RPAS over Natura 2000 areas: Disturbance responses of wildlife and opportunities for research

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Introduction

Plants and animals will not stop at national borders. Protection of wild plants and animals should therefore be an international effort. The network of Natura 2000 was designed to focus on conservation and development of biodiversity throughout Europe. Natura 2000 is the umbrella name for areas that are protected under the European Birds and Habitats Directives. According to these directives, EU member states must protect specific animal species and their natural habitat in order to preserve biodiversity. For the Netherlands, the Natura 2000 network concerns 163 areas on land and 3 marine areas that have now been formally designated.

Lensink *et al*. (2011) published a guidance document for potential effects of small aviation to wildlife in Natura 2000 areas, including the wise usage of airspace by small aviation above Natura 2000 areas. Present paper provides input for a similar document for RPAS over Natura 2000 areas. It may form the ecological basis for a guidance document on the responsible usage of RPAS over Natura 2000 areas. It provides insight into the legislation and regulations with regard to RPAS use in general and with regard to the Dutch Act of Nature Protection. Thereafter, we will discuss disturbing effects of RPAS to wildlife based on recent scientific literature, followed by a review of ecological research and monitoring for which RPAS have already been used.

Dutch Legislation and policy with regard to RPAS

A brief general overview
Flying RPAS weighing 25-150 kg require a permit following the Aviation Act, which must be requested from the relevant authorities. Flying lighter RPAS does not require permits from the Aviation Act but are still regulated depending on the user (recreational or professional user). Users of RPAS must have a good view of the RPAS during the entire flight and cannot operate a RPAS outside the daylight period (UDP).

Recreational users of RPAS can only fly RPAS with a weight of up 25 kg and up to 120 m high. No-fly zones for recreational users include airports, urbanization, roads, railway lines and industrial and port areas. It is also not allowed to fly above crowds of people. For professional users, rules are more complicated. For them, an operator certificate is needed, which depend on RPAS weight. Flying a RPAS with a weight of 4-150 kg requires a stricter operator certificate) than RPAS that are no heavier than 4 kg. Lighter types (mini-RPAS between 1-4 kg and micro-RPAS <1 kg) can be flown to a maximum height of 50 m and must remain at least 50 m away from urbanization, crowds of people and other no-fly zones.

RPAS usage in Natura 2000 areas
Restrictions for flying RPAS may apply for Natura 2000 areas. The network of Natura 2000 areas focuses on the preservation and development of nature areas throughout Europe. It is the umbrella name for areas that are protected under two European directives, the Bird Directive and/or the Habitat Directive. According to these directives, EU member states must protect specific animal species and their natural habitat in order to preserve biodiversity. In the Netherlands, more than 160 areas have been definitively designated as such. For each specific area in the Netherlands, a set of conservation objectives have been formulated that the country pursues, for example which plant species and animal species within the designated area deserve protection. Management of all areas is regulated through area-specific management plans. In such plans, measures needed to achieve the objectives are described, for instance by minimizing disturbance on wildlife. Allowable activities per Natura 2000 area are mentioned in the management plan to avoid having to go through a separate permit procedure for each activity with a potential negative effect on the achievement of conservation objectives. The management plan describes which activities are automatically permitted, which activities are permitted under certain conditions and for which activities a permit under the Dutch Act for Nature Protection (hereafter Wnb) is required. The provinces and sometimes Rijkswaterstaat (main large water bodies) or the national government are the relevant permitting authorities to assess permit applications. Since flying with RPAS is a relatively

new activity, restrictions to RPAS usage are mostly not yet included in management plans. This means that a permit is thus required for flying RPAS above most Natura 2000 areas. In other words, there is no total ban on flying with RPAS above Natura 2000 areas, but a permit may be necessary if flying with RPAS is not regulated in the management plan or if the activity deviates from what is described in the management plan and negative effects cannot be excluded.

For several Natura 2000 areas, access of the airspace for recreational RPAS has been regulated through special rulings established by the central government (mostly the Minister of Defence, the Minister of Infrastructure & Water Management or the Minister of Agriculture & Nature). This has been done for several large water bodies in the southwest (Delta-region), known for their large concentrations of waterbirds and seals. In these cases, restrictions may be set for certain parts of a Natura 2000 area like locations used by resting seals or high-tide roosts for shorebirds. For the well-known Wadden Sea area with similar wildlife values, RPAS usage is regulated through a code of conduct rather than a set of restrictions.

European RPAS 2020 regulation

In June 2020, new European regulations for RPAS must be implemented in all EU countries. This will then replace the Dutch regulations for RPAS described above. In the EU regulations, the difference between amateur pilots and professionals has been dropped. Rather, flight movements are classified according to risk, in three categories: *open*, *specific* and *certified*. The majority of RPAS flights will fall into the low risk category *open*. With the new rules, RPAS of up to 500 grams may fly above buildings provided that they do not fly over people. Certain distances to buildings and people apply to heavier RPAS. The categories *specific* and *certified* concern flights with a (much) higher risk. The category *specific* may include, for example, flights above people or in controlled airspace, and the category *certified* to flights that take place out of sight. There may be restrictions or prohibitions on flying with RPAS in certain areas due to safety, security, privacy or the environment. This is determined when the regulations are implemented.

Effects of RPAS disturbance on wildlife

Disturbance in general

Effects of disturbance on animals come in different levels (figure 1). The levels together form a chain of cause and effect. Effects at the front of the chain are easier to determine in the field than effects lower down the chain. The most immediately observable effects are changes in behaviour (alarm, flying away, etc.). These primary responses can trigger a chain of cause and effect, which may ultimately lead to a decrease in reproduction and survival of individuals and even a lowering in population size (figure 1).

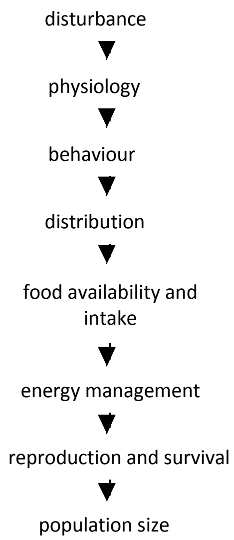

Figure 1: Chain of cause and effect of disturbance of wildlife (Lensink *et al*. 2005).

Disturbance as defined in the Dutch Act of Nature Protection (Wnb)

The Wnb roughly consists of an area protection component and a species protection component.

We focus here on the assessment of effects of RPAS in the context of area protection. The protection of nature values (habitat types, habitat directive species and bird directive species) in Natura 2000 areas is regulated through the area protection section of the Wnb. Before spatial development and other potentially disturbing activities (such as flying with RPAS), it must be demonstrated that these will not have any significant negative effects on achieving the conservation objectives of habitat types, habitat directive species and/or bird directive species in Natura 2000 areas. According to the Wnb, disturbance only occurs when it is on purpose and when the effect is permanent. This means that effects at the front of the chain are not considered disturbance when they do not lead to permanently altered situations (i.e. death or population changes). A flying RPAS disturbing a colony of breeding birds quickly settling after the RPAS has passed is thus not considered to create disturbance. A situation during which the birds fly away for a much longer period, leaving the eggs or chicks available to predators, may however be considered disruptive.

RPAS and disturbance

Fly-away and return times
The response of an organism to disturbance can be measured by determining the distance of the responding animal to the disturbing source (fly-away distance or flight initiation distance FID), or ecologically more correct, by determining the time it takes for the animal to return to the original location after disturbance (return time). Little research has been done into both parameters.

