antibodies to viruses in ACAP species. Findings are restricted to antibodies specific for Adenoviruses in 3 serosurveys involving BBA, SGP and WA (Uhart *et al.* 2003, 2004, Padilla *et al.* 2003), and 1 study for each Avian Encephalomyelitis virus in WA (Padilla *et al.* 2003), Avian Influenza in SGP (Baumeister *et al.* 2004), and Paramyxovirus type 1 in Shy albatross (Wang *et al.* 2014). Four different studies (Uhart *et al.* 2003, 2004, Padilla *et al.* 2003, Wang *et al.* 2014) explored a suite of viral diseases but were unable to find indication of exposure, even though in one occasion samples were collected from animals during a mortality event investigation (Wang *et al.* 2014).

In the case of antibodies to bacterial agents, 2 studies report positives for *Chlamydophila spp*. in SGP (Munday 1972, Uhart *et al.* 2004) and 1 for *Salmonella spp*. in BBA (Uhart et al 2003).

Available serosurvey reports suggest albatrosses are occasionally exposed to common avian viruses and bacteria, but in absence of sequenced sampling to examine change over time, or indication of clinical disease in the individuals sampled, their utility remains limited. Furthermore, they might represent cross-reactivity with other pathogens given the lack of validation of the serological tests used, a common limitation in disease surveillance via serologyin wild species (Gardner *et al.* 1996). Notwithstanding, implementing long-term disease surveillance programs via measurement of antibodies in blood is recommended because antibodies are typically easier to detect and persist longer than the inciting infectious agents. In addition, presence and distribution of infectious diseases in wild animal populations can be inferred from serological surveys. This is particularly significant for risk assessments preceding reintroductions and translocations (ie. serosurveys of source stock) (Gardner *et al.* 1996). To ensure that reliable and meaningful data are obtained,serosurveys would benefit from modelling prior to field sampling, greater consideration of pathogenesis and age structure in the population, investment in longitudinal studies whenever possible, and standardized sample collection, storage and testing protocols (Gilbert *et al.* 2013).

5. MAIN CONCLUSIONS AND SPECIFIC RECOMMENDATIONS

5.1. ALL conclusions from Quintana (2011) still apply.

5.2. Only 2 new papers on pathogens or albatross health have been published since Quintana's review (refs Mironov *et al.* 2013 and Wang *et al.* 2014), and 1 more was reported as *in prep* in AC7 (Jaeger *et al.* 2013).

5.3. It is particularly worrying that in some cases reports of avian cholera mortalities have been ongoing for more than ten years (Weimerskirch 2004, Rolland *et al*. 2009, Jaeger *et al.* 2013), particularly since recent findings suggest impact from this disease could be escalating.Consultation with experts is recommended to define ways forward.

5.4. The most significant bacterial findings still refer to *P. multocida* and, more recently, *Erysipelothrixsp*. in Amsterdam Island species. From available reports however it is not possible to evaluate the full extent of the problem (ie. number of animals dying from the disease annually, age category, species affected, potential carrier species, environmental sources, etc.) nor the effectiveness of biosecurity and mitigation measures being implemented. A thorough analysis of the epizootiology of these pathogens in Amsterdam Island albatrosses is urgently needed to allow for appropriate interventions.

5.5. Investigated viral infections seem to be restricted to poxviruses. This could be related to the obvious visibility of the disease and its ability to infect many individuals due to its highly contagious nature. Chick mortality from pox appears to be low, and adults seem to be immune or overcome infection. Monitoring the behaviour of this disease over time, particularly in areas subject to influences from global climate change, is recommended.

5.6. Overall viral exposure appears to be minimal in albatrosses and petrels, as suggested by a limited number of available serosurveys. Long-term and adequately designed serosurveillance programs should be implemented, particularly in populations where reintroductions or translocations are being considered, and in areas under increasing anthropogenic pressure.

5.7. Most findings in mortality investigations include bacteria. However, only in some cases were bacterial isolates reported to be the cause of death, as evidenced by histological lesions (ie. *Salmonella sp.* (Work *et al.* 1998), *Cl. perfringens (Shearn-Boschler et al. 2008)*). This reinforces the need to accompany all pathogen isolation findings with histopathology when investigating disease or mortality. Determining cause of death will improve understanding of knowledge on disease pathogenesis and virulence, allow for evaluation of the potential population-level impact of the disease, and enable adequate mitigation and preventative measures.

