EARTHJUSTICE

July 13, 2023

Deb Haaland, Secretary
Department of the Interior
1849 C Street, N.W.
Washington, D.C. 20240
exsec@ios.doi.gov

Martha Williams, Director
U.S. Fish and Wildlife Service
Department of the Interior
1849 C Street, N.W.
Washington, D.C. 20240
martha_williams@fws.gov

Randy Moore, Chief
U.S. Forest Service
1400 Independence Ave., SW
Washington, D.C. 20250
randy.moore@usda.gov

BY EMAIL AND CERTIFIED U.S. MAIL

Re: Sixty-Day Notice of Intent to Sue to Remedy Violations of the Endangered Species Act

Dear Secretary Haaland, Director Williams, and Chief Moore:

On behalf of Patagonia Area Resource Alliance, Arizona Mining Reform Coalition, Borderlands Restoration Network, Center for Biological Diversity, Earthworks, Friends of Santa Cruz River, Friends of Sonoita Creek, Save the Scenic Santa Ritas, and Tucson Audubon Society, we hereby provide notice in accordance with the citizen suit provision of the Endangered Species Act ("ESA"), 16 U.S.C. § 1540(g), that the United States Fish and Wildlife Service ("FWS") is in violation of the ESA, 16 U.S.C. § 1536, and its implementing regulations, 50 C.F.R. § 402 *et seq.*, with regard to FWS's December 1, 2022, Biological Opinion ("BiOp") determining that the Sunnyside exploratory mineral drilling project ("Sunnyside Project") is not likely to jeopardize the continued existence of ESA-listed species. Further, the United States Forest Service ("USFS") is in violation of the ESA, 16 U.S.C. § 1536, and its implementing regulations, 50 C.F.R. § 402 *et seq.*, by unlawfully relying on FWS's flawed BiOp to fulfill USFS's own ESA obligations. USFS additionally violated the ESA with regard to USFS's May 10, 2022, Biological Assessment ("BA") determining that the Flux Canyon exploratory mineral drilling project ("Flux Canyon Project") will have no effect, or would be unlikely to adversely affect, ESA-listed species. Finally, FWS again violated the ESA by concurring in certain of

USFS's effect determinations by a letter signed on September 23, 2022. These violations are detailed in the discussion that follows.

In June 2023, USFS authorized the Sunnyside Project, a seven-year program of exploratory drilling that Arizona Standard, LLC has proposed in southeast Arizona's Patagonia Mountains, one of the most biologically diverse mountain ranges in the United States. Just days earlier, in May 2023, USFS separately authorized the Flux Canyon Project, another drilling plan that South32 Hermosa Inc. also known as Arizona Minerals Inc. has proposed nearby in the same mountain range. Both projects would involve the development of new roads and drill pads in the Coronado National Forest, with industrial machinery to run 24 hours a day, 7 days a week.

The Patagonia Mountains are a region of extraordinary biodiversity, with many ESA-listed species relying on the mountains' rugged and isolated terrain, including the Mexican spotted owl, Western yellow-billed cuckoo, jaguar, and ocelot. Cumulatively, the Sunnyside and Flux Canyon projects would disrupt the project areas and surrounding lands with a constant disruption of noise, lights, dust, human activity, and vehicle traffic. These impacts threaten to drive Mexican spotted owls and Western yellow-billed cuckoos from established breeding and foraging territories, and to disrupt the ability of jaguars and ocelots to occupy the area or utilize its habitat to successfully move from Mexico into their historical range in the United States.

Nonetheless, FWS concluded that the Sunnyside Project is "not likely to jeopardize the continued existence" and is not likely to "destroy or adversely modify critical habitat" of the Mexican spotted owl, yellow-billed cuckoo, jaguar, or ocelot, despite acknowledging that the Project would result in "take" of these species (i.e., harassment, harm, etc.). FWS exempted USFS's approval of the Project from the ESA's take prohibition for these species, and in the case of Mexican spotted owls did so without providing any terms or conditions or reasonable and prudent measures to minimize or mitigate the Project's impact. *See* U.S. Fish & Wildlife Serv., Biological Opinion (Dec. 1, 2022) ("Sunnyside BiOp").

USFS relied on FWS's action to fulfill its own ESA obligations regarding the Sunnyside Project. *See* U.S. Forest Serv., Decision Notice and Finding of No Significant Impact for the Sunnyside Exploration Drilling Project 8, 19–20 (June 16, 2023).

Regarding the Flux Canyon Project, USFS determined that Project operations would have "no effect" on the Western yellow-billed cuckoo or Mexican spotted owl and therefore evaded further ESA analysis of that Project's impacts on those species. U.S. Forest Serv., Flux Canyon Exploration Drilling Project Plan of Operations: Biological Assessment and Evaluation 33 (May 10, 2022) ("Flux Canyon BA"). USFS further determined that the Flux Canyon Project may effect, but is not likely to adversely affect, the jaguar or ocelot. *Id.* at 36-37. FWS concurred in these jaguar and ocelot determinations. *See* Letter from Julie McIntyre, U.S. Dep't of Interior, to Kerwin Dewberry, Forest Supervisor, Coronado Nat'l Forest, Proposed Flux Canyon Exploration Drilling Project, Sept. 23, 2022, at 1 ("Flux Canyon Concurrence").

As this letter and its attachments show, in reaching and relying on these conclusions, both agencies acted arbitrarily, misread or ignored applicable scientific and commercial information, and overlooked significant risks to the ESA-listed species of the Patagonia Mountains. Accordingly, pursuant to the citizen suit provision of the ESA, 16 U.S.C. § 1540(g)(2), this letter provides you notice that, unless within 60 days of receipt of this letter FWS withdraws its

Sunnyside BiOp and Flux Canyon Concurrence, and USFS withdraws its authorizations for the Sunnyside and Flux Canyon Projects, we intend to challenge these agency actions under the ESA in federal district court.

I. FWS and USFS Failed to Use Best Available Science and Arbitrarily Minimized the Sunnyside Project's Threat of Injury to Mexican Spotted Owls

First, FWS failed to utilize the best available scientific information in addressing the Sunnyside Project's threat of injury to Mexican spotted owls. As a result, FWS arbitrarily minimized the Project's impact to Mexican spotted owls and issued irrational and unlawful no-jeopardy and no-adverse-modification conclusions for this species. And USFS acted arbitrarily in relying on FWS's flawed BiOp.

Under section 7(a)(2) of the ESA, FWS and USFS must "insure that any action authorized . . . by [USFS] is not likely to jeopardize the continued existence of any endangered species or threatened species . . . ." 16 U.S.C. § 1536(a)(2). In fulfilling the requirements of section 7(a)(2), FWS and USFS must "use the best scientific and commercial data available." *Id.* This requirement "prohibits an agency from disregarding available scientific evidence that is in some way better than the evidence it relies on." *Kern Cty. Farm Bureau v. Allen*, 450 F.3d 1072, 1080 (9th Cir. 2006) (alterations omitted) (quoting *Sw. Ctr. For Biological Diversity v. Babbitt*, 215 F.3d 58, 60 (D.C. Cir. 2000)).

In its BiOp, FWS dismissed the potential for the chronic noise of the Sunnyside Project to injure Mexican spotted owls. In reaching this conclusion, FWS misread the study on which it relied and wholly ignored several other contrary studies. Specifically, FWS's BiOp concluded that noise levels from the Sunnyside Project would "attenuate below the threshold for injury of owls"—which it identified as 92 dBA (weighted decibels)—"at approximately 100 feet from any drill area or area of heavy equipment use." Sunnyside BiOp at 35. FWS further concluded that "[o]wls experiencing short-term harm" from Project operations "may fail to successfully rear young or may depart in one or more breeding seasons, but will not likely permanently desert the area because of the disturbance." *Id*. at 40. In reaching both of these conclusions, FWS relied exclusively on one scientific study: David K. Delaney et al., *Effects of Helicopter Noise on Mexican Spotted Owls*, 63 J. WILDLIFE MGMT. 60 (1999) ("Delaney (1999)") (Ex. 1). Yet, on its face, the Delaney study supported neither of these conclusions.

At the outset, Delaney (1999) identified the 92 dBA noise level cited by FWS only as the threshold for Mexican spotted owls to flush and fly away in response to helicopter disturbance, *see* Delaney (1999) at 68, not as an all-encompassing "threshold level for injury of owls," as the BiOp claimed. BiOp at 35. In fact, Delaney (1999) identified a much lower noise threshold—46 dBA—for the owls' flushing response to chain saw disturbance, which it deemed to validate "the already established pattern that ground-based activities are typically more disturbing to raptors than aerial activities." *Id.* at 68, 74. FWS in the BiOp did not explain why it determined the Sunnyside Project's threshold noise level for *any* injury to owls based on Delaney (1999)'s higher threshold for aerial helicopter disturbance rather than its lower threshold for ground-based chain saw disturbance, given that Sunnyside Project impacts will result from ground-based construction and drilling activities.

More fundamentally, Delaney (1999) documented Mexican spotted owls' reactions only to intermittent bursts of less than ten minutes of helicopter disturbance and five minutes of chainsaw disturbance per day—not any kind of long-term disturbance and certainly not the round-the-clock, chronic noise disturbance for up to seven years that the Sunnyside Project threatens. Delaney (1999) at 65. Further, it focused on measuring specific owl responses to these short-term disturbances, including flushing and alert behavior, and offered no evidence about whether owls were likely to "permanently desert the area because of the disturbance," as the BiOp claimed. *Id*. at 60–61; Sunnyside BiOp at 40. And it explicitly stated that its findings were specific to the circumstances it studied and "caution[ed] against use of [its] findings to infer how spotted owls would respond under different circumstances that were not directly tested," including more frequent disturbances. Delaney (1999) at 74. In relying on the Delaney study to reach conclusions wholly unsupported by that study and ignoring the express limitations and cautions of the study's authors, FWS violated the ESA.

FWS also acted illegally when it "ignore[d] available biological information." *Kern Cty. Farm Bureau*, 450 F.3d at 1080–81 (quoting *Conner v. Burford*, 848 F.2d 1441, 1454 (9th Cir. 1988)). Although overlooked by FWS in its BiOp, available studies suggest that the Sunnyside Project's chronic noise is likely to significantly impair Mexican spotted owls' ability to successfully forage by diminishing their ability to hear prey. One study, J. Tate Mason et al., *Anthropogenic Noise Impairs Owl Hunting Behavior*, 199 BIOLOGICAL CONSERVATION 29, 31 (2016) (Ex. 2), determined that chronic noise levels of 61 dBA so interfered with the hearing of Northern saw-whet owls that the owls were unable to capture any mice at all. Another study, Masayuki Senzaki et al., *Traffic Noise Reduces Foraging Efficiency in Wild Owls*, 6 SCI. RPTS. 30602, 30603 (2016) (Ex. 3), determined that chronic noise levels of just 40 dBA reduced long-eared and short-eared owls' ability to detect prey, while noise levels of 80 dBA made prey detectability virtually impossible. As set forth at more length in the attached declaration from expert wildlife ecologist Douglas Tempel, who has extensive experience with spotted owls and has specifically studied their responses to noise disturbance:

> These findings are likely to be representative of chronic noise impacts on Mexican spotted owls because, like the owl species involved in the cited papers, Mexican spotted owls rely heavily upon auditory cues when hunting. These findings therefore indicate that chronic noise impacts from the proposed Sunnyside Project would seriously compromise the affected spotted owls' ability to hunt in the Project area and surrounding vicinity. In fact, the noise attenuation projections for the Sunnyside Project that were utilized in the Biological Assessment for this Project (Table 5-1) indicate that, even up to 1,600 feet from drilling and construction equipment, noise from the Project is expected to exceed the 61 dB(A) threshold that was associated with no owl hunting success in Mason, et al. (2016). These attenuation projections further indicate that Project noise is expected to reach Senzaki, et al. (2016)'s documented threshold for impacts on owls' ability to detect prey—40 dB(A)—as far as 12,800 feet (more than two miles) from the noise source.
>
> Because of the likelihood that the Sunnyside Project's chronic noise impacts will extensively interfere with the affected Mexican spotted owls' ability to forage throughout a large area surrounding the proposed drilling and construction activity, there is also a high likelihood that the affected owls will permanently abandon territories in the impacted area for at least the full duration of proposed drilling activities (i.e., up to seven

> years), and potentially longer depending on the extent of disturbance associated with subsequent reclamation activities.