A few sources determined the return time after a RPAS disturbance. Return time turned out to be 1 to 2 minutes for ducks and dunlins outside the breeding season (Drever *et al.* 2015). Similarly, there was a short return time of birds in their breeding colonies after disturbance by RPAS (gulls within 5 minutes: Brisson-Curadeau *et al.* 2017; terns within 1 minute: Reintsma *et al.* 2018). On the other hand, outside the breeding season, gulls did not return after they were disturbed by a RPAS (Drever *et al.* 2015).

Egan (2018) made an estimate of the FID of blackbirds that were approached by a RPAS at a height of 5-10 m. They took flight at a distance between 51 m and 103 m, depending on RPAS type.

Visual and auditory disturbance
Studies on disturbance by aviation in general often make no distinction between visual and auditory aspects of disturbance (Busnel 1978). Nevertheless, both aspects are potentially contributing to disturbance. For RPAS, this is also true (Dulava *et al.* 2015; Smith *et al.* 2016). The influence of both components is probably dependent on flight height, whereby the influence of visual disturbance increases as flight height decreases.

Species-, time- and location-specific factors
Krijgsveld *et al.* (2008) and Smits & Lensink (2014) describe the factors that determine the susceptibility to disturbance of bird species. These factors can be roughly divided into species-, time- and location-specific factors.

Species-specific factors
Krijgsveld *et al.* (2008) provide an overview of the susceptibility to disturbance of bird species, varying from very insensitive to highly sensitive. Body size plays a major role: disturbance distance generally increases as body size (weight) increases. For example, both the heron-species bittern and the reed warbler breed in the same reed habitat, but the smaller-sized reed warbler is less susceptible to disturbance than the (larger) bittern. In addition, factors such as openness of the habitat, sociability and food choice play a role: a species of open landscapes is more susceptible to disturbance than a forest species (eg lapwing versus black woodpecker); a social species is more susceptible to disturbance than a solitary species (for example colony breeders or foraging bird flocks versus single territorial birds) and herbivorous and carnivorous birds appear more susceptible to disturbance than seed eaters. This for instance applies that as the group becomes larger, the disturbance distance also increases.

In a number of RPAS studies differences in disturbance response between species have been investigated. Drever *et al.* (2015) found different responses to RPAS in water birds; ducks often did not show a response to a RPAS and only occasionally flew away, while dunlins tended to fly away when a RPAS flew over, but returned quickly; gulls also often flew away and did not always return. Brisson-Curadeau *et al.* (2017) likewise found that many gulls flew away in response to a RPAS, but also that they returned within a few minutes. Weimerskirch *et al.* (2018) observed various responses to RPAS among penguins, albatrosses, petrels and cormorants. Adult breeding penguins and some albatross species showed little response to the approach of a RPAS (3 m away). Petrels and cormorants, on the other hand, seemed very sensitive to disturbance by RPAS. Rümmler *et al.* (2018) did observe behavioural changes in penguins in response to the RPAS: adelie penguins already responded when the RPAS was at a height of 50 m, whereas gentoo penguins did so at 30 m in height. Different responses to RPAS were also observed for terrestrial mammals. Bennitt *et al.* (2019) found that elephant, giraffe, gnu and zebra were more alert and moved away in response to a RPAS than did impala and lechwe. When monitoring mammals in the rain forest, a difference in response was observed to RPAS flights at less than 40 m above the foliage; kinkajous showed no reaction, but howler monkeys uttered alarm calls and hid under the foliage (Kays *et al.* 2018).

The difference in response to RPAS flights between species is furthermore described in the reviews of Rebolo-ifrán *et al.* (2019) and Mulero-Pázmány *et al.* (2017). Rebolo-ifrán *et al.* (2019) report effects on coastal, sea and water birds in the form of flight behaviour (Drever *et al.* 2015, Dulava *et al.* 2015), but no responses in snow geese and Canada geese (Chabot & Bird 2012), killer whales (Durban *et al.* 2015) and rhinoceroses (Mulero-Pázmány *et al.* 2014). Mulero-Pázmány *et al.* (2017) concluded that birds responded to RPAS faster than other species groups.

<u>Time-specific factors</u>
The time of year has a major impact on the response to disturbance. This can be understood from the evolutionary principle that individuals maximize their total reproductive success. Survival and reproduction are the main drivers. In general, the greater the investment already made, the greater the urge to stay. Particularly in the breeding season much energy is invested: leaving a nest exposes the eggs or young to an increased chance of predation and the direct influence of weather, such as hot sun or precipitation. Permanent abandonment of nests by birds mainly occurs early in the season, when relatively little time has been invested in the nest, or later in the season, when the young are ready to leave the nest (Keller 1995, Delaney *et al.* 1999, Osiejuk & Kuczynski 2007, Mallory 2016, Fuller *et al.* 2018). Birds are therefore less inclined to be permanently disturbed later in the season than earlier in the season.

For example, Brisson-Curadeau *et al.* (2017) found varying responses of guillemots in breeding colonies in case of disturbance by RPAS; actual breeding individuals fled less after disturbance than individuals without a nest. Weimerskirch *et al.* (2018) also found a difference among king penguins in their response to disturbance by RPAS depending on the breeding stage they were in; breeding adults showed little to no response to closely approaching RPAS, while moulting adults and chicks showed strong responses and left the site that was approached by a RPAS. Pomeroy *et al.* (2015) found for seals that the effects were greater on individuals during nursing period than during moulting period.

Mulero-Pázmány *et al.* (2017) thus concluded that animals in general are less likely to flee in the breeding season compared to non-breeding animals, probably because they do not want to leave the offspring (nest or young) or because of their reduced mobility. Nevertheless, animals in the breeding season may respond aggressively to a RPAS, which may have to do with increasing territoriality or defence of offspring.

<u>Location-specific factors</u>
Location-specific factors influence the extent to which RPAS disturb, for example the presence of vegetation that obscures the view of RPAS or the presence of background noise that masks the sound of the RPAS.

Some studies investigated the effects of RPAS in different habitats or as a function of location-specific factors. Bevan *et al.* (2018) investigated the effects of a RPAS on saltwater crocodiles in different habitats. Saltwater crocodiles near the coast responded to the RPAS when it flew below 30 m and went into hiding when it descended to less than 10 m. Resting on the beach or in the surf, reactions were however seen at higher altitudes, namely when the RPAS came below 50 m. Pomeroy *et al.* (2015) observed responses in common seals at nursing period that differed between sites. At a more isolated resting site seals responded with nervous behaviour and some adults with puppies fled into the water. In contrast, little reaction was observed on the same day at another resting site. For birds, Egan (2018) found that the chance of leaving a field due to disturbance by a RPAS was dependent on the size of the field in which they are located (in addition to group size).

Dose-effect relationship
In addition to the species-, time- and location-specific factors, distance and height at which an aircraft passes determine the degree of disturbance. A certain degree of dose-effect relationship applies here: height and distance of passage are related to the noise level to which animals are exposed and the degree of visual threat. In general, when aircraft fly closer or at a lower altitude, they cause a higher degree of disturbance. An increase in behavioural changes with decreasing heights has also been demonstrated for various species in RPAS studies (Drever *et al.* 2015, Dulava *et al.* 2015, Pomeroy 2015, McEvoy *et al.* 2016, Rümmler *et al.* 2016, Weimerskirch *et al.* 2017, Bevan *et al.* 2018, Rush *et al.* 2018, Bennitt *et al.* 2019, Brunton *et al.* 2019, Penny *et al.* 2019, Wandrie *et al.* 2019). Birds respond much more strongly to RPAS when the RPAS approach the birds vertically (Vas *et al.* 2015, Rümmler *et al.* 2016).