5.8. Bacterial studies that were not focused on identifying potential mortality factors (as mentioned above), were exploratory studies for signalling interactions with humans/poultry (Palmgrem *et al.*2000, Jorge *et al.*2002). The evidence to support this hypothesis is inconclusive, though it is possibly more valid for scavenger species such as the SGP. Monitoring for foreign pathogens in species prone to interactions with human waste and human dwellings (ie. SGP, skuas, gulls) would enable testing the effectiveness of biosecurity and hygiene best practices.

5.9. Some of the isolated pathogens, for instance *Salmonella sp.,* can infect humans. Personal protection and adequate hygiene to avoid zoonosis is therefore recommended. Furthermore, best practices in biosecurity should always be followed when visiting albatross reproduction sites and/or when handling birds, even in absence of obvious disease.

5.10. There are no reports of studies repetitively sampling species or sites over time, beyond those conducted in Amsterdam Island in response to noticeable mortality. As conservation and management plans for ACAP species are designed, adequate risk assessments, biosecurity and long-term disease surveillance plans must be proactively defined and incorporated, particularly for significant reproduction sites.

5.11. Some recent translocation reports indicate health monitoring was restricted to blood chemistries, omitting disease screening (Deguchi *et al.*2014). This is particularly risky as animals with no obvert signs of disease can be infected and spreading pathogens, including pathogenic bacteria such as *P. multocida* (Friend 1999). Reintroductions and translocations must include diseases in their risk factor analysis and follow expert guidance. Useful resources are available from IUCN Wildlife Health Specialist Group (http://web.oie.int/boutique/index.php?page=ficprod&id_produit=1334&PHPSESSID=067ea164ae3711a489d6ce7e61b544d6).

5.12. There seems to be little use of new available technologies, particularly those that relieve from use of cold chain (ie. filter papers, Blood spot cards, RNA later and other lysis buffers). Broader sample collection, both in a systematic and opportunistic way, would greatly enhance current knowledge on albatross health.

5.13. Given limited access to specimens, it is notable (and of concern) that no health studies beyond exposure to contaminants (information not included in this report) are being undertaken on animals recovered from fisheries bycatch, particularly considering the numerous on-board observer programs in place worldwide.

5.14. Information on the threat from disease for relevant ACAP species conservation sites should be timely shared with other intergovernmental treaties (ie. RAMSAR) to reinforce global policy efforts. For example, in the case of RAMSAR site 1837Réserve Naturelle Nationale des Terres Australes Françaises, which includes Amsterdam Island, the threats have not been updated since 2008 and only mention non-native species as having on impact on bird reproduction (RAMSAR, 2014).

6. GENERAL RECOMMENDATIONS

6.1. Continue and expand research on the three albatross species currently known to be suffering mortality and reproductive failure from disease. Further investigate *P. multocida* disease epidemiology in Amsterdam Island, and consider revisiting the current biosecurity strategy. Consultation with experts is advised.

6.2. To improve sample sizes and species representation, consider overcoming logistic limitations by using innovative technologies (ie. VTM, RNA later, filter paper).

6.3. Similarly, make better use of specimens recovered from bycatch. Collecting adequate samples from animals killed in fisheries would facilitate health studies as well as allow for improving knowledge on genetics, feeding ecology, etc.

6.4. Performing necropsies (all levels), plus sample collection and histological evaluation of dead bird tissues (tissues in formalin are easy to preserve and do not require cold chain), should be a top priority for investigating and determining cause of morbidity and death.

6.5. Timely publication and informal sharing of news on disease events, case reports, and pathological findings within ACAP parties would aid in better documenting the pathogenesis of diseases and the interpretation of their significance for albatross health.

6.6. Conservation strategies, such as reintroductions and translocations, should carefully consider and address risk of disease spread in their risk factor analysis, and would benefit from following internationally accepted guidelines.

6.7. Implement adequate biosecurity and best practices protocols at all albatross and petrel breeding sites to avoid inadvertent introduction of pathogens.