Tempel Decl. ¶¶ 12–13 (Ex. 4). In completely failing to consider the Mason and Senzaki studies, FWS ignored available scientific information on the impacts of chronic noise on owl hunting, issued arbitrary conclusions regarding the likely impacts of the Sunnyside Project, and thereby violated the ESA. *See* 16 U.S.C. § 1536(a)(2).

For its part, USFS arbitrarily relied on the BiOp to satisfy its own ESA obligations regarding the Sunnyside Project. USFS's reliance on the flawed BiOp violated the ESA and rendered USFS's authorization of the Sunnyside Project unlawful. *See Ctr. for Biological Diversity v. U.S. Bureau of Land Mgmt.*, 698 F.3d 1101, 1127–1128 (9th Cir. 2012) ("[A]n agency cannot meet its section 7 obligations by relying on a Biological Opinion that is legally flawed . . . .").

II. USFS Arbitrarily and Unlawfully Determined that the Flux Canyon Project Would Have "No Effect" on Western Yellow-Billed Cuckoos

USFS further violated the ESA by issuing an arbitrary and unlawful "no effect" determination for Western yellow-billed cuckoos regarding the Flux Canyon Project. As discussed above, under section 7(a)(2) of the ESA, USFS must ensure that any action it authorizes "is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification" of such species' designated critical habitat. 16 U.S.C. § 1536(a)(2). In fulfilling the requirements of section 7(a)(2), USFS must prepare a BA, *see* 50 C.F.R. § 402.12, and this BA cannot "entirely fail[] to consider an important aspect of the problem," *Mont. Wilderness Ass'n v. Fry*, 310 F. Supp. 2d 1127, 1148 (D. Mont. 2004) (quoting *Motor Vehicle Mfrs. Ass'n of U.S., Inc. v. State Farm Mut. Auto. Ins. Co*., 463 U.S. 29, 43 (1983)), or overlook "relevant factors." *Native Ecosystems Council v. Krueger*, 946 F. Supp. 2d 1060, 1079–80 (D. Mont. 2013) (quoting *Selkirk Conservation All. v. Forsgren,* 336 F.3d 944, 953–54 (9th Cir. 2003)). In its BA, USFS concluded that the Flux Canyon Project would have "no effect" on Western yellow-billed cuckoos, a conclusion that did not require a concurrence from FWS, *see* Flux Canyon Concurrence at 1, thus ending the agencies' inquiry into impacts on the cuckoo. USFS's Decision Memo approving the Flux Canyon Project echoed this conclusion. *See* U.S. Forest Serv., Decision Memo, Flux Canyon Exploration Drilling 12 (May 30, 2023). In reaching this conclusion, however, USFS ignored important evidence concerning cuckoo habitat and overlooked relevant factors.

USFS based its no-effect determination on the assertion that Western yellow-billed cuckoos are unlikely to occur in the Flux Canyon project area, because this area "does not contain suitable foraging or breeding habitat." Flux Canyon BA at 33. In reaching this conclusion, USFS did not actually survey the project area but instead relied on the assumption that cuckoos in Arizona are "most commonly found in lowland riparian woodlands," while the project would occur in "the upper hillsides." *Id*. at 33; *see also id.* at 78. Yet the assumption that cuckoos are unlikely to breed or forage in the hillsides where the Flux Canyon Project would take place is contrary to the information available to the agency. As FWS elsewhere has acknowledged, in southeastern Arizona locations such as the Patagonia Mountains, cuckoo "breeding habitat is more variable than in the rest of its range" and "may include . . . hillsides," *see* Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Western Distinct Population Segment of the Yellow-Billed Cuckoo, 86 Fed. Reg. 20,798, 20,836–37 (Apr. 21, 2021); *see also id*. at 20,841, 20,845, and cuckoos are known to forage in "upland areas" following precipitation. *Id*. at 20,840. Indeed, in considering the environmental consequences of the Sunnyside Project, USFS itself acknowledged that recent surveys of southeastern Arizona have found cuckoos breeding "in upland areas." U.S. Forest Serv., Sunnyside Exploration Drilling Project: Environmental Assessment 30 (Jan. 2023) (citing Jennie MacFarland & Jonathan Horst, Yellow-Billed Cuckoo Surveys on the Coronado National Forest Within Eight Sky Island Mountain Ranges in Southeastern Arizona (Oct. 2015)). In completely failing to consider this information, and thus the likelihood of cuckoo foraging or breeding habitat in the project area, USFS ignored important and relevant factors that undermined its "no effect" determination for this species. For this reason too, USFS violated the ESA.

III. FWS and USFS Repeatedly Ignored or Misconstrued Relevant Information and Reached Arbitrary Conclusions in Their Effect Determinations

In addition, both FWS and USFS repeatedly ignored or misconstrued relevant information in determining that the Sunnyside and Flux Canyon Projects would have no effect, may affect but would not adversely affect, or would be unlikely to jeopardize or destroy or adversely modify critical habitat for the Mexican spotted owl, Western yellow-billed cuckoo, jaguar, and ocelot. As a result, both agencies reached arbitrary and unlawful conclusions about the effects of these projects on these four ESA-listed species. These errors include the following:

- In evaluating cumulative effects of the Sunnyside Project, FWS's BiOp repeatedly ignored the "best . . . commercial data available" concerning the Hermosa Project located immediately east of the proposed Sunnyside Project on a 450-acre private parcel called the Trench Camp property. 16 U.S.C. § 1536(a)(2). Specifically, FWS ignored the project proponent's own January 17, 2022, update advising that the Hermosa Project currently involves drilling of two sloped tunnels as a prelude to 22 years of mining production commencing as soon as Fiscal Year 2027. *See Hermosa Project Update*, SOUTH32, at 2, 4, 10 (Jan. 17, 2022) (Ex. 5). In addition to mine shafts, planned surface developments for the Hermosa Project include a paste plant, processing plant, and dry-stack tailings storage facility. *See id.* at 10-11. Instead of considering this information—which was available nearly a full year before FWS issued the BiOp—FWS evaluated the Sunnyside Project's cumulative effects with the Hermosa Project based only on a stale media report and omitted key information concerning the scope of the project's threat to listed species and their habitats. *See* Sunnyside BiOp at 19, 38, 58. FWS thus failed in its obligation to consider cumulative effects using the best available information, 16 U.S.C. § 1536(a)(2); 50 C.F.R. § 402.14(g), and USFS erred in relying on FWS's flawed BiOp.

- FWS and USFS arbitrarily relied on affected species' ability to avoid impacts of the Sunnyside and Flux Canyon Projects simply by moving to other locations. These agencies' analyses repeatedly concluded that Sunnyside and Flux Canyon would not have adverse effects on ESA-listed species largely because the Projects occupy only a small proportion of these species' total habitat and they can simply go elsewhere to avoid project disturbance. *See* Sunnyside BiOp at 18, 20, 35-36, 56; Flux Canyon Concurrence at 7–8, 10; Flux Canyon BA at 28, 30. Such agency reasoning ignores the threat that, in doing so, these species would then be harmed by ongoing and foreseeable developments occurring simultaneously at numerous nearby sites, including, at minimum, the Sunnyside and Flux Canyon Projects themselves and the Hermosa Project.

- USFS arbitrarily discounted any effect to Mexican spotted owls from the Flux Canyon Project on the basis that owls occupying the nearest designated PAC do not use the perimeter of that area that is closest to the Project, and "there have been no MSO detections within 0.5 miles of the Project in eight years of survey in the area." Flux Canyon BA at 26-27. Yet reliance on this historical record of owl activity to dispel any possible effect of the Flux Canyon Project failed to consider an important factor: the onset of new disturbance in nearby owl PACs from the Sunnyside Project and its potential to displace owls to locations much closer to the Flux Canyon Project. In short, the future will not look like the past for Mexican spotted owls in the Flux Canyon Project vicinity. The Sunnyside BiOp explicitly anticipates that Sunnyside Project impacts just upslope from the Flux Canyon Project may cause owls to use "unfamiliar habitats" or "shift their activities within their existing home ranges to avoid areas with increased human activities," Sunnyside BiOp at 35—both of which threaten to bring owls within the impact zone of the Flux Canyon Project. USFS ignored this threat in determining that the Flux Canyon Project poses no effect to Mexican spotted owls.

- USFS and FWS arbitrarily discounted any adverse effect to jaguars from the Flux Canyon Project on the basis that jaguars are rare. USFS asserted that information from field camera surveys "supports the notion that there are no jaguars currently in the vicinity of the Project." Flux Canyon BA at 28. FWS stated that "jaguars in Arizona are rare in any one specific location, making the probability of jaguar presence during project implementation unlikely." Flux Canyon Concurrence at 10. Yet FWS's own Sunnyside BiOp concluded that, given evidence of jaguar presence north of the Patagonia Mountains in the Santa Rita Mountains, and south of the Patagonia Mountains in Sonora, Mexico, "the possibility that a jaguar may occur in the action area at some time during the [Sunnyside] Project cannot be discounted." Sunnyside BiOp at 47–48. USFS and FWS arbitrarily offered no justification for their contrary decision to discount the possibility that such a jaguar occurrence could occur in proximity to, and during operation of, the Flux Canyon Project. Indeed, by concurring with USFS's effects determination for jaguars on the basis that jaguars' rarity in Arizona makes "the probability of jaguar presence during project implementation unlikely," Flux Canyon Concurrence at 10, FWS adopted a rationale that could be used to avoid ESA formal consultation requirements for virtually *any* development in jaguar habitat. Yet FWS itself has documented that jaguars *do* occur in Arizona. *See* Flux Canyon Concurrence at 9-10; Sunnyside BiOp at 47-48. FWS and USFS violated the ESA by dismissing any threat to the jaguar based on a speculative and overbroad dismissal of the species' presence that does not conform with FWS's own analysis and evidence about jaguar occurrence in Arizona.

IV. Conclusion

As set forth in this letter, FWS and USFS violated the ESA in evaluating the impacts of the Sunnyside and Flux Canyon Projects on threatened and endangered species. If FWS and USFS do not withdraw their unlawful actions within 60 days of the receipt of this letter, the parties to this notice letter intend to institute a legal action to challenge these agency actions in federal district court.

Sincerely,

Timothy J. Preso (Montana Bar No. 5255)
Earthjustice
313 East Main Street
PO Box 4743
Bozeman, MT 59715-4743
tpreso@earthjustice.org
Phone: (406) 586-9699

Scott W. Stern (California Bar No. 336427)
Earthjustice
50 California Street, Suite 500
San Francisco, CA 94111
sstern@earthjustice.org
Phone: (415) 217-2117

Roger Flynn (Colorado Bar No. 21078)
Jeffrey C. Parsons (Colorado Bar No. 30210)
Western Mining Action Project
PO Box 349
440 Main Street, Suite 2
Lyons, CO 80540
wmap@igc.org
Phone: (303) 823-5738

Counsel for Plaintiffs

cc: Tyler M. Alexander, tyler.alexander@usdoj.gov (counsel for the United States)
Andrew A. Smith, andrew.smith@usdoj.gov (counsel for the United States)
Carla Consoli, cconsoli@maypotenza.com (counsel for Arizona Standard, LLC)
Laura K. Granier, LKgranier@hollandhart.com (counsel for South 32 Hermosa, Inc.)