Effects differ between RPAS types
Different effects apply to different RPAS types. The two main types, rotor and fixed-wing RPAS, differ in shape, with the shape of fixed-wing RPAS somewhat resembling a bird of prey. This difference leads to different reactions in birds.

Fixed-wing RPAS caused a greater flight response among water birds, especially if such RPAS performed unexpected movements above the group (McEvoy *et al.* 2016). A greater disturbance by fixed-wing RPAS than by rotor RPAS was also observed by Egan (2018) and Vallery (2018). However, Barr (2017) did not observe any disturbance by a fixed-wing RPAS, although he did with a rotor RPAS. In this study, however, the fixed-wing RPAS was flown at a high altitude (200-300 m). In the study by McEvoy *et al.* (2016), a type of RPAS, resembling a bird of prey most, caused by far the largest flight reactions. Egan (2018), who investigated the effect of a bird of prey model RPAS, also observed this.

Effects due to differences in coloration of RPAS have not been demonstrated (Vas *et al.* 2015). However, an effect of engine type, electric or fuel, has been demonstrated. RPAS with a fuel engine can cause a greater disturbance than electric RPAS, because they produce more noise. This has been demonstrated by Korczak-Abshire *et al.* (2016): a fixed-wing fuel RPAS already caused disturbance at an altitude of 350 m, while no effects were found for flights with a fixed-wing electric RPAS at the same height.

Disturbing effects of RPAS on protected species

<u>Birds</u>

Breeding birds

RPAS can be used to study nest contents and to count the number of breeding pairs in colonies. During nest checks it appeared that approaching a nest can lead to disturbance of the parent birds. Weissensteiner *et al.* (2015) found that hooded crows were alerted and started flying over the nest at a RPAS flying height of 5 m and less. In their study of oystercatchers Valle & Scarton (2019) found significant disturbance at a RPAS altitude of more than 50 m above ground: all breeding oystercatchers flew away. The time spent away from the nest after a disturbance was approximately 1 minute. In the presence of gulls, which are potential predators of eggs and chicks, this time was shorter. Adult Steller's sea-eagles generally responded little to the presence of a RPAS (Potapov *et al.* 2013). Some of the birds that were sitting on the nest flew away. Birds at some distance from the nest did not respond. Junda *et al.* (2015) found no effect of a RPAS within a flight height of 3-6 m, as most birds had flown away earlier, when the nest had been approached by researchers on foot. McClelland *et al.* (2016) found no indications of disturbance during their monitoring of Tristan albatross. They flew at a height of 20 m. Also, with the sage grouse, no to little reaction was observed when flying over by a RPAS (flight altitudes between 30 m and 100 m; Hanson *et al.* 2014). All the above references, with the exception of Hanson *et al.* (2014) concerned monitoring and investigations with a rotor RPAS.

Flying with RPAS over colonies at altitudes between 30 m and 80 m did not appear to cause disturbance (gulls: Sardà-Palomera *et al.* 2012, Diaz-Delgado *et al.* 2017; penguins: Goebel *et al.* 2015, Ratcliffe *et al.* 2015). Even at a height of 15 m, gulls in some colonies showed no reaction (Grenzdörffer 2013, Rush *et al.* 2018). Brisson-Curadeau *et al.* (2017) found that nesting cliff birds (especially guillemots) hardly fled when approached by a RPAS, except from a single location where sea eagles were present that made the birds skittish. Reintsma *et al.* (2018) found no behavioural changes in cattle egrets, great blue herons, glossy ibises and a colony of common terns when a RPAS flew at a (minimum) 12 m height. Weimerskirch *et al.* (2018) only found a response in various species of seabirds (some of which were colonial breeders) at a low flight height, namely, depending on the species, between 10-25 m.

Adelie penguins, on the other hand, responded when the RPAS flew at a height of 50 m (Rümmler *et al.* 2016, 2018). Gentoo penguins did not respond when the RPAS flew at a height of less than 30 m (Rümmler *et al.* 2018). This is in line with the findings of Goebel *et al.* (2015). Korczak-Abshire *et al.* (2016) found that Adelie penguins responded to a fuel motor RPAS at a higher altitude; 80% of the birds exhibited alert behaviour on flights at a height of 350 m. This effect was not observed with an electric RPAS. Korczak-Abshire *et al.* (2016) used fixed-wing RPAS, while Rümmler *et al.* (2016, 2018) and Goebel *et al.* (2015) used a rotor RPAS. Chabot *et al.* (2015) report minimal disturbance of colony-brooding terns by a fixed-wing RPAS at an altitude of 91-122 m. Moreover, habituation quickly seemed to occur. Bevan *et al.* (2018) performed observations with a RPAS of terns in the breeding period but resting outside the colony. They found a minimal disturbance (less than 10% of the birds flew away) at a flight height of less than 70 m. Spaans *et al.* (2016) found no visible disturbance in nesting terns during flights with a rotor RPAS on 15-20 m height. Barnas *et al.* (2018b) observed responses from snow geese with a fixed-wing RPAS flying at a higher altitude. On days when a RPAS was flown (75-120 m), resting behaviour of birds on the nest decreased and alert behaviours and leaving the nest increased.

Table 1: review of response of breeding birds to RPAS

Author(s)	**Type RPAS**	**Type of (main) response**	**Flight height of RPAS with reported disturbance (m)**	**Species**
Afán *et al.* 2018	rotor	none	50	glossy ibis
Barnas *et al.* 2018	fixed-wing	alert behaviour and leaving nest	75-120	snow goose
Bevan *et al.* 2018	rotor	flying off	<70	crested tern
Brisson-Curadeau *et al.* 2017	rotor	flying off	-	glaucous gull, iceland gull, guillemot, Brunnich’s guillemot (all cliff-breeding)
Chabot *et al.* 2015	fixed-wing	flying off	91-122	common tern
Díaz-Delgado *et al.* 2017	rotor	none	48-80	slender-billed gull
Goebel *et al.* 2015	rotor	none	30-60	chinstrap penguin, gentoo penguin
Grenzdörffer 2013	rotor	none	>15	common gull
Hanson *et al.* 2014	fixed-wing	none	30-100	sage grouse
Junda *et al.* 2015	rotor	none	-	osprey, ferruginous hawk, red-tailed hawk
Korczak-Abshire *et al.* 2016	fuel-motor fixed-wing	alert behaviour	300-400	adelie penguin
McClelland *et al.* 2016	rotor	none	20-150	Tristan albatross
Potapov *et al.* 2013	rotor	flying off	-	Steller’s sea-eagle
Ratcliffe *et al.* 2015	rotor	none	30	gentoo penguin
Reintsma *et al.* 2018	rotor	flying off (V)	12-27 (V), 15-50 (O)	cattle egret, snowy egret, glossy ibis (O), common tern (V)
Rümmler *et al.* 2016	rotor	alert behaviour	<50	adelie penguin
Rümmler *et al.* 2018	rotor	alert behaviour	<50 (A), <30 (E)	adelie penguin (A), gentoo pinguin (E)
Rush *et al.* 2018	rotor	alert behaviour, alarm and flying off	<15	lesser black-backed gull
Sardà-Palomera *et al.* 2012	fixed-wing	none	30-40	black-headed gull
Spaans *et al.* 2018	rotor	none	15-20	sandwich tern
Valle & Scarton 2019	rotor	flying off	>50	oystercatcher
Weimerskirch *et al.* 2018	rotor	alert behaviour	<10-25	several sea bird species
Weissensteiner *et al.* 2015	rotor	alarm and flying off	<5	hooded crow

Foraging and resting birds

Vas *et al.* (2015) established that response to a rotor RPAS by free-flying ducks in a zoo and with greenshanks in the wild only occurred at a distance of 4-10 m. A flamingo, known to be a species that is very susceptible to disturbance, could be approached up to 5-30 m before a reaction occurred.