6.8. Design and put into practice preventative early warning systems via disease surveillance programs and undertake thorough investigations when disease-associated mortality is suspected to enable appropriate and timely interventions.

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Table 1. Summary of reports on viral pathogens in albatrosses and large petrels. (Location: SA: Sub-Antarctic, A: Antarctic, Other)

	Virus						
Host species	**Antibodies**		**Isolation**		**Location**	**Study type**	**Potential reservoir/vector**
	positive	**negative**	**positive**	**negative**			
Black-browed Albatross *Thalassarche melanophrys*	Adenovirus (46)	Avian Encephalomyelitis virus (46) Infectious Laryngotracheitis virus (46) Influenza A virus (46, Malvinas 2008, Uhart unpubl. data) Reovirus (46) Infectious Bursal Disease virus (46) Infectious Bronchitis virus (46) Avian Paramyxovirus types 1, 2, and 3 (46) Marek's disease (46)	*Avipoxvirus* (34)	Influenza A virus (Malvinas 2008, Uhart unpubl. data)	other	Mortality event[34], baseline[46]	Phylogenetic proximity with an Avipoxvirus found in penguins from coastal Argentina, suggests a long-term circulation of seabird Avipoxviruses in the Southwest Atlantic[34], possibility of transmission between colonies by tourists/visitors, researchers, or dispersion by fomites[34]
Laysan Albatross *Phoebastria immutabilis*			Avian pox virus (*Poxvirus avium*) (15, 37)		other	Effects of pox on fledging rates and postfledging survival of chicks[15], NA[37]	Introduced mosquito, *Culex quinquefasciatus*+ human creates conditions for mosquito breeding[15], NA[37]
Waved Albatross	Adenovirus (16)	Influenza A virus (16)			other	Baseline	NA

Phoebastria irrorata	Avian Encephalomyelitis virus (16)	Avian Paramyxovirus types 1, 2, and 3 (16) Marek's disease (16) Infectious Bursal Disease virus (16) Infectious Bronchitis virus Conn and Mass strains (16)					
Southern Giant Petrel *Macronectes giganteus*	Influenza A virus (18) Adenovirus (22)	Avian Encephalomyelitis virus (22) Infectious Laryngotracheitis virus (22) Influenza A virus (22) Reovirus (22) Infectious Bursal Disease virus (22) Infectious Bronchitis virus (22) Avian Paramyxovirus types 1, 2, and 3 (22)	Avian poxvirus (21)		A[18, 21], other[22]	NA[18], diseased chicks[21], baseline[22]	Migratory birds could be potential vector and reservoirs of pathogen, however presence of antibodies in chicks suggests they acquired the infection locally[18], chicks from parental feeding, ticks? [21]
Shy Albatross *Thalassarche cauta*		Influenza A virus (42)	Avian poxvirus (30)	common Bunyaviruses (Orthobunyavirus, Phlebovirus, and Nairovirus) (42)	other[30], SA[42]	Symptoms of pox virus infection, diseaseassociated with chick mortality and low	NA[30], HIGV closely related to 2 newly discovered tickborne zoonotic phleboviruses (SFTSV and HRTV)responsible for severe disease and death in

	Avian Paramyxovirus type 1 (42)	Infectious Bursal Disease virus (42) Fowlpox virus (42)	Hunter Island Group virus I, seq (HIGV, new tick-borne Phlebovirus) (42)			breeding success[30], mortality event investigation[42]	humans in 4 separate countries in Asia and N. America. Possible vectors (e.g., phlebotomine sandflies, mosquitoes, and ticks)[42]
Black Petrel *Procellaria parkinsoni*			Avian poxvirus(32)		other	NA	NA

Table 2. Summary of reports on bacterial and fungal pathogens in albatrosses and large petrels. (Location: SA: Sub-Antarctic, A: Antarctic, Other)