Exhibit 1

Effects of Helicopter Noise on Mexican Spotted Owls

Author(s): David K. Delaney, Teryl G. Grubb, Paul Beier, Larry L. Pater and M. Hildegard Reiser

Source: *The Journal of Wildlife Management*, Jan., 1999, Vol. 63, No. 1 (Jan., 1999), pp. 60-76

Published by: Wiley on behalf of the Wildlife Society

Stable URL: https://www.jstor.org/stable/3802487

EFFECTS OF HELICOPTER NOISE ON MEXICAN SPOTTED OWLS

DAVID K. DELANEY,[1][2] U.S. Forest Service, Rocky Mountain Research Station, 2500 South Pine Knoll Drive, Flagstaff, AZ 86001, USA
TERYL G. GRUBB, U.S. Forest Service, Rocky Mountain Research Station, 2500 South Pine Knoll Drive, Flagstaff, AZ 86001, USA
PAUL BEIER, School of Forestry, Northern Arizona University, Flagstaff, AZ 86001, USA
LARRY L. PATER, U.S. Army Construction Engineering Research Laboratories, P.O. Box 9005, Champaign, IL 61826, USA
M. HILDEGARD REISER, 49th Civil Engineer Squadron/Environmental Flight, 550 Tabosa Avenue, Holloman Air Force Base, NM 88330, USA

Abstract: Military helicopter training over the Lincoln National Forest (LNF) in southcentral New Mexico has been severely limited to protect nesting Mexican spotted owls (*Strix occidentalis lucida*). To evaluate nesting and nonnesting spotted owl responses to helicopter noise, we measured flush frequency, flush distance, alert behavior, response duration, prey delivery rates, female trips from the nest, and nest attentiveness during manipulated and nonmanipulated periods, 1995–96. Chain saws were included in our manipulations to increase experimental options and to facilitate comparative results. We analyzed stimulus events by measuring noise levels as unweighted one-third-octave band levels, applying frequency weighting to the resultant spectra, and calculating the sound exposure level for total sound energy (SEL) and the 0.5-sec equivalent maximum energy level (LEQ $_{\text{max 0.5-sec}}$) for helicopters, and the 10-sec equivalent average energy level (LEQ $_{\text{avg. 10-sec}}$) for chain saws. An owl-weighting (dBO) curve was estimated to emphasize the middle frequency range where strigiform owls have the highest hearing sensitivity. Manipulated and nonmanipulated nest sites did not differ in reproductive success ($P = 0.59$) or the number of young fledged ($P = 0.12$). As stimulus distance decreased, spotted owl flush frequency increased, regardless of stimulus type or season. We recorded no spotted owl flushes when noise stimuli were >105 m away. Spotted owls returned to predisturbance behavior within 10–15 min after a stimulus event. All adult flushes during the nesting season occurred after juveniles had left the nest. Spotted owl flush rates in response to helicopters did not differ between nonnesting (13.3%) and nesting seasons (13.6%; $P = 0.34$). Spotted owls did not flush when the SEL noise level for helicopters was ≤102 dBO (92 dBA) and the LEQ level for chain saws was ≤59 dBO (46 dBA). Chain saws were more disturbing to spotted owls than helicopter flights at comparable distances. Our data indicate a 105-m buffer zone for helicopter overflights on the LNF would minimize spotted owl flush response and any potential effects on nesting activity.

JOURNAL OF WILDLIFE MANAGEMENT 63(1):60–76

Key words: chain saws, disturbance, flush response, helicopters, Mexican spotted owls, noise, response thresholds, sound measurements, *Strix occidentalis lucida*.

To maintain tactical proficiency for low-level search-and-rescue missions, military air crews require frequent training. Recently, low-level training flights have come under scrutiny for their potential effects on wildlife, which has led to reductions in military access to potential training areas (Holland 1991). Holloman Air Force Base (HAFB), located in southcentral New Mexico, lacks sufficient area and habitat diversity to conduct effective helicopter training operations, but the Sacramento Ranger District of the LNF in the Sacramento Mountains contains the habitat diversity necessary to conduct such training operations. However, to avoid potential effects on nesting Mexican spotted owls (hereafter, spotted owl), military helicopters have been precluded from flying over the LNF during the February–August nesting season. To gain year-long access to the forest for training of the 48th Rescue Squadron (48 RQS), HAFB had to determine if and to what extent their activities might affect nesting spotted owls.

Much of the information about noise effects on raptors is anecdotal and fails to quantitatively measure either the stimulus or a behavioral response related to the animal's fitness. Predictive models for the relation between disturbance dosage and quantifiable effects are even more scarce (Awbrey and Bowles 1990, Grubb and Bowerman 1997). Although many types of human disturbance can affect birds of prey (Fyfe and Olendorff 1976), very little research has addressed the effects of human activity on owls (Wesemann and Rowe 1987; J. C. Bednarz and

---

[1] Present address: U.S. Army Construction Engineering Research Laboratories, P.O. Box 9005, Champaign, IL 61826, USA.

[2] E-mail: d-delaney@cecer.army.mil

T. J. Hayden. 1988. The Los Medanos cooperative raptor research and management program, unpublished. Final Report 1985–87 for Department of Energy and Bureau of Land Management. University of New Mexico, Albuquerque, New Mexico, USA.). Presently, there is no published research available on the possible effect of noise on spotted owls.

The objectives of this study were (1) record, characterize, and quantify helicopter overflights at spotted owl roost sites during a post- or nonnesting season (1995) and at active nest sites during the nesting season (1996); (2) develop a dose-response threshold relation for quantifying spotted owl behavioral responses to variation in noise levels and stimulus distances; (3) determine if helicopter overflights affect spotted owl reproductive success (successful nests) or productivity (young fledged); and (4) develop disturbance-specific management guidelines to minimize potential effects from helicopter overflights on the LNF.

STUDY AREA

This study was located within the Sacramento Ranger District of the LNF in southcentral New Mexico, Otero County. This area was chosen for its large population of spotted owls and its importance as a potential training site for the 48 RQS. Vegetation is primarily Rocky Mountain conifer forest (Brown and Lowe 1980) dominated by Douglas-fir (*Pseudotsuga menzii*) with some southwestern white pine (*Pinus strobiformes*) and ponderosa pine (*P. ponderosa*; Alexander et al. 1984). Elevation in the mountainous terrain ranges between 1,372 and 2,957 m.

METHODS

Surveys and Territory Selection

Territories were surveyed between 15 June and 6 July 1995 and between 15 March and 15 April 1996. We selected territories for our study based on (1) presence of mated pairs of spotted owls, and (2) no captures or manipulations prior to our research. During the 1996 nesting season, a third criterion required pairs to be reproductively active. Seven female and 6 male spotted owls were tested in the nonnesting season. During the nesting season, we concentrated on testing females because of their nest fidelity. Sample sizes in both the nonnesting and nesting seasons were limited by the number of pairs that fit the foregoing criterion.

Vocal imitations of spotted owl calls (Forsman 1983) were used during nocturnal and diurnal point surveys to locate both nonnesting and nesting spotted owls. During nocturnal surveys, we determined initial spotted owl locations between dusk and 2200 (all times reported as Mountain Standard Time). Spotted owl positions were triangulated by plotting compass bearings on topographic maps so that each area could be visited for diurnal surveys (predawn to 0800), when we followed spotted owls to a daytime roost. During the 1995 nonnesting season, we then radioed the location to the 48 RQS for an overflight later that day or conducted a chain saw manipulation. Upon finding a spotted owl during the 1996 nesting season, we attempted to determine its reproductive status by feeding it live mice. Nesting spotted owls take prey back to the nest, while nonreproductive spotted owls either cache or eat the prey (Forsman 1983). Once a territory was determined to be reproductively active, the nest location was recorded for future testing. To minimize interactions with spotted owls, we used the least number of mice necessary to determine reproductive activity.

Spotted Owl Behavior and Response Measures

We documented spotted owl behavior during manipulated and nonmanipulated periods by direct observation (camouflaged blinds 25–30 m from nest or roost) and through video surveillance. To evaluate spotted owl response behavior to helicopter and chain saw manipulations and contrast it with pre- and postmanipulated behavior, we measured the following: (1) flush frequency = proportion of manipulations that elicited a flight response; (2) flush distance = distance (m) flown by a spotted owl in response to a sound stimulus; (3) alert behavior = number of head movements averaged per 5-min block, before, during and after manipulations; (4) time to alert = minutes between start of a manipulation and when a spotted owl initially responded with a head movement in the direction of the manipulation; (5) response duration = minutes following a noise stimulus until a disturbed spotted owl returned to prestimulus behavior; (6) prey deliveries = number of prey deliveries recorded at each nest site (calculated per hour for diurnal, nocturnal, and 24-hr periods); (7) trips = number of times the attending female left the nest (calculated per hour for diurnal, nocturnal, and 24-hr periods); and (8) nest attentiveness = proportion of time the adult female spotted owl spent on the nest through the nesting season (calculated for diurnal, nocturnal, and 24-hr periods, as well as for nesting phases; see Delaney et al. 1999).

Video Surveillance

Because our use of video was a new and unique application of the various hardware components, we had to design, construct, test, and modify our video surveillance system before applying it in the field (Delaney et al. 1998). We used Marshall black-and-white, miniature video cameras (Marshall Electronics, Culver City, California, USA) with night vision to monitor spotted owl behavior. (Use of trade names does not imply endorsement by the U.S. Forest Service Rocky Mountain Research Station, U.S. Air Force, U.S. Army Construction Engineering Research Laboratories, or Northern Arizona University to the exclusion of other potentially suitable products.) In addition to the 6 infrared light-emitting diodes (LEDs) on the camera board, 9-LED supplemental light sources were constructed to approximately double night-vision capabilities. Panasonic industrial-grade video recorders provided up to 24-hr coverage/VHS tape (Panasonic Corporation of America, Secaucus, New Jersey, USA). Between 9 April and 27 May 1996, cameras were placed at 20 nest sites in adjacent trees, averaging 6.9 m from nests (range = 3.0–10.3 m). A 15-m, power-line-and-coaxial-cable down line and a 60-m trunk line were used to minimize potential disturbance to spotted owls by offsetting the recorder and batteries to an out-of-sight tarpaulin blind. Between 25 April and 3 July 1996, video surveillance systems at 19 successful nests yielded >2,655 hr of spotted owl behavior coverage. All cameras and related equipment were removed after the 1996 nesting season.

Sound Measurements

Instrumentation and Recording.—Sony TCD-D7, digital audio tape (DAT) recorders continuously recorded all noise events, along with exact time and date (Sony Corporation of America, New York, New York, USA). We attached a Bruel & Kjaer (B&K) Type 4149, 1.3-cm condenser microphone (Bruel & Kjaer, Naerum, Denmark) with a 7.5-cm wind screen to a B&K Model 2639 preamplifier, mounted the microphone on a 1-m stick, and placed the unit directly under a spotted owl location (roost or nest) about 1 m from the tree trunk. Using 3 10-m connecting cables attached to the preamplifier, we located the B&K Model 2804 power supply and DAT recorder at our observation point in a camouflaged blind 25–30 m from the spotted owls. A 1.0-kHz, 94-dB calibration signal from a B&K Type 4250 sound level calibrating system was recorded before and after each recorded manipulation. This signal provided an absolute, standardized reference point for sound levels and spectra when data were later reduced via a B&K Type 2144 frequency analyzer. All noise data were analyzed at the U.S. Army Construction Engineering Research Laboratories, Champaign, Illinois, USA.

Sound Metrics.—We used 3 sound metrics in this study: (1) SEL = the sound exposure level, which represents total sound energy for helicopters; (2) $\mathrm{LEQ}_{\mathrm{avg.\ 0.5\text{-}sec}}$ = the 0.5-sec equivalent average peak energy level for helicopters; and (3)$\mathrm{LEQ}_{\mathrm{avg.\ 10\text{-}sec}}$ = the 10-sec equivalent average energy level for chain saws. Noise is defined as sound that is undesired or that constitutes an unwarranted disturbance; it can alter animal behavior or normal functioning. We analyzed noise events as unweighted one-third-octave band levels, applied frequency weighting to the resultant spectra, and calculated the above metrics. Chain saw noise was relatively steady and most appropriately described by the average sound level, LEQ, over a specified time interval (10-sec). Helicopter noise was more varied and could not be described as well by the average noise level. Aircraft noise events are typically described in terms of SEL, which correlates well with human annoyance to aircraft noise. However, SEL levels cannot be meaningfully compared to LEQ levels; therefore, we also represented helicopters with LEQ for comparison with chain saws.