At high altitudes (higher than 60 m) no or hardly any disturbance of birds by RPAS was observed (geese: Chabot & Bird 2012 and ducks: Drever *et al.* 2015). Results were more varied at lower altitudes. Nevertheless, McEvoy *et al.* (2016) and Dulava *et al.* (2015) found no disturbance of water birds (including ducks) and / or sea birds resting on the water surface when a RPAS was flying at a height of 40 m and 30 m above the water surface respectively. Allport (2016) anecdotally reported that whimbrels flew away at a RPAS flight at a height of 20 m, although, in this particular case, the RPAS took off just 5 m away from the birds and additional disturbance was caused by the presence of people controlling the RPAS. Wandrie *et al.* (2019) found no disturbance of blackbirds when a fixed-wing RPAS flew over at 52 m. On the other hand, a rotor RPAS did cause disturbance in blackbirds when it flew below 30 m.

Table 2: review of response of non-breeding birds to RPAS

Author(s)	**Type RPAS**	**Type of (main) response**	**Flight height of RPAS with reported disturbance (m)**	**Species**
Allport 2016	rotor	flying off	20	whimbrel
Chabot & Bird 2012	fixed-wing	none	183	Canada goose, snow goose
Drever *et al.* 2015	rotor	none	>60	water birds
Dulava *et al.* 2015	rotor and fixed-wing	flying off	<30	water birds
McEvoy *et al.* 2016	rotor (R) and fixed-wing (F)	alert behaviour	<60 (F), <50 (R)	water birds
Vas *et al.* 2015	rotor	alert behaviour and fleeing	4-10 (WE and GR) , 5-30 (F)	mallard (WE), greenshank (GR), flamingo (F)
Wandrie *et al.* 2019	rotor (R) and fixed-wing (F)	alert behaviour and fleeing (R)	52 (F), <30 (R)	common blackbird

<u>Bats</u>

Research on the effects of aviation on bats is still in its infancy. Kloepper & Kinniry (2018) investigated the usefulness of RPAS in recording sounds. Ground-based monitoring of both bats and RPAS led to the conclusion that bats were not adversely affected by the flying RPAS. Although bats approached the RPAS, they recognized it as an (uninteresting) object, after which they flew on again. There were no collisions between bats and RPAS during a total flight period of 84 minutes (spread over seven research nights). Broset (2018) and August & Moore (2019) also investigated the use of RPAS for bio-acoustic monitoring. They did not perceive a clear disturbance. However, Broset (2018) indicates that the RPAS produces ultrasound, which can influence the behaviour of bats. Research to test this is lacking.

Table 3: review of response of bats to RPAS

Author(s)	**Type RPAS**	**Type of (main) response**	**Flight height of RPAS with reported disturbance (m)**	**Species**
August & Moore 2019	rotor and fixed-wing	none		bat species
Broset 2018	rotor and fixed-wing	none	10-20	bat species
Kloepper & Kinniry 2018	rotor	none	5-40	bat species

<u>Marine mammals</u>

RPAS can cause disturbance to marine mammals such as pinnipeds, when they are resting on land or floating at the surface of the water. Species responded differently. Pomeroy *et al.* (2015) observed disturbance in seals by a RPAS at a flight height of 50 m or less. Goebel *et al.* (2015), on the other hand, found no disturbance at a flight height of at least 23 m with Antarctic fur seals, Weddell seals and sea leopards. Krause *et al.* (2017) also found no disturbance in sea leopards for this height. This is in line with the findings of McIntosch *et al.* (2018) who found no visible disturbance during fur seal counts by a RPAS at a height of 40 m. Observed differences can be species-specific or can be attributed to differing circumstances (eg Pomeroy *et al.* 2015). Barnas *et al.* (2018a) observed disturbance by polar bears due to a RPAS. The degree of disturbance was comparable to that observed in tourist activities. Flight reactions were not observed, so disturbance appears to be less than with the traditional mark-recapture technique. If disturbance responses to RPAS occur, they are less strong than responses during traditional observation methods from a helicopter (Acevedo-Whitehouse *et al.* 2010, Moreland *et al.* 2015).

Theoretically, marine mammals close to the surface of the water can hear a RPAS, but in many habitats the noise is masked by background noise (Christiansen *et al.* 2016). Moreover, it has not been demonstrated that noise levels below 100 dB cause disturbance of the behaviour. In most marine mammalian studies using a RPAS, few or no behavioural changes were observed. This was the case in Koski *et al.* (2015) to bowhead whales (flight at a height of 120-210 m), in Pirotta *et al.* (2017) to humpback whales, in Durban *et al.* (2015) to killer whales (flight at 35-40 m altitude) and in Arona *et al.* (2018) to pinnipeds (flight at 75-80 m).

Table 4: review of response of marine mammals to RPAS

Author(s)	Type RPAS	Type of (main) response	Flight height of RPAS with reported disturbance (m)	Species
Acevedo-Whitehouse *et al.* 2010	rotor	none	13	eight species of whale
Arona *et al.* 2018	fixed-wing	none	75–80	grey seal
Barnas *et al.* 2018	fixed-wing	alert behaviour	75-120	polar bear
Christiansen *et al.* 2016	rotor	none	-	-
Durban *et al.* 2015	rotor	none	35-40	killer whale
Goebel *et al.* 2015	rotor	none	>23	Antarctic fur seal, Weddell se leopard seal
Koski *et al.* 2015	fixed-wing	none	120-210	bowhead whale
Krause *et al.* 2017	rotor	none	23-45 m	leopard seal
McIntosh *et al.* 2018	rotor	none	40	Australian fur seal
Moreland *et al.* 2015	fixed-wing	alert behaviour	90-200	ribbon seal, spotted seal
Pirotta *et al.* 2017	rotor	none	<10	humpback whale
Pomeroy *et al.* 2015	rotor	alert behaviour and moving of short distances	<50	grey seal, harbour seal

<u>Terrestrial mammals</u>

Bennitt *et al.* (2019) observed disturbance of large mammals by RPAS: most species (including elephant, giraffe and zebra) responded to a RPAS when it flew within 100 m horizontal distance and within 60 m height. Penny *et al.* (2019) also observed behavioural changes in mammals in response to a RPAS. They used RPAS to scare off white rhinoceroses and consequently move them from risk areas related to poaching. The RPAS was noticed by rhinoceroses up to a height of at least 100 m and they moved most when a RPAS was flying at a low altitude (10 m). Kays *et al.* (2018) used a RPAS for monitoring mammals in the rainforest. They recorded that kinkajous and howler monkeys would not be disturbed if the RPAS flew more than 40 m above the foliage. Kangaroos displayed alert behaviour due to RPAS flights but rarely fled (Brunton *et al.* 2019). In contrast, Ditmer *et al.* (2015) observed virtually no behavioural changes in bears that were approached by a RPAS at an average distance of 43 m and a height of 21 m, although they did find strong physiological changes (increase in heartbeat indicating stress). Bushaw *et al.* (2019) noticed that cattle in the vicinity of the research location responded strongly to RPAS and often fled. No behavioural changes indicating disturbance were found in Tibetan antelopes (flight height at 75-750 m; Hu *et al.* 2018), in cattle (Mulero-Pázmány *et al.* 2015), and in hippopotamuses (flight height at 40-120 m; Inman *et al.* 2019).