	Bacteria and fungi						
Host species	**Antibodies**		**Isolation**		**Location**	**Type of study**	**Potential reservoir/vector**
	positive	**negative**	**positive**	**negative**			
Black-footed Albatross *Diomedea nigripes*				Borrelia (6)	other	NA	NA
Black-browed Albatross *Thalassarche melanophrys*	*Chlamydophila psittaci*(46)	*Salmonella pullorum*(46)	*Salmonella newport (7)* *Borrelia garinii* (11)	*Salmonella havana* (7) *Salmonella typhimurium* (7) *Salmonella enteriditis* (7) *Rickettsia-like microorganism ("Mayes agent")* (41)	SA[7, 11, 41], other[46,11]	Baseline[7, 41], global distribution of Lyme disease[11], NA[41], baseline[46]	Human visitors, migrating sp., scavenger sp. (skuas)[7], Borrelia DNA in *Ixodes uriae* ticks from BB albatross in Campbell Island suggests Lyme disease enzootic foci[11].Although not isolated from BB chicks, were isolated from *I.uriae* ticks collected from penguis in nearby colonies[41]
Grey-headed Albatross *Thalassarche chrysostoma*			*Aspergillus flavus-oryzae group* (43) *Proteus spp* (43)	*Salmonella havana* (7) *Salmonella typhimurium* (7) *Salmonella enteriditis* (7) *Salmonella newport* (7)	SA[7], other[43]	Baseline[7],morib und animals[43]	Domestic poultry?[43]
Laysan Albatross *Phoebastria immutabilis*			*Salmonella ohio* (14) *Salmonella oranienburg* (14)		other[14, 37]	Chick mortality[14], extensive and regular epizootic mortality of	Necrotizing enteritis possibly sequela of dehydratation. Lesions compatible with salmonellosis but isolation in only 4 of 10 birds makes diagnosis suspect[14], NA[37]

			Salmonella san-diego (14) *Nocardia asteriodes* (37)			chicks[37]	
Waved Albatross *Phoebastria irrorata*		*avian cholera* (16)*		*Chlamydophila psittaci* (16)	other	Baseline	NA
Southern Giant Petrel *Macronectes giganteus*	*Salmonella pullorum* (22) *Psittacosis-Lymphogranuloma group* (27)**	*Aspergillus spp(22)* *Chlamydophila spp.(22)* *Mycoplasma gallisepticum* (25) *Mycoplasma synoviae* (25) *Salmonella gallinarum* (25) *Salmonella pullorum*(25)	*Pasteurella multocida subsp. gallicida*(17) *Escherichia coli* (17, 20) *Enterococcus faecalis* (20) *Bacillus subtilis* (20) *Brevibacterium brunneum* (20) *Alcaligenes faecalis* I (20) *Plesiomonas sp* (20) *Clostridium perfringens(21)* *Edwardsiella tarda* (26)	*Chlamydophila psittaci (17)* *Mycoplasma spp (17)* *Campylobacter lari* (28) *Campylobacter jejuni* (28) *Salmonella spp* (28) *Yersinia spp* (28)	A[17, 20, 21, 25, 26, 28], other[22, 27]	During surveillance, mortality one adult[17], role as reservoirs or vectors[20,25],dised chicks, with multiple proliferative nodules on bills and skin[21], baseline[22, 26, 27], role of tourism in introduction of pathogens[28]	During migration, eating diseased animals (penguins, gulls, skuas)[17, 20, 22], feeding on waste from scientific stations[20, 25], clostridial overgrowth in gut triggered by pox infections[21], spread of pathogens by scavenger seabirds such as gulls[22], trophic chain link of transmission[26], NA[27],
Indian Yellow-nosed Albatross			*Pasteurella multocida (12, 31, 33, 44)*		SA	Population and breeding success declines: chick	Albatrosses and skuas from Amsterdam Is. winter along the coasts of Australia and South

*Thalassarche carteri****			*Erysipelothrix rhusiopathiae (12, 33)*			and adult mortality	Africa, potential contact with other species. Also, infected skuas on Amsterdam Is. could disperse pathogens between colonies. *Erysipelas* could have been introduced through pigs or naturally, present in fish
Amsterdam Albatross *Diomedea amsterdamensis*			*Pasteurella multocida (44)*		SA	Mortality and low reproductive success investigation	Colony located near *T.carteri* infected colonies: skuas potential vectors.
Sooty Albatross *Phoebetria fusca*			*Pasteurella multocida (12, 44)*		SA	Very low breeding success due to high mortality of chicks, similar to *T. carteri and D. amsterdamensis*	Skuas as vectors between infected *T. carteri* and *P. fusca* colonies

* Padilla *et al.* 2003: Samples were tested for antibodies to avian cholera by microagglutination at the Diagnostic Laboratory of the University of Missouri–Columbia, College of Veterinary Medicine, Columbia, Missouri 65211, USA.