Frequency weighting is an algorithm of frequency-dependent attenuation that simulates the hearing sensitivity of the study subjects. Frequency weighting discriminates against sound which, while easily measured, is not heard by the subjects. Flat-weighting (or absence of any weighting function) does not emphasize any portion of the frequency spectrum and therefore represents the true sound level and frequency for a noise stimulus event (Fig. 1). The commonly used A-frequency weighting attenuates noise energy according to human hearing range and sensitivity and generally will not be appropriate for animal species. However,

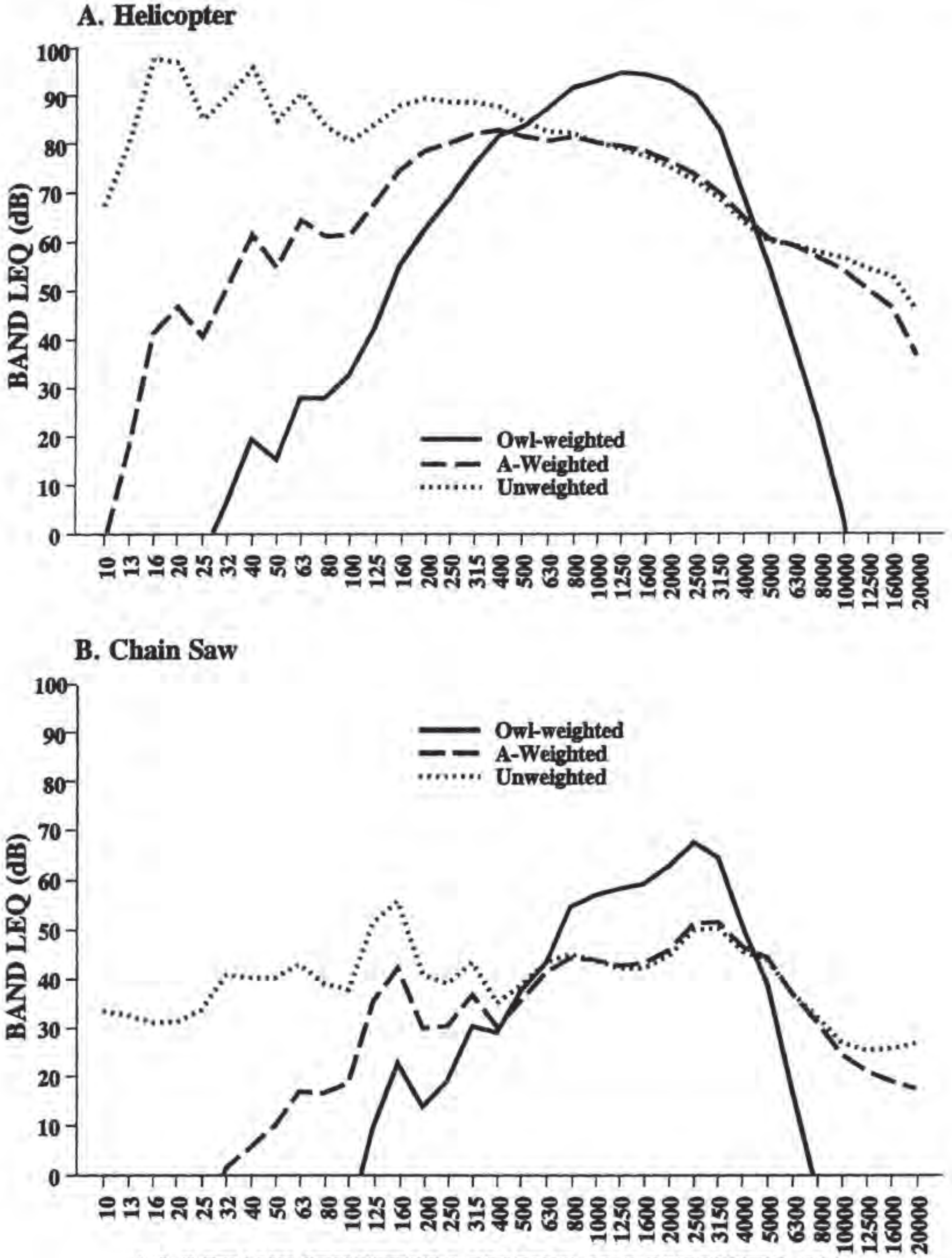


Fig. 1. (A) A comparison of owl-, A-, and unweighted equivalent maximum (helicopter) and average (chain saw) noise energy levels (LEQs) for a 60-m helicopter manipulation on 5 June 1996, and (B) a 60-m chain saw manipulation on 11 June 1996 at the same Mexican spotted owl territory in the Sacramento Mountains, New Mexico.

Table 1. Distribution of sample size by season, manipulation type, and Mexican spotted owl nest sites for noise-effect testing in the Sacramento Mountains, New Mexico, 1995–96. Site totals are not necessarily additive because some sites were manipulated in both years, and not all sites received both helicopter and chain saw manipulations.

	Helicopter		Chain saws		Season totals	
Season	Manipulations	Sites	Manipulations	Sites	Manipulations	Sites
Nonnesting (1995)	24	8	25	13	49	13
Nesting (1996)	57	22	55	21	112	22
Totals	81	26	80	27	161	28

it is useful to present A-weighted noise levels (dBA), as well as more appropriately weighted levels, because this weighting algorithm occurs on sound-level meters and is ubiquitously used.

Because both flat- and A-weighting do not accurately reflect the way a spotted owl hears noise, we developed an estimated owl-weighting (dBO) curve. An audiogram describes hearing range and sensitivity and provides information on which a frequency weighting algorithm can be based for a specific species. Available information indicates hearing is quite similar among members of a taxonomic order. Within the order Strigiformes, we found audiograms for 2 species (great horned owl [*Bubo virginianus*], barn owl [*Tyto alba*]) within the same Suborder (Strigi) as spotted owls. These audiograms were used to approximate frequency-weighted noise levels for spotted owls. This owl-weighting emphasized the middle frequency range where test spotted owls had the highest hearing sensitivity (Trainer 1946, Konishi 1973).

Field Manipulations

We conducted a pilot test in January 1995 on HAFB and at an inactive nest site on the LNF to determine experimental flight profiles and microphone placement. Helicopter manipulations occurred between 1 and 22 August 1995 and between 30 April and 25 July 1996. Chain saw manipulations were conducted between 9 July and 23 September 1995 and between 11 June and 26 July 1996. We manipulated 28 spotted owl territories (13 in 1995 and 22 in 1996, with 7 sites manipulated in both years). Twenty-five of these sites received both helicopter and chain saw manipulations, while the remaining 3 sites received only 1 chain saw or helicopter manipulation (Table 1). We tried to minimize the overall number of manipulations and to maximize the time between manipulations, while still striving to conduct as complete an array of manipulations as possible during the incubation, nestling, and fledgling phases of the nesting season. However, because of administrative and logistical delays, as well as to remain conservative in our approach, only 3 chain saw tests and 8 helicopter flights were conducted during incubation. The average interval between consecutive manipulations, regardless of type or season, was 12.8 days (range = 4–79).

During the 1995 field season, spotted owls were manipulated after the normal nesting cycle so that any behavioral responses could not have an adverse effect on nesting success or productivity. Only after spotted owls showed minimal responses during nonnesting did we focus manipulations on nesting spotted owls. Helicopter manipulations were comparable between seasons but, as explained below, a threshold validation approach was taken with chain saws during the 1996 nesting season to limit potential experimental effects. Therefore, we could only compare helicopter and chain saw results for the nonnesting season. This research was conducted under a U.S. Forest Service subpermit to the U.S. Fish and Wildlife Service Region 2 Endangered Species and Special Purpose-Master-Migratory Bird Permits.

Helicopters.—Helicopter tests were conducted with the actual aircraft used by the 48 RQS (Sikorsky, HH-60G, Pave Hawk, twin-jet helicopters). The blade design of the HH-60G greatly reduces blade-slap ('whopping' sound) of an approaching helicopter. Spotted owl territories were randomly presented with 1 of 3 controlled helicopter flight profiles on any 1 day: (1) 15-m vertical, (2) 30-m vertical–30-m lateral, and (3) 60-m vertical. All flights were above tree canopy. The 15-m flight represented a minimum altitude that 48 RQS pilots would rarely fly during training missions. The 60-m profile represented the maximum diurnal altitude and a minimum nocturnal flight altitude. The 30-m vertical–30-m lateral profile approximated a more typical daytime overflight. At each site, we tried to conduct all 3 diurnal profiles during both the nonnesting and nesting seasons, plus at least 1 nocturnal profile during the nesting season.

Terrain, tree heights, and variation among pilots caused deviations from the intended profiles. To account for these variations and to facilitate a comparison with chain saw results, we calculated straight-line distances from spotted owl to helicopter for all aircraft manipulations. We used field observations of aircraft from 2 to 3 positions of varying elevation and lateral offset, measured tree and spotted owl heights, topographic features, pilot information (Global Positioning System [GPS] flight path data, aircraft altitude, crew observations), and triangulation for these calculations, which we estimated to be ± 10% accurate. In addition to calculating closest distance, we also calculated spotted owl-to-aircraft distance during the approach, using flight speed data to determine the distance at which spotted owls first responded to approaching helicopters. We conducted only 1 pass/flight over any roost or nest site per day, with the entire manipulation lasting <10 min in total audible duration and <30 sec in the immediate vicinity of the spotted owls. Helicopter speed was 150–170 km/hr (80–90 knots).

To define the specific flight line, we positioned 2 1-m-diameter red, helium-filled weather balloons above the canopy approximately 50 m on either side of a spotted owl's position. To position nocturnal flights, we used flashlights (4 D-cell Mag Lites; Mag Instruments, Ontario, California, USA) pointed skyward in conjunction with the pilots' night-vision capabilities. Diurnal flights usually occurred between 1200 and 1300 and nocturnal flights between 2000 and 2200. The 48 RQS developed a pilot's in-flight guide which detailed all spotted owl territories and access routes so pilots could circumvent nontarget and control sites en route to manipulated sites.

Chain Saws.—Stihl Model 025, 44-cc chain saws were used for noise testing (Stihl, Virginia Beach, Virginia, USA). To satisfy LNF fire and safety restrictions, bars and chains were removed and there was no actual cutting during manipulation testing. However, the noise levels and frequency spectra were similar for chain saws tested with and without bars and chains. We used forest vegetation to hide the operator and eliminate visibility as an influencing factor as we ran chain saws continuously for 5 min, alternately revving for 10 sec and idling for 10 sec. In 1995, nonnesting spotted owls were exposed to chain saw noise from 1 of 5 randomly selected initial distances (30, 45, 60, 75, and 90 m). If spotted owls flushed during the initial presentation, the test was ended for that day and the next scheduled manipulation was initiated 15–30 m farther away to establish a distance-response threshold. If the initial manipulation did not cause a flush, the next manipulation about 5–7 days later was presented 15 m closer. Because 60 m was the greatest distance at which chain saws elicited a flush response in 1995, only distances ≥60 m were examined in 1996 (60, 105, 250, and 400 m). This approach minimized potential effects on nesting spotted owls.

Habituation

We used experimental testing and treating sites as their own controls to evaluate possible habituation to repeated noise stimuli. At the end of the 1996 nesting season, we exposed 4 previously unmanipulated sites and 4 manipulated sites to 1 helicopter and 1 chain saw manipulation each, and we compared spotted owl flush response. Helicopter flights followed the most aggressive 15-m profile, while chain saw tests were run at 60 m to remain consistent with our conservative approach to nesting season manipulations. In addition, manipulated sites were used as their own self-controls throughout the study. We measured temporal changes in spotted owl response toward disturbance based on seasonal (response duration and time-to-alert) as well as proximate scales (alert responses pre-, during, and postmanipulation).

Data Analyses

Numbers of manipulated sites and sample sizes for individual analyses varied due to different inclusion criteria, missing data, 7 sites being manipulated in both years, and not all sites receiving both helicopter and chain saw manipulations. We used SPSS 7.5 for Windows (SPSS 1997) to perform descriptive statistics, independent-samples t-test for comparing mean values of young fledged and variation in sound levels, Tukey's HSD test in the 1-way analysis of variance for comparing distances for alert, react, and flush responses, and linear regression for exploring the relation between noise levels and distance by type and between net differences in prey deliveries before and after manipulations. We used net differences in prey deliveries because of repeated-measures limitations. We calculated a potential threshold distance for zero-difference with a 95% calibration interval (Graybill 1976). We used a 1-tailed Fisher's exact test to assess 2 × 2 contingency tables for flush response variability with manipulation type, stimulus distance, nesting season and phase, and for reproductive success between experimental and control sites (Zar 1984). To evaluate mean alert response (i.e., head movements) for 5-min intervals pre-, during, and postmanipulation, we used a nonparametric, Multi-Response Permutation Test for matched pairs (PTMP; Mielke and Berry 1982; Slauson et al. 1991. User manual for BLOSSOM statistical software, unpublished. National Ecological Research Center, U.S. Fish and Wildlife Service, Fort Collins, Colorado, USA). We used power analyses (Steidl et al. 1997) on reproductive success and productivity for comparisons between experimental and control sites. All means are reported ± SD. We considered alpha levels of $P < 0.05$ significant.

RESULTS

Manipulation Summary

We presented 161 helicopter and chain saw manipulations during the 1995 nonnesting and the 1996 nesting seasons (Table 1). The fledgling phase received 30 helicopter and 43 chain saw manipulations. The nestling phase received 19 helicopter and 9 chain saw manipulations, and the incubation phase received 8 helicopter and 3 chain saw manipulations. We were not able to compare spotted owl response levels between diurnal and nocturnal periods because, due to scheduling and logistical difficulties, there were only 5 nocturnal helicopter flights over spotted owl nests during the nesting season. Because we analyzed only first exposures (when >1 occurred) for each categorical manipulation distance at each site for flush response, our effective sample size by distance was reduced to 126: 58 helicopters (4 at ≤30 m, 13 at 30–45 m, 15 at 46–60 m, 20 at 61–105 m, 6 at >105 m) and 68 chain saws (6 at 30 m, 3 at 45 m, 23 at 60 m, 3 at 75 m, 2 at 90 m, 16 at 105 m, 13 at 250 m, 2 at 400 m). The 8 helicopter and 8 chain saw postexperiment habituation manipulations were in addition to this sample of 126.