Table 5: review of response of terrestrial mammals to RPAS

Author(s)	Type RPAS	Type of (main) response	Flight height of RPAS with reported disturbance (m)	Species
Bennitt *et al.* 2019	rotor	alert behaviour (A), fleeing (F)	Z: >100 (A); G, T, W: 50-80 (A); I, E, L: 30-50 (A); E, G, W, Z: 50-60 (F), T: 30 (F), I, L: 15 (F)	African elephant (E), giraffe (G), zebra (Z), tsessebe (T), gnu (W), impala (I), lechwe (L)
Brunton *et al.* 2019	rotor	alert behaviour, increase of fleeing	30	kangaroo
Bushaw *et al.* 2019	rotor	none	75	eight species of meso-carnivores
Ditmer *et al.* 2015	rotor	none	21 (mean)	Amerikaanse black bear
Hu *et al.* 2018	fixed-wing	none	75-750	Tibetan antilope
Inman *et al.* 2019	rotor	none	40, 80, 120	hippopotamus
Kays *et al.* 2019	rotor	alarm calls, hiding	<40	kinkajou, howler monkey
Mulero-Pázmány *et al.* 2015	fixed-wing	none	100	cattle and other ungulates
Penny *et al.* 2019	rotor	alert behaviour (A) and fleeing over short	at least 100 (A), 10 (V)	white rhinoceros

Author(s)	**Type RPAS**	**Type of (main) response**	**Flight height of RPAS with reported disturbance (m)**	**Species**
		distances (V)		

Fish and amphibians

Only few authors have used RPAS to study fish. They did not describe disturbing effects, which also seems unlikely, following the findings by Christiansen *et al.* (2016) into noise propagation due to flying RPAS into water.

We know of no studies researching amphibians with RPAS. Effects of disturbance by RPAS are probably few (if any). Dutch amphibians prefer shallow water (toads) or deeper water (frogs and most newts). All larvae live below the water surface. Auditory disturbance can be excluded for newts, since newts do not communicate by noise. Frogs and toads are however noisy during the mating period but mostly at night when RPAS are not often flown. Visual disturbance by aviation will play a minor role because they live in the water or, amphibians, remain hidden in burrows or under leaves on land.

Reptiles

Dutch reptile species (snakes and lizards) live hidden in vegetation and hide quickly when disturbed. Disturbance by sound is excluded for many snakes as they cannot hear well (Hartline 1971). Lizards do have sensitive hearing organs (Christensen-Dalsgaard & Manley 2005). Due to their behaviour of quickly hiding by danger, they will not be easily disturbed by RPAS. Perhaps for this reason, research into the effects of RPAS on reptiles is minimal and concerns crocodiles and turtles. For example, Biserkov & Lukanov (2017) noticed that freshwater turtles were disturbed when the RPAS flew lower than 10 m.

Insects (butterflies, dragonflies, beetles and other invertebrate species)

We do not know of specific studies that looked into disturbance of insects by RPAS. Larvae of most species often live well hidden while most adult insects fly low above the surface in the vicinity of their preferred habitat. There are no indications nor are there studies showing that RPAS disturb insects as RPAS often move relatively high above the ground (eg, to avoid disturbance of birds and or mammals).

Application of RPAS in ecological research and monitoring

Brief review

RPAS are used to collect information quickly and efficiently in various types of ecological research and monitoring, although not always without difficulties. Usage of RPAS above Natura 2000 areas can contribute to the collection of sound scientific and policy-relevant information. RPAS are for example frequently used to count individual birds, to determine the nest content, or to inventory a bird colony. RPAS are used to listen for bird song in highly inaccessible places. On Hawaii, a plant species feared to be extinct was rediscovered by flying RPAS along steep cliffs. In addition, RPAS have been used to map habitats, habitat types or host plants and to count the number of mammals on land or at sea (seals, dolphins and whales).

We performed a literature review on RPAS usage in ecological research and monitoring. We found 223 publications using adequate search strings on especially google scholar. In most studies, vegetation had been studied (38% of the publications) followed by birds and mammals (figure 2). Rotor RPAS were most often used in research (in 56% of the publications). They were more often used than fixed-wing RPAS in bird research but both types were equally used in vegetation and mammal research. In the remainder of this section we will give examples of the studies performed per species group.

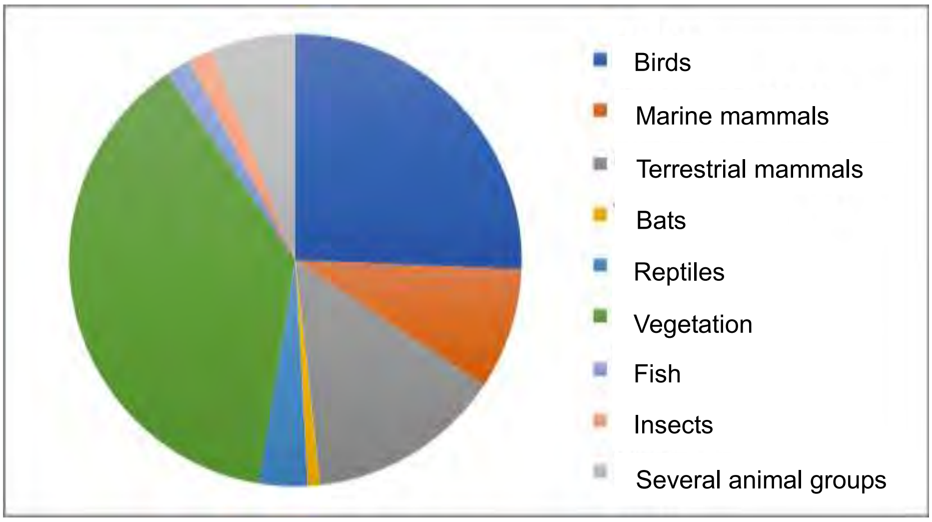

Figure 2 Number of publications of ecological research using RPAS per species group.

Birds

Studies of birds with RPAS relate to both breeding birds (table 6) and non-breeding birds (table 7).

Breeding birds

RPAS have been widely used to monitor and collect information on number of nests and breeding pairs (Potapov *et al.* 2013, Junda *et al.* 2015, Weissensteiner *et al.* 2015, Muller *et al.* 2019, Valle & Scarton 2019), colonies (Sardà-Palomera *et al.* 2012, 2017, Ratcliffe *et al.* 2015, Diaz-Delgado *et al.* 2017, Hodgson *et al.* 2018, Rush *et al.* 2018, Spaans *et al.* 2018, Pfeifer *et al.* 2019), breeding populations (Afán *et al.* 2018, McClelland *et al.* 2016, Han *et al.* 2017, Marinov *et al.* 2016, Pöysä *et al.* 2018) and breeding habitat and habitat selection (Rodriguez *et al.* 2012, Chabot *et al.* 2014, Kamm & Reed 2019). Data on breeding status, number of offspring and age of birds was all successfully collected. This has been done for the Eurasian oystercatcher and diverse penguin, gull and tern species. RPAS have less successfully been used in bio-acoustic monitoring of songbirds because the sound by the RPAS masked songs of birds with low-frequency singing (Wilson *et al.* 2017). As a result, the number of birds and species diversity were underestimated for these species. Successful usage of RPAS in breeding bird monitoring has been demonstrated by several studies. Hodgson *et al.* (2016) found for instance that counts of colony birds with a RPAS were more precise than traditional, land-based, counting methods, partly because areas that were difficult to access could be investigated by RPAS. Other studies found that RPAS counts yielded 93-96% of the regular land-based counts (Chabot *et al.* 2015, Pöysä *et al.* 2018).