** Chlamydial bacteria underwent several taxonomic miss-classifications in the past. It is likely that the authors refer to the bacteria *Chlamydophila psittaci* a common avian pathogen, or another pathogen within the *Chlamydophila* genera (Nunes and Gomes 2014).

***Weimerskirch (2004, ref n°12) monitored 200 pairs of yellow-nosed albatrosses (*Diomedea chlororhynchos*) annually since 1979 at Pointe d'Entrecasteaux, on the western coast of Amsterdam island (37 S, 70 E). *Diomedea chlororhynchos* (Sibley and Monroe 1990, 1993) has been divided into *chlororhynchos* and *carteri* and both placed in the genus *Thalassarche* (Brooke, 2004). *T. chlororhynchos* or Atlantic Yellow nosed albatross breeds on Atlantic Ocean islands (Tristan da Cunha and Gough Island). *T. carteri* or Indian Yellow nosed albatross is the species that breeds in Indian Ocean (Amsterdam Islands). Therefore we refer to the individuals included in reference No 12 (Weimerskirch 2004) as Indian Yellow nosed albatross (*Thalassarche carteri*).

Table 3. Summary of reports on Protozoa in albatrosses and large petrels. (Location: SA: Sub-Antarctic, A: Antarctic, Other)

	Protozoa			
Host species	**Pathogen**	**Location**	**Study type**	**Potential reservoir/vector**
Wandering Albatross *Diomedea exulans*	*Hepatozoon albatrossi* (1)	SA	NA	Vector may be *Ixodes uriae* or one of several species of mites commonly found in association with the host
Black-browed Albatross *Thalassarche melanophrys*	*Hepatozoon albatrossi* (1)	SA	NA	Vector may be *Ixodes uriae* or one of several species of mites commonly found in association with the host
Grey-headed Albatross *Thalassarche chrysostoma*	*Hepatozoon albatrossi* (1)	SA	NA	Vector may be *Ixodes uriae* or one of several species of mites commonly found in association with the host
Southern Giant Petrel *Macronectes giganteus*	*Sarcocystis sp.* (19)*	A	NA	NA

* Ippen R and Henne D (1989). Information on source of pathogen (blood, other tissue) not available.

Table 4. Summary of reports on gastrointestinal parasites in albatrosses and large petrels. (Location: SA: Sub-Antarctic, A: Antarctic, Other)

	Gastrointestinal parasites			
Host species	**Pathogen**	**Location**	**Study type**	**Potential reservoir/vector**
Black-browed Albatross *Thalassarche melanophrys*	*Kathleena scotti* (40)	A	NA	NA
Southern Giant Petrel *Macronectes giganteus*	*Stegophorus macronectes* (23) *Stegophorus arctowski* (23)	A	Baseline	NA
	Stegophorus sp.(21)	A	Diseased chicks, with multiple proliferative nodules on their bills and skin.	No pathological changes associated with these nematodes, and no other internal or external parasites found.
Short-tailed Albatross *Diomedea albatrus*	*Tetrabothrius sp.(45)* *Stegophoms stellaepolaris(45)*	other	NA	NA

Table 5. Summary of reports on ectoparasites in albatrosses and large petrels. (Location: SA: Sub-Antarctic, A: Antarctic, Other)