Reproductive Success

Manipulated and nonmanipulated nest sites did not differ in reproductive success (Fisher's exact test: $P = 0.59$) or the number of young fledged ($t_{20} = 0.95$, $P = 0.12$). We conducted power analyses based on data from 17 experimental and 5 control sites. Power levels were 0.22 for detecting a 10% difference in reproductive success between nests and 0.11 for productivity. Power increased to 0.29 and 0.16 for detecting a 15% difference, and 0.36 and 0.21 for a 20% difference. Fifteen of 17 manipulated spotted owl nest sites produced 1.4 young/occupied nest (1.6 young/successful nest), while all 5 nonmanipulated sites were successful in producing 1.8 young/occupied nest and 1.8 young/successful nest. Neither of the failed pairs flushed nor exhibited any unusual response to manipulations during the nesting season. One pair lost their chick to predation 9 days after the last manipulation, while apparently infertile eggs at the other site never hatched, despite normal incubation.

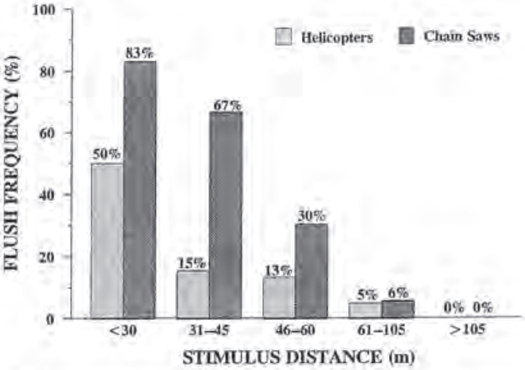


Fig 2. A comparison of Mexican spotted owl flush frequency by stimulus type and distance for helicopter and chain saw manipulations in the Sacramento Mountains, New Mexico, 1995–96.

Flush Response and Associated Thresholds

Distance Thresholds.—As stimulus distance decreased, spotted owl flush frequency increased (Fig. 2), regardless of stimulus type (Tables 2, 3) or season (nesting, nonnesting). We recorded no spotted owl flushes when the noise stimulus was >105 m distant. Only 2 flushes occurred at >60 m stimulus distance (1 helicopter at 89 m, 1 chain saw at 105 m). Chain saws consistently elicited higher response rates than helicopters at similar distances (Fig. 2). At ≤60 m stimulus distance during the nonnesting season, response to chain saws (72%) was greater than response to helicopters (20%; Fisher's

Table 2. Helicopter manipulations eliciting a Mexican spotted owl flush response during the 1995 nonnesting and 1996 nesting seasons in the Sacramento Mountains, New Mexico.

Season	Stimulus distance	Number of presentations	Number of flushes	Flush frequency
Nonnesting (1995)	≤30	1	1	100.0
	30–45	6	1	16.7
	46–60	8	1	12.5
	61–105	7	0	0.0
	≤105	22	3	13.6
	>105	0	0	0.0
1995 season totals		22	3	13.6
Nesting (1996)	≤30	3	1	33.3
	30–45	7	1	14.3
	46–60	7	1	14.3
	61–105	13	1	7.8
	≤105	30	4	13.3
	>105	6	0	0.0
1996 season totals		36	4	11.1
Helicopter totals		58	7	12.1

exact test: $P < 0.01$). In 11 instances at 6 territories (46% of the 24 helicopter flights during nonnesting), spotted owls did not flush in response to helicopter noise that averaged 21 dBO louder than chain saw manipulations that did cause a flush at the same territory (Fig. 3). All flushes recorded during the nesting season occurred after fledging; no flushes were elicited by manipulations during the incubation and nestling phases. Overall, helicopters elicited 0% spotted owl response when beyond 105 m, 14% within 105 m, 19% within 60 m, and 50% within 30 m.

Spotted owl flush rates did not differ between nesting (13.6%) and nonnesting (13.3%) seasons for helicopter manipulations at ≤105 m (Fisher's exact test: $P = 0.34$; Table 2). Flush rates were lower during the incubation and nestling phases (0%) than during the fledgling phase (28%; Fisher's exact test: $P = 0.04$). Adults also roosted farther from juveniles as the number of days postfledging increased (1–20 days: $\bar{x} = 9.7$ m, $n = 10$; 21–40 days: $\bar{x} = 18.2$ m, $n = 15$; 41–60 days: $\bar{x} = 29.3$, $n = 11$). After 20 days, adult flush distance was typically less than adult-to-juvenile distance (21–40 days: $\bar{x} = 10.8$ m, $n = 2$; 41–60 days: $\bar{x} = 13.7$, $n = 3$). An adult spotted owl flew closer to a juvenile during only 1 of these latter 5 manipulations; however, regardless of adult flush distances, new diurnal roosts averaged only 6.5 m farther from juveniles.

Table 3. Chain saw manipulations eliciting a Mexican spotted owl flush response during the 1995 nonnesting and 1996 nesting seasons in the Sacramento Mountains, New Mexico.

Season	Stimulus distance (m)	Number of presentations	Number of flushes	Flush frequency (%)
Nonnesting (1995)	30	6	5	83.3
	45	3	2	66.7
	60	9	6	66.7
	75	3	0	0.0
	90	2	0	0.0
	105			
	≤105	23	13	56.5
1995 season totals		23	13	56.5
Nesting[a] (1996)	60	14	1	7.1
	105	16	1	6.3
	250	13	0	0.0
	400	2	0	0.0
1996 season totals		45	2	4.4
Chain saw totals		68	15	22.1

[a] To minimize additional potential disturbance at nest sites, only chain saw distances ≥60 m were tested in 1996; therefore, season totals are not comparable.

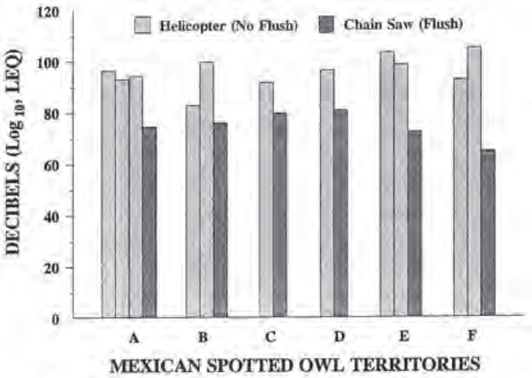


Fig. 3. A comparison of Mexican spotted owl flush response to chain saw and no-flush response to louder helicopters flown at equal or lesser distances at 6 territories during the 1995 nonnesting season in the Sacramento Mountains, New Mexico.

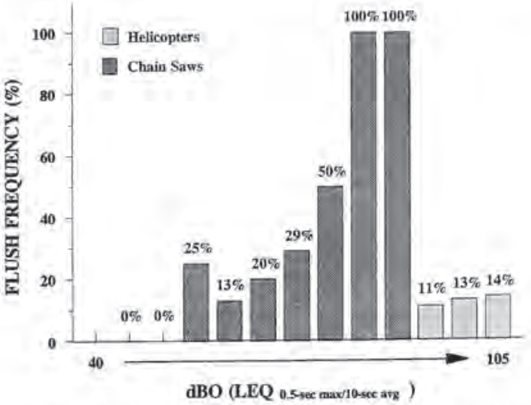


Fig. 4. A comparison of Mexican spotted owl flush frequency by stimulus type and noise level for helicopter and chain saw manipulations in the Sacramento Mountains, New Mexico, 1995–96.

Noise Thresholds.—During the nonnesting season, spotted owls did not flush when the SEL noise level for helicopters was ≤104 dBO (92 dBA) and the LEQ level for chain saws was ≤65 dBO (51 dBA). During the nesting season, spotted owls did not flush when the SEL sound level for helicopters was ≤102 dBO (92 dBA) and the LEQ level for chain saws was ≤59 dBO (46 dBA). These dB levels represent the noise level thresholds below which there were no spotted owl flush responses for the stimulus type and season indicated. Noise levels recorded near nest sites before and after disturbance trials were usually 25–35 dB (reaching upwards of 40 dB on windy days). Helicopters typically became audible at approximately 2,000 m.

Owl-, A-, and flat-weighting curves differed for 2 equidistant helicopter and chain saw trials at the same site (Figs. 1A,B). Within the midfrequency range, helicopters were louder than chain saws; yet, more of the total chain saw noise energy was in the midfrequency range where estimated spotted owl sensitivity was greatest. Helicopter energy level peaked at the lower end of the spectrum below the estimated spotted owl hearing sensitivity range. This difference partially explains the higher response rates for chain saws at lower noise levels than for helicopters (Fig. 4).

Alert Response

Spotted owls exhibited alert responses (i.e., head movements) when helicopters were an average of 403 ± 148 m away ($n = 34$; Fig. 5) but showed no response when helicopters were >660 m distant. Distances between helicopter and spotted owl for react responses (i.e., wing and body movements; $\bar{x} = 124 \pm 59$ m, $n = 2$) and flush responses (i.e., flight; $\bar{x} = 45 \pm 28$ m, $n = 7$) were shorter than for alert responses (Tukey's HSD: $P < 0.01$). The stimulus distances for react and flush responses did not differ (Tukey's HSD: $P = 0.75$), but sample sizes were very limited. However, the indicated trend was for severity of response type to increase as stimulus distance decreased.

We compared average head-movements/5 min for the 30–60 min prior to a manipulation (i.e., the mean of all 5-min, premanipulation means), the 5-min interval of the manipulation, and the 30–60 min following the manipulation. Spotted owls responded to noise stimuli with more alert movements ($\bar{x} = 7.4 \pm 5.6$, $n = 91$)

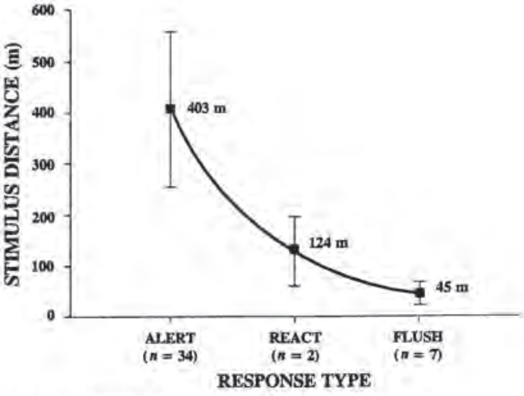


Fig. 5. Relation between stimulus distance and Mexican spotted owl response type during helicopter flights at 26 nest sites in the Sacramento Mountains, New Mexico, 1995–96. Error bars denote 2 standard deviations of the mean.

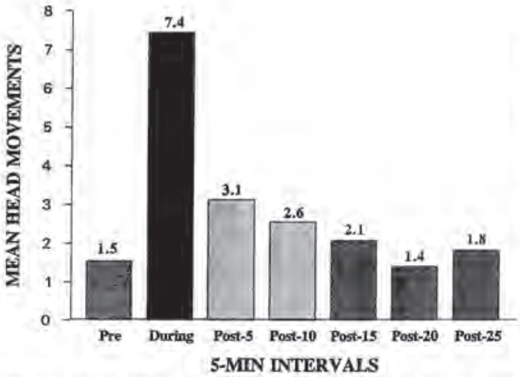


Fig. 6. Variation in mean frequency of Mexican spotted owl head movements (alert response) pre-, during, and postmanipulation for helicopter and chain saw noise events in the Sacramento Mountains, New Mexico, 1995–96. Bar shading indicates significant variation ($P \leq 0.08$).

than during premanipulation intervals ($\bar{x} = 1.6 \pm 1.5$, $n = 84$; PTMP: $P < 0.01$; Fig. 6). Spotted owls typically returned to premanipulation behavior in the third 5-min interval (between 10–15 min) after a stimulus event. Only the first (3.1 ± 3.7, $n = 57$; PTMP: $P = 0.01$) and second 5-min intervals (2.6 ± 3.0, $n = 51$; PTMP: $P = 0.08$) following a manipulation had greater frequencies of head movements than premanipulation levels.