Eurasian oystercatcher (José van Zundert/Bureau Waardenburg)

Table 6: review of application of RPAS in breeding bird research

Author(s)	**Type RPAS**	**Species(group)**	**Subject of study**
Afán *et al.* 2018	rotor	glossy ibis	monitoring breeding population
Chabot *et al.* 2014	fixed-wing	least bittern	determining habitat quality
Chabot *et al.* 2015	fixed-wing	common tern	survey
Díaz-Delgado *et al.* 2017	rotor	slender-billed gull	mapping colony size and productivity
Han *et al.* 2017	rotor	Water birds	monitoring population and habitat
Hodgson *et al.* 2016	rotor	royal penguin, lesser frigatebird and crested tern	counts
Hodgson *et al.* 2018	rotor	seabirds	counts
Junda *et al.* 2015	rotor	osprey, bald eagle, ferruginous hawk and red-tailed hawk	nest survey
Kamm & Reed 2019	rotor	American kestrel	land cover classification
Marinov *et al.* 2016	fixed-wing	great white pelican	monitoring breeding population
McClelland *et al.* 2016	rotor	Tristan albatross	population estimate
Muller *et al.* 2019	rotor	yellow-eyed penguin	locating nests
Pfeifer *et al.* 2019	fixed-wing	chinstrap penguin	distribution and abundance
Potapov *et al.* 2013	rotor	Steller's sea eagle	nest survey
Pöysä *et al.* 2018	rotor	ducks	brood survey
Ratcliffe *et al.* 2015	rotor	gentoo penguin	survey
Rodríguez *et al.* 2012	fixed-wing	lesser kestrel	studying habitat selection
Rush *et al.* 2018	rotor	lesser black-backed gulls	survey
Sardà-Palomera *et al.* 2012	fixed-wing	black-headed gull	monitoring temporal changes in breeding colony size
Sardà-Palomera *et al.* 2017	fixed-wing?	black-headed gull	monitoring spatial and temporal dynamics of colony
Spaans *et al.* 2018	rotor	sandwich tern	counting number of nests and determining fledging success
Valle & Scarton 2019	rotor	Eurasian oystercatchers	counts
Weissensteiner *et al.* 2015	rotor	hooded crow	assessing the breeding status, offspring number and age
Wilson *et al.* 2017	rotor	songbirds	bio-acoustic monitoring

Foraging and resting birds

RPAS have been deployed outside the breeding season to investigate bird populations and to research bird habitat (Drever *et al.* 2015, Han *et al.* 2017). In addition, Wandrie *et al.* (2019) used RPAS as a deterrent of blackbirds in fruit orchards. Approaches of the birds at lower heights provoked more responses: blackbirds did for instance not respond to a fixed-wing RPAS at a height of 52 m. A rotor RPAS at 30 m did however cause behavioural changes in the birds.

Chabot & Bird (2012) compared the data from land-based counts with those from a RPAS. The results appeared to be species-dependent; compared to land-based counts, the white-coloured snow geese were counted with more precision using a RPAS than the black-and-grey coloured Canada geese as the latter did not contrast as much as snow geese in the arable fields.

Canada geese (Hein Prinsen/Bureau Waardenburg)

Table 7: review of application of RPAS in non-breeding bird research

Author(s)	Type RPAS	Species(group)	Subject of study
Chabot & Bird 2012	fixed-wing	snow and Canada geese	counts
Drever *et al.* 2015	rotor	water birds	monitoring bird populations and habitat
Han *et al.* 2017	rotor	water birds	monitoring bird populations and habitat
Wandrie *et al.* 2019	rotor and fixed-wing	blackbird	deterrent

<u>Bats</u>

RPAS can be used to monitor bats acoustically (table 8). Detection distance and detection probabilities using different types of RPAS were compared with results from standard monitoring from the ground (Broset 2018, August & Moore 2019). Monitoring by a RPAS was found to underestimate the number of bats compared to standard monitoring: it could thus not replace the standard method. The use of quieter RPAS may improve results. August & Moore (2019) furthermore adapted RPAS and microphone design, improving the recorded calls due to the reduction of ultrasonic sound of the RPAS to a negligible level. They, and Fu *et al.* (2018) and Kloepper & Kinnery (2018), showed that bat monitoring with RPAS and microphone is possible. Fu *et al.* (2018) furthermore made thermal images of bats in flight with a RPAS.

Table 8: review of application of RPAS in bat research

Author(s)	Type RPAS	Species(group)	Subject of study
August & Moore 2019	rotor and fixed-wing	bats	acoustic monitoring
Broset 2018	rotor and fixed-wing	bats	acoustic monitoring
Fu *et al.* 2018	rotor	bats	acoustic monitoring
Kloepper & Kinnery 2018	rotor	bats	acoustic monitoring

<u>Marine mammals</u>

Studies of marine mammals with RPAS relate to several whale species and seals (table 9).

Probability of detection of marine mammals was not lower than that of aircraft monitoring (Koski *et al.* 2009). The area to be explored was however smaller with a RPAS. Whales could be individually recognized using photos collected with a RPAS (Durban *et al.* 2015, 2016, Koski *et al.* 2015). Durban *et al.* (2015, 2016) furthermore collected information about the body size of whales. Torres *et al.* (2018) studied whale behaviour with a RPAS. They could be observed more and longer with a RPAS than with the traditional observing method, in particular foraging behaviour. Two studies have described research estimating the health of whales using a RPAS. In both studies, samples were taken of whale spouts, in which pathogens were identified that could potentially lead to diseases.

Arona *et al.* (2018) mapped density and behaviour of grey seals to determine effects of disturbance of seals by RPAS. Pomeroy *et al.* (2015) also collected information about the relative density of seals using a RPAS. Furthermore, they collected information on identification of individuals and on species composition and age classes of groups of seals. Finally, body size measurements could also be collected, although a further refinement proved necessary. Krause *et al.* (2017) estimated body size, as well as weight and body condition. Weight was accurately estimated with a deviation of approximately 4%. McIntosch *et al.* (2018) showed that monitoring using a RPAS yielded higher counts of seal pups than from the ground, provided the quality of images was high. Weather conditions however influenced results. Monitoring of seals in a large isolated region with RPAS proved unfortunately difficult as Moreland *et al.* (2015) showed while counting spotted seals and ribbon seals on the ice in the Bering Sea. They argued that a helicopter is more efficient in such difficult regions.