	Ectoparasites				
Host species	**Pathogen**	**Parasite type**	**Location**	**Study type**	**Potential reservoir/vector**
Wandering Albatross *Diomedea exulans*	*Ixodes uriae (13)*	*tick*	SA	baseline (13)	*NA*
	Naubates pterodromi (3)	*louse*	SA	baseline	Close encounters between individuals of different host species are opportunities for lice to straggle. Also contamination by researchers from one colony to another (3)
	Austromenopon sp. (3)	*louse*			
	Pseudonirmus gurlti (4)	*louse*	SA	baseline	*NA*
	Trabeculus hexacon (4)	*louse*			
	Austromenopon affine (5)	*louse*	SA	baseline	*NA*
	Perineus concinnoides (5)	*louse*			
	Episbates pederiformis (5)	*louse*			
	Docophoroides brevis (3, 4, 5)	*louse*			
	Harrisoniella hopkinsi (3, 5)	*louse*			
	Paraclisis hyaline (3, 5)	*louse*			
	Naubates fuliginosus (4, 5)	*louse*			
	Ixodes kerguelenensis (39)	*tick*	SA	prevalence of *B. burgdorferi* in penguins	*Pelecanoides georgicus, D.exulans* and *P.a equinoctialis* are hosts for *I. kerguelenensis,* suggested as possible vector of *(Borrelia burgdorferi,* Lyme disease agent)
Black-footed Albatross *Diomedea nigripes*	Carios (Ornithodoros) capensis(6)	tick	other	NA	NA
Black-browed Albatross *Thalassarche melanophrys*	*Ixodes uriae* (9, 10, 11, 35)	*tick*	SA (9, 10, 11) other (35, 11)	NA (9,35), chick mortality (10), global distribution of Lyme disease (11)	On species that nested in large and dense colonies, carried by bird's feet (9, 10). *Borrelia* DNA in *I. uriae* ticks obtained from BB albatross in Campbell Island suggests that Lyme disease enzootic foci are present (11)

	Paraclisis diomedeae (3, 5)	*louse*	SA	baseline	Close encounters between individuals of different host species are opportunities for lice to straggle. Also contamination by researchers from one colony to another (3)
	Perineus circumfasciatus (3, 5)	*louse*			
	Docophoroides brevis (4)	*louse*	SA	baseline	NA
	Austromenopon affine (5)		SA	baseline	NA
	Harrisoniella ferox (5)	*louse*			
	Docophoroides brevis (5)	*louse*			
	Parapsyllus longicornis (35)	*flea*	other	NA	NA
Grey-headed Albatross *Thalassarche chrysostoma*	*Ixodes uriae* (9, 13)	*tick*	SA	NA (9), baseline (13)	*I. uriae* only on species that nested in large, dense, persistent colonies, carried by bird's feet
	Docophoroides simplex (3)	*louse*	SA	baseline	Close encounters between individuals of different host species are opportunities for lice to straggle. Also contamination by researchers from one colony to another (3)
	Paraclisis diomedeae (3, 5)	*louse*			
	Austromenopon affine (5)		SA	baseline	NA
	Perineus circumfasciatus (5)	*louse*			
Atlantic Yellow-nosed Albatross *Thalassarche chlororhynchos*	*Ixodes diomedeae* I (35)	*tick*	other	NA	NA
	Docophoroides brevis (4)	*louse*	SA	baseline	NA
	Naubates fuliginosus (4)	*louse*			
Light-mantled Albatross *Phoebetria palpebrata*	*Ixodes uriae (9, 13)*	*tick*	SA	NA (9), baseline (13)	*I. uriae* only on species that nested in large, dense, persistent colonies, carried by bird's feet (13)
	Paraclisis diomedeae (3, 5)	*louse*	SA	baseline	Close encounters between individuals of different host species are opportunities for lice to straggle. Also contamination by researchers from one colony to another (3)
	Perineus circumfasciatus (3, 5)	*louse*			