Habituation

Experimental Testing.—Three of 4 previously unmanipulated spotted owls flushed in response to helicopter flights, while none of the 4 previously manipulated spotted owls flew (Table 4; Fisher's exact test: $P = 0.07$). During chain saw testing, 2 of the 4 unmanipulated spotted owls flushed, while no manipulated spotted owls flew ($P = 0.21$). Spotted owls may have habituated to the manipulations during successive exposures, and more so to helicopters than to chain saws. However, sample sizes were too small to establish significance for indicated trends.

Seasonal Change in Response Duration.—Response duration was consistently longer for chain saws than helicopters, was inversely related to stimulus distance, and generally decreased as the nesting season progressed. Mean response duration following helicopter flights dropped from 10.3 ± 9.4 min ($n = 14$) in July to 8.2 ± 5.5 min ($n = 12$) in August. Mean response durations following chain saw manipulations were 22.2 ± 22.3 min ($n = 19$) in July and 10.7 ± 8.6 min ($n = 5$) in August. Response durations following chain saw manipulations were 1.3–2.2 times longer than following helicopter flights.

Response duration averaged 16.6 ± 16.8 min ($n = 47$) when stimuli were ≤ 60 m away, and 7.0 ± 7.9 min ($n = 25$) when stimuli were >60 m away. Spotted owls required 11.6 ± 10.5 min ($n = 24$) to return to prior resting condition after helicopter flights of ≤ 60 m, compared to only 6.0 ± 8.8 min ($n = 11$) when flights were >60 m away. Response durations for chain saws were 21.1 ± 20.9 min ($n = 23$) at ≤ 60 m and 7.4 ± 7.6 min ($n = 14$) at >60 m, which was 1.2–1.8 times longer than helicopter durations.

Table 4. Habituation testing of helicopter and chain saw noise stimuli at 4 manipulated Mexican spotted owl nest sites and 4 previously unmanipulated sites in the Sacramento Mountains, New Mexico, 1996.

Parameter	Helicopter		Chain saw	
	Unmanipulated	Manipulated	Unmanipulated	Manipulated
Dates	8–25 Jul	8–22 Jul	19–23 Jul	16–26 Jul
Flushes	3 (75%)	0	2 (50%)	0
Distance (m, SLD)[a]				
Mean	36.5	42.8	60.0	60.0
Range	33–40	40–47	60.0	60.0
Owl-weighting (dB)[b]				
Mean	101.7	100.9	69.9	68.5
Range	[c]	99.8–102.3	64.9–72.9	65.2–74.5
A-weighting (dB)[b]				
Mean	95.5	90.4	56.4	56.0
Range	[c]	89.9–91.4	51.3–59.7	53.8–60.5

[a] SLD = straight-line distance between stimulus and spotted owl.
[b] dB = decibels.
[c] Only 1 noise level recording was available for analysis.

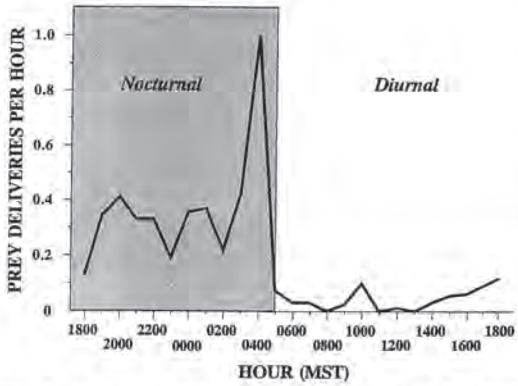


Fig. 7. Mean prey deliveries per hour (Mountain Standard Time [MST]) averaged across the entire nesting season for Mexican spotted owls in the Sacramento Mountains, New Mexico, 1996.

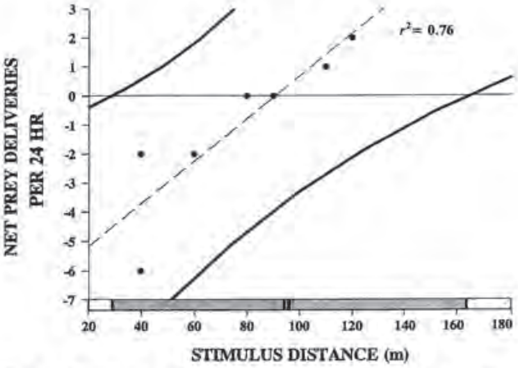


Fig. 8. The linear regression and 95% prediction interval between stimulus distance and net difference in prey deliveries (postmanipulation deliveries minus premanipulation deliveries) for the 24-hr periods after and before helicopter and chain saw manipulations at 4 Mexican spotted owl nest sites in the Sacramento Mountains, New Mexico, 1996. Shading along the distance axis indicates the 95% calibration interval (± 68 m) around the estimated potential threshold distance (96 m) for zero-difference in prey deliveries (Graybill 1976).

Seasonal Change in Time to Alert.—Time to alert increased as the nesting season progressed and as stimulus distance increased. Spotted owls exhibited alert responses after only 0.6 ± 0.7 min ($n = 13$) during helicopter flights in July, compared with 1.4 ± 1.4 min ($n = 9$) in August and 1.6 ± 0.6 min ($n = 6$) in September. Spotted owl response was quicker during chain saw manipulations: <0.2 ± 0.4 min ($n = 22$) in June, >0.2 ± 0.4 min ($n = 13$) in July, 0.3 ± 0.5 min ($n = 6$) in August, and 0.5 min ($n = 1$) in September. When helicopter flights were ≤60 m away, spotted owls responded in 1.0 ± 1.0 min ($n = 21$) compared to 1.2 ± 1.0 min ($n = 10$) for flights >60 m. Spotted owls responded to chain saws in 0.1 ± 0.2 min ($n = 26$) at distances ≤60 m, and in 0.3 ± 0.5 min ($n = 16$) when saws were >60 m away. Time to alert was consistently 3.0–10.0 times longer for helicopters than for chain saws.

Prey Delivery Rates and Related Behaviors

Over 81% of all prey deliveries within the nesting season ($n = 387$) occurred during nocturnal hours ($n = 16$ spotted owl territories). Mean prey deliveries per hour were highest (1.00) at 0400, when >18% of all prey were delivered (Fig. 7). Prey deliveries per hour averaged 0.03 during diurnal hours compared with 0.37 during nocturnal hours, which translates to 0.36 prey deliveries/12-hr diurnal period and 4.20 deliveries/12-hr nocturnal period.

There were only 7 instances of full 24-hr video records 1–2 days before and immediately after a manipulation. Net differences in prey deliveries for the 24-hr periods after and before noise manipulations (postmanipulation deliveries minus premanipulation deliveries; Fig. 8) were highly correlated with stimulus distance ($r^2 = 0.76$, $n = 7$ at 4 sites). The estimated potential threshold distance for a negative effect on prey deliveries was 96 m, which is consistent with the 105-m threshold for flush response described above. Because of limited sample size, the 95% calibration interval around this estimated threshold ranged between 28 and 164 m. Experimental helicopter and chain saw manipulations did not affect spotted owl nest attentiveness or the number of female trips from the nest; differences for the 24-hr periods pre- and postmanipulation were not correlated with stimulus distance.

DISCUSSION

Research Effects

Spotted owls tend to be less affected by nearby, nonthreatening human activity than most other raptor species. Sovern et al. (1994) found both nesting and nonnesting spotted owls became accustomed to observers sitting quietly 25–50 m away in only 10–15 min. Our use of blinds and their placement, along with the microphones, 1–4 hr in advance of manipulations provided additional visual and temporal buffering. Monitoring spotted owl behavior during those premanipulation hours and through unattended video camera coverage at other times confirmed undisturbed, normal activity. While monitored spotted owls were aware of the cameras, we recorded no unusual behaviors or changes in activity patterns in response to their presence. In fact, spotted owls that used the camera trees, and sometimes the same branch, for perching continued to do so after camera placement. Neither locator balloons, which were above the canopy and obscured by intervening vegetation, nor flashlights with directional beams pointed skyward were normally visible to manipulated spotted owls. Our data collection activities did not seem to affect spotted owl responses to experimental manipulations.

Reproductive Success

Other noise disturbance research suggests aircraft overflights alone have a negligible effect on raptor reproductive success and young fledged per nest (Platt 1977, Anderson et al. 1989, Ellis et al. 1991). We believe the small, nonsignificant decrease in reproductive success between manipulated ($n = 17$) and nonmanipulated ($n = 5$) sites in our study was attributable to natural attrition inherent in the larger manipulation sample.

Our ability to detect a biologically meaningful difference in reproductive success and productivity between manipulated and nonmanipulated nests was limited by population size. Sample sizes of 116 nests for measuring success and 362 nests for measuring productivity would have been required to reach an adequate power level of 0.80. With only 30–50 spotted owl territories reproductively active on the Sacramento Ranger District each year, and only about 80% of those sites successfully producing young in a good year, adequate power levels can never be reached.

Although we were not able to relate the number of flushes or the number of manipulations to the number of young fledged, both parameters should be addressed in noise disturbance research (Awbrey and Bowles 1990). Helicopter-induced flushes have been found to affect the number of young gyrfalcons (*Falco rusticolus*) that fledged in Alaska (Platt 1977), while Awbrey and Bowles (1990) hypothesized flushes may be the best predictor of eventual reproductive loss.

Flush Response

The proportion of spotted owls flushing in response to a manipulation was negatively related to stimulus distance and positively related to noise level. Grubb and King (1991), McGarigal et al. (1991), Stalmaster and Kaiser (1997), and others reported similar findings for bald eagles (*Haliaeetus leucocephalus*), with response to human activity increasing as stimulus distance decreased. Platt (1977) describes a comparable pattern for gyrfalcon response to helicopter flights.

The dose-response relations of flush frequency with distance (Fig. 2) and noise level (Fig. 4) indicated that chain saws, although not as loud as helicopters, caused spotted owls to respond from farther away and at higher frequencies. Results for both stimuli are consistent with a model derived from 9 studies of aircraft disturbance effects on several species of nesting raptors (Bowles et al. 1990), which predicts increasing flush probability with increasing noise levels.

Temporal Variation in Spotted Owl Flush Response.—Most studies have not examined the effects of human activities during the incubation and fledgling phases of the nesting season, primarily because of concerns over causing early nesting failure and premature fledging by juveniles (Awbrey and Bowles 1990). However, we observed a strong dichotomy in response behavior between prefledging and postfledging periods, with female spotted owls only flushing after their chicks had left the nest. Spotted owls, like other raptors, appear reluctant to leave the nest during the incubation and nestling phases (Craig and Craig 1984, Fraser et al. 1985, Anderson et al. 1989, Ellis et al. 1991). For bald eagles, flush frequency increased as the nesting season progressed and nest attendance declined, with the highest response rate occurring postfledging (Grubb and Bowerman 1997).

The fact that adult spotted owls were more likely to flush in response to manipulations later in the reproductive cycle also suggests a decrease in adult defensive or protective behavior as juveniles mature. Because adult spotted owls roosted at increasing distances from maturing juveniles, flush distance may become less critical as the fledgling phase progresses, especially because adults did not flush farther than their original distance from juveniles. Although season and nesting phase influence avian response to disturbance (Thiessen 1957, Knight and Temple 1986), prior experience, habituation, and animal temperament may be more important factors (Hart 1985, Manci et al. 1988). In fact, prior experience may be the best indicator of animal response to overflights (Bowles 1995).

Distance and Sound Thresholds.—Our distance-response threshold for spotted owls was similar to that of most other raptor species exposed to aircraft overflights (N. F. R. Snyder et al. 1978. An evaluation of some potential impacts of the proposed Dade County training jetport on the endangered Everglade Kite, unpublished report. U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, Laurel, Maryland, USA; Craig and Craig 1984, Anderson et al. 1989). For example, Grubb and Bowerman (1997) recommended helicopter survey flights remain >150 m from bald eagle nests and be <1 min in duration. Despite the aggressive nature of our testing regime (i.e., close proximity, repeated exposure, little or no prior experience), spotted owl behavioral responses were minimal when noise disturbance stimuli were >105 m away, and reproduction was not detrimentally affected. Because the 48 RQS varies every flight path during normal training operations over the forest, spotted owls on the LNF would not likely receive as much military helicopter disturbance within any year as the manipulated pairs received during this study.

Distance was a better predictor of spotted owl response to helicopter flights than noise levels. Even when we controlled for distance, noise levels varied among helicopter flights more than among chain saw manipulations. Helicopter noise varied not only with distance but also with rotor pitch, rotor torque, power levels, pilot technique, aircraft loading, speed, topography, and weather. Awbrey and Bowles (1990) described distance as the most commonly used surrogate for noise exposure in the animal effects literature, and suggested distance may be the best representative for the relation between stimulus and response measures. Grubb and King (1991) determined distance was the single most important predictor of bald eagle response in a classification tree model. Their model ranked noise sixth, behind distance, duration of disturbance, visibility, number of disturbances per event, and stimulus position relative to the affected eagle.