Table 9: review of application of RPAS in marine mammal research

Author(s)	**Type RPAS**	**Species(group)**	**Subject of study**
Arona *et al.* 2018	fixed-wing	grey seal	density population and behaviour
Durban *et al.* 2015	rotor	killer whale	identification individuals, collection data on morphological characteristics
Durban *et al.* 2016	rotor	blue whale	identification of individuals, collection data on morphological characteristics
Koski *et al.* 2009	fixed-wing	marine mammals	survey
Koski *et al.* 2015	fixed-wing	bowhead whale	identification of individuals
Krause *et al.* 2017	rotor	leopard seal	body size measurements
McIntosh *et al.* 2018	rotor	Australian fur seal	determining abundance
Moreland *et al.* 2015	fixed-wing	spotted and ribbon seal	counts
Pomeroy *et al.* 2015	rotor	grey and harbour seal	density population, identification of individuals and collection of data on species composition and age classes of groups of seals
Torres *et al.* 2018	rotor	grey whale	studying behaviour

Grey seals sunbathing (Jan Dirk Buijzer/Bureau Waardenburg).

<u>Terrestrial mammals</u>
RPAS have been used to research habitat of mammals (Puttock *et al.* 2015), the demography of mammalian populations (Wich *et al.* 2015, Hu *et al.* 2018, Inman *et al.* 2019) and presence and distribution of species (Wich *et al.* 2015, Gentle *et al.* 2018, Kays *et al.* 2018, Bushaw *et al.* 2019) (table 10).

Puttock *et al.* (2015) demonstrated that using a RPAS an area can effectively be monitored for beaver activity based on structural changes in the landscape like presence of dams. Stark *et al.* (2017) successfully mapped the habitat of a group of proboscis monkeys. Michez *et al.* (2016a) monitored the landscape with a RPAS for damage to agricultural crops by wild boar.

Bushaw *et al.* (2019) concluded that RPAS in combination with a heat camera are an effective tool for monitoring meso-carnivores. Israel (2011) used a RPAS and thermal imaging camera, investigating the possibility of detecting deer calves in a meadow in order to prevent them from being killed when mowing. In good weather and light conditions, determining deer calves with this system proved to be very effective. Rey *et al.* (2017) could automatically detect large mammals in a savannah by means of machine learning on the basis of images made with a RPAS. Patterson *et al.* (2016) were able to detect 78% of the reindeer in an area using a RPAS. They concluded that their detection depended on the habitat type being monitored, the contrast of the target against the background and the monitoring time. Crétien *et al.* (2015) established that bison and moose could be detected successfully using a RPAS. For deer and wolves, numbers were incorrectly estimated by 0-2 individuals per flight. The system therefore has potential to monitor these species. Nyamuryekung'E *et al.* (2016) observed the behaviour of cattle with RPAS. RPAS can furthermore be applicable in epidemiology, for example to determine occurrence and density of hosts of pathogens (Barasona *et al.* 2014).

Studies of effectiveness of RPAS research compared with regular research methods vary. Inman *et al.* (2019) compared effectiveness of RPAS in collecting numbers and age classes of a hippopotamus population compared with ground-based observations. Flying with a RPAS at a height of 40 m yielded counts of more hippopotamuses than in land-based observations and with a RPAS flying at a higher altitude. Results of determining age classes were similar between flying a RPAS at a height of 40 m and from the ground but ground-based counts resulted in better counts of young and sub-adult individuals. Wich *et al.* (2015) investigated density and distribution of the Sumatran orangutan. Data collected with the RPAS and with ground-based counts were comparable. For Tibetan antelopes, Hu *et al.* (2018) achieved more accurate counts using a RPAS than in ground-based monitoring. In contrast, Gentle *et al.* (2018) found that the probability of finding kangaroos was higher using a helicopter rather than a RPAS, due to the distances being covered. Chrétien *et al.* (2015) also found that detection probability compares to traditional aerial observation techniques, but that RPAS are limited in their flight distances. Mulero-Pázmány *et al.* (2015) indicated that data on the distribution of animals collected with a RPAS compared well to data collected with dataloggers. However, cattle densities were overestimated using RPAS data. Penny *et al.* (2019) applied RPAS with a much different goal, namely as a deterrent to keep rhinoceroses away from risky areas (for for instance poaching). It turned out that rhinoceroses were easier to manipulate with RPAS than with scent or sound. Mulero-Pázmány *et al.* (2014) also focused on establishing poaching activities. They used a RPAS to locate rhinoceroses and to check fences of the park.

Table 10: review of application of RPAS in terrestrial mammal research

Author(s)	Type RPAS	Species(group)	Subject of study
Barasona *et al.* 2014	fixed-wing	ungulates	determining occurrence and density of hosts of pathogens
Bushaw *et al.* 2019	rotor	meso-carnivores	survey
Chrétien *et al.* 2015	rotor	bison, moose, deer and wolf	detecting animals
Gentle *et al.* 2018	fixed-wing	kangaroo	detecting animals
Hu *et al.* 2018	fixed-wing	Tibetan antelope	counts
Inman *et al.* 2019	rotor	hippopotamus	collecting data on numbers and age classes of individuals in a population
Israel 2011	rotor	deer	detecting calves in meadows
Kays *et al.* 2019	rotor	kinkajou and howler monkey	monitoring populations
Michez *et al.* 2016a	fixed-wing	wild boar	monitoring damage to crops
Mulero-Pázmány *et al.* 2014	fixed-wing	rhinoceros	locating animals
Mulero-Pázmány *et al.* 2015	fixed-wing	cattle	population density and distribution
Nyamuryekung'e *et al.* 2016	rotor	cattle	observing behaviour
Patterson *et al.* 2016	fixed-wing	reindeer	detecting animals
Penny *et al.* 2019	rotor	rhinoceros	deterrent
Puttock *et al.* 2015	rotor	beaver	monitoring activity based on landscape changes
Rey *et al.* 2017	fixed-wing	large mammals	detecting animals
Stark *et al.* 2017	fixed-wing	proboscis monkey	mapping of habitat
Wich *et al.* 2015	fixed-wing	Sumatran orangutan	population density and distribution

Beaver (Annette Karels/Bureau Waardenburg)

Fish and amphibians

RPAS are used in fish research to determine densities of fish or to determine suitable habitat (table 11). Kiszka *et al.* (2016) determined the density of sharks and rays in coral reefs in a lagoon with a RPAS. Kudo *et al.* (2012) and Groves *et al.* (2016) counted the number of salmon through RPAS images. Groves *et al.* (2016) found that more salmon was counted annually with a RPAS than from a helicopter. Unfortunately, the application of RPAS in fish research seems to be limited to suitable habitats, namely wide and shallow clear water without cover (Kudo *et al.* 2012). Ventura *et al.* (2015) successfully mapped both geographical characteristics and specific vegetation of nursing grounds of fish with a RPAS. We do not know any examples of research on amphibians in which RPAS are used.

Table 11: review of application of RPAS in fish research

Author(s)	**Type RPAS**	**Species(group)**	**Subject of study**
Kiszka *et al.* 2016	rotor	blacktip reef shark and pink whipray	density population
Kudo *et al.* 2012	rotor	salmon	counts
Groves *et al.* 2016	rotor	salmon	counts
Ventura *et al.* 2015	rotor	several fish species	habitat assessment

Reptiles

The only reptile species researched by RPAS so far are turtles and crocodiles (table 12). Biserkov & Lukanov (2017) were able to identify both sunbathing and hiding turtles. This is an advantage over land-based monitoring. Bevan *et al.* (2015) determined the density and movement of turtles and successfully identified underwater objects using a RPAS. Crocodile counting was performed with RPAS by Ezat *et al.* (2018). They found that 26% more crocodiles were detected with the RPAS survey than during land-based monitoring. Evans *et al.* (2015, 2016) used RPAS for detection of crocodile nests. Ground-truthing remained however necessary. Apart from determining their occurrence, RPAS have been used in studies to collect data on morphological characteristics (Nile crocodile: Ezat *et al.* 2018; loggerhead turtle: Schofield *et al.* 2017). These involved determining body and tail length and distinguishing between adult male and female. In addition, behaviour was recorded by Schofield *et al.* (2017).