	Naubates fuliginosus (4)	*louse*	SA	baseline	NA
Laysan Albatross *Phoebastria immutabilis*	*Myialges nudus* (38)	*mite*	other	Mange caused by ectoparasite in dead chicks	Could have been introduced on hippoboscid flies, on canaries or common mynahs as pets.
	Womersia midwayensis (37, 8)	*mite*	other	Chick mortality (37) NA (8)	NA
Waved Albatross *Phoebastria irrorata*	*Aedes taeniorhynchus (36)*	mosquito	other	desertion of eggs, apparently in response to ectoparasites	NA
Southern Giant Petrel *Macronectes giganteus*	Ixodes uriae **(Neg)** (21)	tick	A	diseased chicks	No mites or ticks were found on the dead chick. The tick Ixodes uriae is ubiquitous in the area and commonly infests Adélie penguins (Pygoscelis adéliae), a seasonally important prey of SGP
	Perineus macronecti (3)	*louse*	SA	baseline	Close encounters between individuals of different host species are opportunities for lice to straggle. Also contamination by researchers from one colony to another (3)
	Naubates fuliginosus (4)	*louse*	SA	baseline	
	Austromenopon ossifragae (5)	*louse*	SA	baseline	NA
	Perineus circumfasciatus (5)	*louse*			
	Docophoroides murphyi (3, 5)	*louse*			
	Paraclisis obscura (3, 5)	*louse*			
	Glaciopsyllus antarcticus ***(Neg)***(24)	*flea*	A	baseline	NA
Northern Giant Petrel *Macronectes halli*	*Docophoroides murphyi (3)*	*louse*	SA	baseline	Close encounters between individuals of different host species are opportunities for lice to straggle. Also contamination by researchers from one colony to another (3)
	Paraclisis obscura (3)	*louse*			
	Perineus macronecti (3)	*louse*			

White-chinned Petrel *Procellaria aequinoctialis*	*Ixodes kerguelensis I (13, 39)*	*tick*	SA (39)	prevalence of B. burgdorferi in penguis(39), baseline (13)	*Pelecanoides georgicus, D.exulans* and *P.aequinoctialis* are hosts for *I. kerguelenensis,* suggested as possible vector for *(Borrelia burgdorferi,* Lyme disease agent)(*39)*
	Zachvakinia robusta (29)	*mite*	A	NA	NA
	Docophoroides brevis (4)	*louse*	SA	baseline	NA
	Pseudonirmus gurlti (4)	*louse*			
	Naubates fuliginosus (4, 5)	*louse*	SA	baseline	NA
	Trabeculus hexacon (4, 5)	*louse*			
Grey petrel *Procellaria cinerea*	*Naubates fuliginosus (3)*	*louse*	SA	baseline	Close encounters between individuals of different host species are opportunities for lice to straggle. Also contamination by researchers from one colony to another (3)
	Trabeculus hexacon (3)	*louse*			
	Halipeurus procellariae (3)	*louse*			
	Halipeurus diversus (3)	*louse*			
			other	baseline	NA
	Zachvatkinia puffini (2)	*mite*			
Shy albatross *Thalassarche cauta*	*Docophoroides brevis (4)*	*louse*	SA	baseline	NA
	Ixodes eudyptidis (42)	*tick*	SA	mortality event	Vector of newly discovered tickborne and potentially zoonotic phlebovirus HIGV

Table 6. Summary of bacterial, viral and fungal isolates by location. Details on type of sample tested and method used for pathogen identification are provided when available in the reference source.

	Location of positive isolates									
	Virus					Bacteria and fungi				
Site / Species	other	Antarctic	SubAntarctic	Diagnostic method	Type of sample	other	Antarctic	SubAntarctic	Diagnostic method	Type of sample
Thalassarche melanophrys	*Avipoxvirus** (34)			PCR (DNA) and sequencing (34)	NA, tissue samples from dead birds inferred (34)	*Borrelia garinii* (11)		*Salmonella newport* (7)	Culture, isolates and serotyping (pulsed-field gel electrophoresis) (7). Culture spirochetes from ticks, PCR (DNA from ticks) and sequencing (11).	Fecal swabs from live birds (7), ticks (11)
Phoebastria immutabilis	Avian poxvirus (*Poxvirus avium*) (15, 37)			Fibrolast culture, PCR (DNA from culture) and sequencing (15), histopathology: skin lesions consistent with avian pox (37)	Epithelial tissue from skin lesions in live chicks (15), nodules on foot webs or phalanges dead chicks (37)					