Helicopters Versus Chain Saws.—Few researchers have directly compared differences in raptor responsiveness between aerial and ground-based disturbances. In our study, ground-based disturbances elicited a greater flush response than aerial disturbances. Nesting bald eagles in Arizona showed the highest response frequency and severity of response to ground disturbances, followed by aquatic and aerial disturbances (Grubb and King 1991). Awbrey and Bowles (1990), in their meta-analysis of noise disturbance research on raptors, noted aircraft overflights were less detrimental than common ground-based activities such as hiking.

Spotted owls may have perceived helicopters as less threatening than chain saws because of their shorter duration, gradual crescendo in noise levels, minimal visibility, and lack of association with human activity. Helicopters would have elicited greater spotted owl response if exposure times were increased through slower maneuvers such as hovering. Chain saws started abruptly with an associated startle effect, whereas approaching helicopters were always preceded by a gradual increase in noise levels. Disturbing activities in close proximity to a spotted owl's location may also be more visible and therefore elicit a greater response than an activity farther away, regardless of noise level. However, we believe visibility had very limited effect on our results; helicopters were usually not visible, or only briefly so, to spotted owls roosting within or beneath the forest canopy. Grubb and Bowerman (1997) found aircraft visibility had little effect on bald eagle responsiveness. Although chain saws were also operated out of sight of reference spotted owls in all but a few instances, field crews had to set up recording equipment beneath the spotted owls for both types of manipulations. Subsequent chain saw operation may have been associated more with this ground-based human activity. In addition, raptors may be less disturbed by aerial manipulations because of their use of that medium (Gilmer and Stewart 1983).

Alert Response

Spotted owls initially responded to noise disturbances by turning toward the source. This orienting, alert response is an example of an animal's awareness of the disturbance through increased readiness to respond (Archer 1979, Brown 1990). Orienting response becomes progressively less frequent with repeated exposure to the same stimuli (Archer 1979). The relatively quick return to predisturbance behavior we documented is consistent with Ellis (1981), who showed heart rates of prairie falcons (*Falco mexicanus*) exposed to aircraft overflights returned to predisturbance levels within 5 min.

Our mean alert response threshold (403 m) corroborates a regional U.S. Fish and Wildlife Service policy that recommends a 400-m buffer zone around spotted owl nest sites (C. Torez, U.S. Fish and Wildlife Service, personal communication).

Habituation

Habituation is defined as an animal's progressive loss in responsiveness toward a stimulus and is an important determinant in overall response behavior (Peeke and Herz 1973). Although statistically insignificant due to small sample size, experimental spotted owls were less likely to flush (0 of 8) in response to helicopter and chain saw manipulations later in the season than control spotted owls (5 of 8 or 62%), suggesting that spotted owls may have been habituating to manipulation testing. Platt (1977) and Anderson et al. (1989) observed a similar decrease in flush response to aircraft overflights between experienced and relatively naive raptors. In northcentral Michigan, a pair of nesting bald eagles near a military air base was 14% less responsive and the median distance to aircraft eliciting a response was half that (400 m vs. 800 m) of 5 other pairs more remotely located (Grubb et al. 1992). In addition, response duration decreased and time to alert increased during the 1996 field season. However, we consider these trends weaker evidence for habituation because the influence of seasonal factors, such as nesting phase, cannot be differentiated.

Prey Delivery Rates and Related Behaviors

The effects of human activity on a raptor's ability to procure prey during the nesting season has not been well documented (Awbrey and Bowles 1990). Holthuijzen et al. (1990) found that prey delivery rates did not differ between experimental and control sites for prairie falcons exposed to construction and mining activity. Comparable examples for nocturnal raptors are lacking. We found prey delivery rates were highly and positively correlated with stimulus distance. Thus, manipulations in close proximity to spotted owl territories may affect prey delivery rates. The estimated threshold for detrimentally affecting prey deliveries (96 m) indicates a subflushing response consistent with the 105-m flush threshold and emphasizes the potential importance of this threshold distance. However, these threshold findings are based on a specific range of manipulations per territory; changes in stimulus frequency, duration, timing, and distance could strongly influence overall spotted owl response behavior.

Weather conditions should be considered when determining the effects of human activity on raptors (Schueck and Marzluff 1995). To control for possible weather effects, we did not conduct any manipulations during periods of inclement weather. This approach was consistent with the training protocol for the 48 RQS, which limited activity during such periods. However, factors such as precipitation, wind, and clouds can limit foraging ability of raptors (Brown et al. 1988, Bosakowski 1989, Flemming and Smith 1990) and thereby place greater importance on the next available foraging times, when disturbance could become more critical.

MANAGEMENT IMPLICATIONS

This research differs from previous noise disturbance studies by a unique combination of factors: (1) interpretation of noise levels via owl-weighting, which is more specific to the subject animal's hearing sensitivity than the generalized and less applicable A- or flat-weighting; (2) field experimentation with a threatened species in its natural habitat during a normal nesting season; and (3) controlled experimentation with the same resource and military aircraft, personnel, and flight profiles that initially raised the question of potential disturbance. A progressive, incremental, and conservative approach made this experimentation possible with no resultant negative effect on spotted owl activity or productivity.

Potentially detrimental noise levels were our initial and primary concern, but stimulus distance evolved as a more easily defined, quantified, and managed characteristic. Spotted owl response data were readily analyzed by distance because manipulation stimuli were presented by distance. In addition, distance results also directly translate into practical management implications. However, any application of our spotted owl response distances to develop management protocols for spotted owls elsewhere is inherently limited because it is predicated on having the same stimulus in a context similar to our experimentation. Alternatively, considering spotted owl response in terms of noise levels enables our results to be more generally applied, with due caution, to other types of helicopters under more varying conditions. This distinction is explained by the fact that noise level at the target species is the final measure of stimulus noise, whereas distance is only 1 of numerous intermediate factors (such as terrain, vegetation, atmospheric conditions, stimulus type, size, operation, etc.) that can affect noise level at the target.

Nonetheless, our data indicate the following recommendations for management of helicopter noise near Mexican spotted owls:

(1) At comparable distances, helicopter overflights were less disturbing to spotted owls than chain saws. This result validates, for this species and aircraft, the already established pattern that ground-based activities are typically more disturbing to raptors than aerial activities.

(2) Spotted owls did not flush when helicopter SEL noise levels were ≤102 dBO (92 dBA). Hence, helicopter noise levels below this threshold should not detrimentally affect nesting spotted owls.

(3) A 105-m radius, hemispherical protection zone should eliminate spotted owl flush response to helicopter overflights on the LNF. Zero flush response beyond 105 m for both helicopters and the more disturbing chain saws support this conclusion. Detrimental effects on prey delivery rates should also be minimized because the estimated threshold for this subflushing response (96 m) was <105 m.

(4) Short duration, single pass, single aircraft overflights had little effect on spotted owls. Other flight maneuvers involving circling, hovering, landing, etc., with potential increases in duration, proximity, or noise levels were not included in our experimentation.

(5) Our behavioral data indicate diurnal flights will likely have less potential for disrupting critical spotted owl activity than nocturnal flights. However, during nighttime hours, the 3 hr following sunset and preceding dawn were most important. Helicopter overflights between these nocturnal hours should minimize effects on spotted owl behavior.

(6) Considering the frequency of our manipulation testing, we recommend separating potential owl overflights along the same route by at least 7 days. Because flights over the same sites were separated as much as possible to minimize effects during our testing, data on the potential effects of more frequent overflights are lacking. However, actual rescue training flights avoid using the same route and therefore should not affect the same nest site twice in a breeding season.

(7) Although multiple flights over any 1 site are not recommended, our trend data indicate the likelihood of habituation with repeated exposures and as the nesting season progressed. Thus, naive, unexposed spotted owls may be more affected than spotted owls that have previously experienced overflights.

(8) Spotted owl flush response to helicopter overflights did not differ between the nesting and nonnesting seasons. Within the context of our experimentation, we found no substantive evidence that helicopter overflights during the nesting season detrimentally affected spotted owl success or productivity.

In conclusion, these research findings are specific to Mexican spotted owls and Pave Hawk helicopters, as well as to the seasons and habitat associated with our testing. Therefore, extrapolation to different avian genera or species, or other aircraft and locations, must be done with caution. For example, changes in forest type or elevation alone may influence prey availability and delivery rates, which may in turn influence spotted owl response behavior. We also caution against use of these findings to infer how spotted owls would respond under different circumstances that were not directly tested, such as spotted owl responses during early courtship and incubation, responses to >1 helicopter or overflight, or responses in different nesting habitat or under different foraging conditions. While our research was effective in answering the original, specific disturbance question, these results must be qualified by the limiting context of their derivation when applied to broader managerial questions.

ACKNOWLEDGMENTS

We thank M. Fay, S. Kyle, T. Narahashi, B. Jones, J. Yates, R. Wilcox , J. Yazzie, R. Lange, and J. Drennan for their field and lab assistance. M. Goodwin, D. Salas, M. Crites, E. Elliott, and R. Smith of the LNF contributed logistical and field support. We particularly appreciate the skill, support, and cooperation of the 48 RQS, commanded by Lieutenant Colonel N. Schoeneberg (1995) and Lieutenant Colonel T. Morris (1996). R. Galeano-Popp (LNF), C. Torez (U.S. Fish and Wildlife Service), and S. Williams, III (New Mexico Game and Fish Department) provided critical input during study design. R. Balda, W. Block, D. Garcelon, R. Kull, Jr., D. Patton, and P. Ward, Jr. reviewed earlier versions of the manuscript. R. King and J. Williams provided statistical advice and assistance throughout the project. This study was funded by HAFB through the Legacy Resources Program. Additional funding and logistical support came from the U.S. Forest Service Rocky Mountain Research Station, LNF, Sacramento Ranger District, Northern Arizona University, and Phillips Laboratory, HAFB.

LITERATURE CITED

ALEXANDER, B. G., F. RONCO, E. L. FITZHUGH, AND J. A. LUDWIG. 1984. A classification of forest habitat types of the Lincoln National Forest, New Mexico. U.S. Forest Service General Technical Report RM-104.

ANDERSON, D. E., O. J. RONGSTAD, AND W. R. MYTTON. 1989. Response of nesting red-tailed hawks to helicopter flights. Condor 91:296–299.

ARCHER, J. 1979. Animals under stress. Edward Arnold Publishers, London, United Kingdom.

AWBREY, F. T., AND A. E. BOWLES. 1990. The effects of aircraft noise and sonic booms on raptors: a preliminary model and a synthesis of the literature on disturbance. Noise and Sonic Boom Impact Technology Technical Operating Report 12. Wright-Patterson Air Force Base, Ohio, USA.

BOSAKOWSKI, T. 1989. Observations on the evening departure and activity of wintering short-eared owls in New Jersey. Journal of Raptor Research 23:162–166.

BOWLES, A. E. 1995. Responses of wildlife to noise. Pages 109–156 *in* R. L. Knight and K. J. Gutzwiller, editors. Wildlife recreationists. Island Press, Washington, D.C., USA.

———, F. T. AWBREY, AND R. KULL. 1990. A model for the effects of aircraft overflight noise on the reproductive success of raptorial birds. Noise and Sonic Boom Impact Technology Inter-Noise 90. Wright-Patterson Air Force Base, Ohio, USA.

BROWN, A. L. 1990. Measuring the effect of aircraft noise on sea birds. Environment International 16: 587–592.

BROWN, D. E., AND C. H. LOWE. 1980. Biotic communities of the Southwest. U.S. Forest Service General Technical Report RM-73.

BROWN, J. S., B. P. KOTLER, R. J. SMITH, AND W. O. WIRTZ, II. 1988. The effects of owl predation on the foraging behavior of heteromyid rodents. Oecologia 76:408–415.

CRAIG, T. H., AND E. H. CRAIG. 1984. Results of a helicopter survey of cliff-nesting raptors in a deep canyon in southern Idaho. Journal of Raptor Research 18:20–25.

DELANEY, D. K., T. G. GRUBB, AND P. BEIER. 1999. Activity patterns of nesting Mexican spotted owls. Condor 101:in press.

———, ——— AND D. K. GARCELON. 1998. An infrared video camera system for monitoring diurnal and nocturnal raptors. Journal of Raptor Research 32:290–296.