Table 12: review of application of RPAS in reptile research

Author(s)	**Type RPAS**	**Species(group)**	**Subject of study**
Bevan *et al.* 2015	rotor	green, flatback and hawksbill turtles and saltwater crocodiles	density population and movement of animals
Biserkov & Lukanov 2017	rotor	turtles	identifying animals
Evans *et al.* 2015	fixed-wing	estuarine crocodile	detecting nests
Evans *et al.* 2016	fixed-wing	estuarine crocodile	detecting nests
Ezat *et al.* 2018	rotor	Nile crocodile	counts and collecting data on morphological characteristics
Schofield *et al.* 2017	rotor	loggerhead turtle	collecting data on morphological characteristics

Author(s)	**Type RPAS**	**Species(group)**	**Subject of study** and behaviour

<u>Insects</u>

RPAS can even be used to monitor small species like insects (table 13). Ivosevic *et al.* (2017) determined their presence with a RPAS by photographing colourful butterflies, although not without difficulties. Kim *et al.* (2018) took samples at a height of 10 m above a rice field to identify potential pest and useful insects.

Habel *et al.* (2016) used RPAS to assess habitat of adult and caterpillars of two butterfly species. They first identified their presence in an area while noting various micro-habitat features of that area, including the number of flower buds and the percentage of open spaces. They then trained a habitat suitability model based on aerial photographs of the area (obtained using a RPAS) to recognize micro-habitat structures suitable for caterpillars of both species. They were able to predict high quality habitat with a high predictive power. This technique can also be applied to the management of pest species. Näsi *et al.* (2015) were for instance able to determine, by images collected with a RPAS, whether trees were infected by the European spruce bark beetle. In this way, RPAS can be useful to monitor forest health and to apply more specific management.

Table 13: review of application of RPAS in insect research

Author(s)	**Type RPAS**	**Species(group)**	**Subject of study**
Habel *et al.* 2016	rotor	common blue and adonis blue	habitat suitability
Ivosevic *et al.* 2017	rotor	nettle-tree butterfly	presence butterfly species
Kim *et al.* 2018	rotor	several insect species	presence insects
Näsi *et al.* 2015	rotor	European spruce bark beetle	damage by insects and forest health

<u>Vegetation</u>

RPAS have been used to monitor plant populations and plant communities (table 14). Tay *et al.* (2018) used ragwort as a model species to investigate the use of RPAS to monitor plant populations. This proved to be possible with high accuracy (over 90%). They noted that image processing took more time compared to standard methods. Lu & He (2017) showed that RPAS can be used for identification and determination of coverage of dominant species in heterogeneous grasslands. Franklin *et al.* (2017) carried out an inventory of deciduous trees with a RPAS and were able to identify 78% using machine learning. Mapping of forest vegetation with RPAS was also carried out, as in restoring forest vegetation (Hird *et al.* 2017) and monitoring of forest (Zhang *et al.* 2016, Puliti *et al.* 2017, Sankey *et al.* 2017). RPAS have also been used for mapping vegetation along rivers and in wetlands (table 11). Husson *et al.* (2014) were able to produce maps of aquatic vegetation in a lake and a river with an accuracy of 95% and 80%, respectively. In addition, RPAS have been used in vegetation research by Boon *et al.* (2016), Chabot & Bird (2013), Dufour *et al.* (2013), Flynn *et al.* (2014), Husson *et al.* (2017), van Iersel *et al.* (2018), Marcaccio *et al.* (2015), Pande-Chhetri *et al.* (2017) and Zweig *et al.* (2015). Beyer *et al.* (2019) successfully deployed RPAS to monitor the recovery of peat areas by monitoring plant communities. Boon *et al.* (2017) mapped various environmental factors using a RPAS, including vegetation, but also erosion, and contours and height differences in a landscape. They concluded that a rotor RPAS produced a higher spatial resolution than a fixed-wing RPAS, probably due to a lower flight speed and the possibility to capture more images. Accuracy and representation of vegetation data was therefore better using a rotor RPAS. Individual species were studied using a RPAS (table 11), for instance by Chabot *et al.* (2017). They were able to classify the species water soldier with 78% accuracy. Müllerová *et al.* (2017) investigated the use of a RPAS to map plants, with false acacia as the model species. Other research into density and distribution of species focused on a maple species (van Auken & Taylor 2017), yellow flag (Hill *et al.* 2017), smooth cordgrass (Wan *et al.* 2014) and reed (Tóth 2018, Zaman *et al.* 2011). Finally, Michez *et al.* (2016b) used a RPAS to record the location of invasive species. For giant hogweed, the results were promising for further management application. On the other hand, results were not sufficiently accurate for Japanese knotweed and Himalayan balsam.

Table 14: review of application of RPAS in habitat and vegetation research

Author(s)	Type RPAS	Species(group)	Subject of study
van Auken & Taylor 2017	rotor	maple species	plant density and distribution
Beyer *et al.* 2019	fixed-wing	peatland vegetation	monitoring recovery of plant communities in peat areas
Boon *et al.* 2016	rotor	wetland	assessment of ecosystem
Boon *et al.* 2017	rotor and fixed-wing	diverse plant species	monitoring environmental factors, such as vegetation
Chabot *et al.* 2017	fixed-wing	water soldier	plant distribution
Chabot & Bird 2013	fixed-wing	wetlands	classifying vegetation and determining land cover
Dufour *et al.* 2013	fixed-wing	riparian vegetation	monitoring of restored vegetation
Flynn & Chapra 2014	rotor	submerged aquatic vegetation	classifying and map vegetation
Franklin *et al.* 2017	fixed-wing	trees	inventory of deciduous trees
Hill *et al.* 2017	rotor	yellow flag	plant density and distribution
Hird *et al.* 2017	rotor	forest vegetation	mapping of vegetation
Husson *et al.* 2014	fixed-wing	riverbank and wetland vegetation	mapping of vegetation
Husson *et al.* 2017	fixed-wing	non-submerged aquatic vegetation	classifying vegetation
van Iersel *et al.* 2018	fixed-wing	river floodplain vegetation	classifying vegetation
Lu & He 2017	rotor	grassland vegetation	identification and determination of coverage of dominant species in heterogeneous grasslands
Marcaccio *et al.* 2015	rotor	wetland vegetation	classify vegetation
Michez *et al.* 2016b	fixed-wing	giant hogweed, Japanese knotweed and Himalayan balsam	mapping invasive species
Müllerová *et al.* 2017	fixed-wing	false acacia	map invasive species
Pande-Chhetr *et al.* 2017	fixed-wing	wetland vegetation	classifying vegetation
Puliti *et al.* 2017	fixed-wing	diverse plant species	forest monitoring
Sankey *et al.* 2017	rotor	diverse plant species	forest monitoring
Tay *et al.* 2018	not specified	ragwort	monitoring plant population
Tóth 2018	rotor	reed	plant density and distribution
Wan *et al.* 2014	not specified	smooth cordgrass	plant density and distribution
Zaman *et al.* 2014	fixed-wing	reed	plant density and distribution
Zhang *et al.* 2016	rotor	diverse plant species	forest monitoring
Zweig *et al.* 2015	fixed-wing	wetland vegetation	classifying plant communities

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