Macronectes giganteus		Avian poxvirus (21)		Culture (tissue homogenates) and electron microscopy + PCR + sequencing, and compared to fowlpox and canarypox (21)	Samples of multiple cutaneous nodules from dead chicks (21)		*Pasteurella multocida subsp. gallicida*(17) *Escherichia coli* (17, 20) *Enterococcus faecalis* (20) *Bacillus subtilis* (20) *Brevibacterium brunneum* (20) *Alcaligenes faecalis* (20) *Plesiomonas sp* (20) *Clostridium perfringens (21)* *Edwardsiella tarda* (26)		Culture, morphologic characteristics and biochemical tests (17, 20, 26). *E. coli* virulence markers by PCR (17, 20). Capsular serotype of *P. multocida* strain by multiplex PCR assay (17). Histopathology (17, 21). Culture for *Cl. perfringens* and alpha toxin by PCR (21)	Tissues collected at necropsy. *E. coli* from pericardial sac and air sacs, *P. multocida* from heart, liver, lung, air sacs, pericardial sac (17), cloacal swabs from live birds (20, 26), ileon (21)

Thalassarche cauta	Avian poxvirus (30)		Hunter Island Group virus I, seq (HIGV, new tick-borne *Phlebovirus*) (42)	Culture (pooled tick homogenates), random PCR amplification (RNA from cultures), next-generation sequencing (42), NA (30)	ticks (*Ixodes eudyptidis*) from healthy and affected birds (42), NA (30)					
Procellaria parkinsoni	Avian poxvirus(32)			NA (32)	NA (32)					
Thalassarche chrysostoma						*Aspergillus flavus-oryzae group* (43) *Proteus spp (*43)			Microscope examination of kidney smears + culture + histopathology (43)	*A. flavus* in kidney, *Proteus* in kidneys, liver and spleen (43)
Phoebastria immutabilis						*Salmonella ohio* (14) *Salmonella oranienburg* (14) *Salmonella san-diego* (14) *Nocardia asteriodes* (37)			Histopathology + culture and strain identification (14) culture + identification + histopathology (37)	Intestines from carcasses (14) air sacs, dead chicks (37)
*Thalassarche carteri***								*Pasteurella multocida* (12, 31, 33, 44)	Bacteriology and histopathology from frozen	Undescribed tissues from chick carcasses

								Erysipelothrix rhusiopathiae (12, 33)	carcasses. Serotyping for Er (12). Bacterial culture and isolation for Pm from tissue samples of dead birds, PCR to test for presence of Pm and Er in swabs (44)	(12). Blood, cloacal and oro-pharyngeal swabs for PCR, undescribed organs from dead birds culture and isolation Pm(44)
Diomedea amsterdamensis								*Pasteurella multocida* (44)		
Phoebetria fusca								*Pasteurella multocida* (12, 44)		

NA: not available.
*Kane et al. (2012)

References: (1) Peirce and Prince (1980), (2) Mironov and Stefan (2013), (3) Palma and Horning (2002), (4) Zlotorzycka and Modrzejewska (1992), (5) Clay and Moreby (1970), (6) Tsurumi and Sato (2002), (7) Palmgrem *et al.* (2000), (8) Goff *et al.*(1989),(9) Bergstrom *et al.* (1999b), (10) Bergstrom *et al.* (1999a), (11) Olsen *et al.* (1995), (12) Weimerskirch (2004), (13) Wilson (1970), (14) Work *et al.* (1998), (15) Young and Vanden Werf (2008), (16) Padilla *et al.* (2003), (17) Leotta *et al.* (2003), (18) Baumeister *et al.* (2004), (19) Ippen and Henne (1989), (20) Jorge *et al.* (2002), (21) Shearn-Boschler *et al.* (2008), (22) Uhart *et al.* (2003), (23) Zdzitowiecki and Drozdz (1980), (24) Whitehead *et al.* (1991), (25) Leotta *et al.* (2001), (26) Leotta *et al.* (2009), (27) Munday (1972), (28) Bonnedahl *et al.* (2005), (29) Mironov (1991), (30) Woods (2004), (31) Rolland *et al.* (2009), (32) Bell *et al.* (2007), (33) Weimerskirch *et al.* (1998), (34) Kane *et al.* (2012), (35) Murray *et al.* (2003), (36) Anderson and Fortner (1988), (37) Sileo *et al.* (1990), (38) Gilardi *et al.* (2001), (39) Gauthier-Clerc *et al.* (1999), (40) Woods *et al.* (2009), (41) Chastel *et al.* (1993), (42) Wang *et al.* (2014), (43) Tham *et al.* (1974), (44) Jaeger *et al.* (2013), (45) Iwaki *et al.* (2006), (46) Uhart *et al.* (2004).