ELLIS, D. H. 1981. Responses of raptorial birds to low-level military jets and sonic booms: results of the 1980–81 Joint U.S. Air Force–U.S. Fish and Wildlife Service Study. Institute for Raptor Studies Report NTIS ADA108-778.

———, C. H. ELLIS, AND D. P. MINDELL. 1991. Raptor responses to low-level jet aircraft and sonic booms. Environmental Pollution 74:53–83.

FLEMMING, S. P., AND P. C. SMITH. 1990. Environmental influences on osprey foraging in northeastern Nova Scotia. Journal of Raptor Research 24:64–67.

FORSMAN, E. D. 1983. Methods and materials for locating and studying spotted owls. U.S. Forest Service General Technical Report PNW-12.

FRASER, J. D., L. D. FRENZEL, AND J. E. MATHISEN. 1985. The impact of human activities on breeding bald eagles in north-central Minnesota. Journal of Wildlife Management 49:585–592.

FYFE, R. W., AND R. R. OLENDORFF. 1976. Minimizing the dangers of studies to raptors and other sensitive species. Canadian Wildlife Service Occasional Paper 23.

GILMER, D. S., AND R. E. STEWART. 1983. Ferruginous hawk populations and habitat use in North Dakota. Journal of Wildlife Management 47:146–157.

GRAYBILL, F. A. 1976. Theory and application of the linear model. Duxbury Press, North Scituate, Massachusetts, USA.

GRUBB, T. G., AND W. W. BOWERMAN. 1997. Variations in breeding bald eagle response to jets, light planes, and helicopters. Journal of Raptor Research 31:213–222.

———, ———, J. P. GIESY, AND G. A. DAWSON. 1992. Responses of breeding bald eagles, *Haliaeetus leucocephalus*, to human activities in north-central Michigan. Canadian Field-Naturalist 106:443–453.

———, AND R. M. KING. 1991. Assessing human disturbance of breeding bald eagles with classification tree models. Journal of Wildlife Management 55:501–512.

HART, B. L. 1985. The behavior of domestic animals. W. H. Freeman, New York, New York, USA.

HOLLAND, E. D. 1991. The environment can ground training. Naval Proceedings, October 1991:71–75.

HOLTHUIJZEN, A. M. A., W. G. EASTLAND, A. R. ANSELL, M. N. KOCHERT, R. D. WILLIAMS, AND L. S. YOUNG. 1990. Effects of blasting on behavior and productivity of nesting prairie falcons. Wildlife Society Bulletin 18:270–281.

KNIGHT, R. L., AND S. A. TEMPLE. 1986. Why does intensity of avian nest defense increase during the nesting cycle? Auk 103:318–327.

KONISHI, M. 1973. How the owl tracks its prey. American Scientist 61:414–424.

MANCI, K. M., D. N. GLADWIN, R. VILLELLA, AND M. G. CAVENDISH. 1988. Effects of aircraft noise and sonic booms on domestic animals and wildlife: a literature synthesis. U.S. Fish and Wildlife Service Technical Report NERC 88.

MCGARIGAL, K., R. G. ANTHONY, AND F. B. ISAACS. 1991. Interactions of humans and bald eagles on the Columbia River estuary. Wildlife Monographs 115.

MIELKE, P. W., AND K. J. BERRY. 1982. An extended class of permutation techniques for matched pairs. Communications in Statistics—Theory and Methods 11:1197–1207.

PEEKE, H. V. S., AND M. J. HERZ. 1973. Habituation. Behavioral studies. Volume 1. Academic Press, New York, New York, USA.

PLATT, J. B. 1977. The breeding behavior of wild and captive gyrfalcons in relation to their environment and human disturbance. Dissertation, Cornell University, Ithaca, New York, USA.

SCHUECK, L. S., AND J. M. MARZLUFF. 1995. Influence of weather on conclusions about effects of human activities on raptors. Journal of Wildlife Management 59:674–682.

SOVERN, S. G., E. D. FORSMAN, B. L. BISWELL, D. N. ROLPH, AND M. TAYLOR. 1994. Diurnal behavior of the spotted owl in Washington. Condor 96:200–202.

SPSS. 1997. SPSS 7.5 for Windows: base, professional statistics, advanced statistics. SPSS, Chicago, Illinois, USA.

STALMASTER, M. V., AND J. L. KAISER. 1997. Flushing responses of wintering bald eagles to military activity. Journal of Wildlife Management 61:1307–1313.

STEIDL, R. J., J. P. HAYES, AND E. SCHAUBER. 1997. Statistical power analysis in wildlife research. Journal of Wildlife Management 61:270–279.

THIESSEN, G. 1957. Acoustic irritation threshold of ring-billed gulls. Journal of the Acoustical Society of America 29:1307–1309.

TRAINER, J. E. 1946. The auditory acuity of certain birds. Dissertation, Cornell University, Ithaca, New York, New York, USA.

WESEMANN, T. W., AND M. ROWE. 1987. Factors influencing the distribution and abundance of burrowing owls in Cape Coral, Florida. Pages 129–137 *in* L. W. Adams and D. L. Leedy, editors. Integrating man and nature in the metropolitan environment. Proceedings of the national symposium on urban wildlife. National Institute for Urban Wildlife, Columbia, Maryland, USA.

ZAR, J. H. 1984. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, New Jersey, USA.

Received 11 February 1998.
Accepted 13 June 1998.
Associate Editor: Lutz.

Exhibit 2

Biological Conservation 199 (2016) 29–32

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/bioc

Short communication

Anthropogenic noise impairs owl hunting behavior

J. Tate Mason [a,b,*], Christopher J.W. McClure [a,b], Jesse R. Barber [a]

[a] Department of Biological Sciences, Boise State University, 1910 University Dr., Boise, ID 83725-1515, USA
[b] The Peregrine Fund, 5668 West Flying Hawk Lane, Boise, ID 83709, USA

ARTICLE INFO

Article history:
Received 19 August 2015
Received in revised form 29 January 2016
Accepted 5 April 2016
Available online 8 May 2016

Keywords:
Noise
Predator–prey interactions
Owl

ABSTRACT

Emerging evidence indicates that anthropogenic noise has highly detrimental impacts on natural communities; however, the effects of noise on acoustically specialized predators has received less attention. We demonstrate experimentally that natural gas compressor station noise impairs the hunting behavior of northern saw-whet owls (*Aegolius acadius*). We presented 31 wild-caught owls with prey inside a field-placed flight tent under acoustic conditions found 50–800 m (46–73 dBA) from a compressor station. To assess how noise affected hunting, we postulated two hypotheses. First, hunting deficits might increase with increasing noise—the dose–response hypothesis. Secondly, the noise levels used in this experiment might equally impair hunting, or produce no impact—the threshold hypothesis. Using a model selection framework, we tested these hypotheses for multiple dependent variables—including overall hunting success and each step in the attack sequence (prey detection, strike, and capture). The dose–response hypothesis was supported for overall hunting success, prey detection, and strike behavior. For each decibel increase in noise, the odds of hunting success decreased by 8% (CI 4.5%–11.0%). The odds of prey detection and strike behavior also decreased with increasing noise, falling 11% (CI 7%–16%) and 5% (CI 5%–6%), respectively. These results suggest that unmitigated noise has the potential to decrease habitat suitability for acoustically specialized predators, impacts that can reverberate through ecosystems.

1. Introduction

Recent work indicates that anthropogenic noise affects animal behavior, distributions, and reproductive success (Francis and Barber, 2013). For example, the densities of many songbird species (Bayne et al., 2008) and the richness of the songbird community (Francis et al., 2009) decline by one-third at loud compressor station sites compared to quiet sites in natural gas extraction fields. Experimental application of traffic noise to the landscape has revealed declines in songbird abundance and near-complete avoidance by some species (McClure et al., 2013). Although several studies have examined species distributions, comparatively little is known about how noise affects predators that rely on sound to hunt. In laboratory studies, gleaning bats displayed up to a 2-fold increase in search time under acoustic conditions matching those encountered 50 m from a highway (Bunkley and Barber, 2015; Siemers and Schaub, 2011). Here, we focus on a predator that relies on low-frequency acoustic information and is thus potentially impacted by a louder soundscape at large spatial scales. We examine northern saw-whet owls (*Aegolious acadius*) hunting mice (*Mus musculus*) in replicated acoustic conditions 50–800 m from noisy infrastructure.

Although owls in general have sensitive visual systems, their prey may be visually inaccessible under snow or vegetation or obscured by complete darkness. Under these conditions, many owls rely on hearing to hunt and this selective pressure has resulted in highly sensitive, directional hearing. Ear asymmetry is critical for sound localization in birds (Konishi, 1973) and has evolved independently at least 4 times in owls (Norberg, 1977). The northern saw-whet exhibits the greatest degree of ear asymmetry of any known owl (Norberg, 1977) and is a good candidate to test the potential effects of noise on acoustically specialized avian predators.

Northern saw-whet owls are likely to encounter many sources of anthropogenic noise as they occur in developed regions and landscapes under intense resource extraction (Allred et al., 2015; Beckett and Proudfoot, 2011). Compressor stations, which are used to pressurize pipelines in energy extraction fields, produce chronic broadband noise (Fig. 1A) and can generate sound levels above the ambient background across an entire natural gas field (Francis et al., 2011). It is currently unknown if noise affects owl hunting behavior.

We challenged northern saw-whet owls to hunt mice in a field-placed flight tent using only acoustic cues under soundscape conditions replicating those found 50–800 m from a compressor station (46–73 dBA; Fig. 1B). We generated and compared two hypotheses: 1) the dose–response hypothesis, where we predicted

---

* Corresponding author at: Department of Biological Sciences, Boise State University, 1910 University Dr., Boise, ID 83725-1515, USA.
E-mail addresses: tmason@peregrinefund.org (J.T. Mason), jessebarber@boisestate.edu (J.R. Barber).

http://dx.doi.org/10.1016/j.biocon.2016.04.009
0006-3207/© 2016 Elsevier Ltd. All rights reserved.

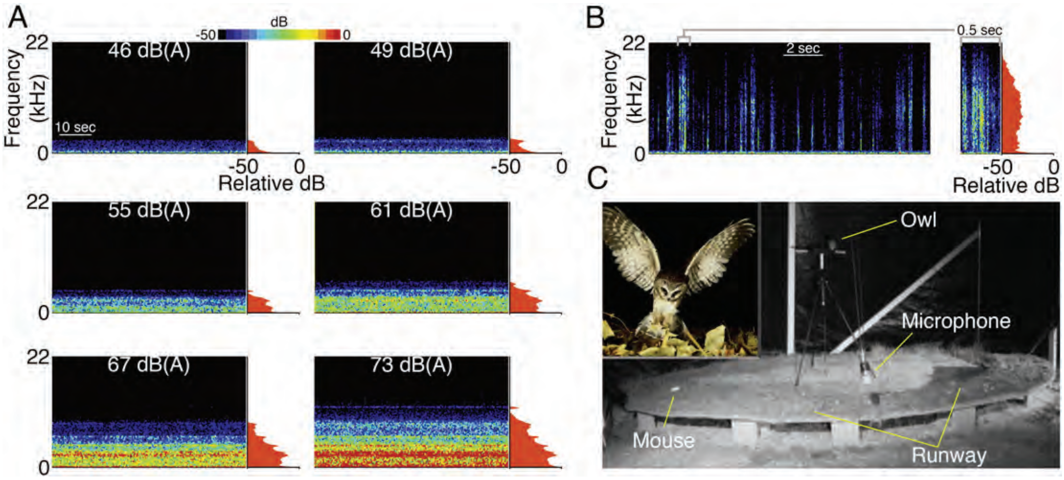


Fig. 1. Spectrograms and power spectra of experimental playback stimuli (A) and mouse footsteps recorded in the experimental paradigm (B). (C) A video frame of the hunting arena inside the flight tent with an inset of a saw-whet owl about to strike a mouse.

that owl hunting success would decrease in acoustic conditions found closer to a compressor station; and 2) the threshold hypothesis, where we predicted all the sound levels used in our experiment were above the threshold that would cause hunting deficits. We quantified overall hunting success, and to determine where in the predatory attack sequence deficits might be occurring, we also quantified three behaviors independently: prey detection, attempted prey capture (strikes), and capture of prey. Understanding the effects of louder acoustic environments on predators is critical for revealing forces that might reverberate through ecological systems (Francis et al., 2012).

2. Materials and methods

We conducted this study under Boise State University IACUC protocol 006-AC11-018. Personnel from the Intermountain Bird Observatory captured owls via mist-net and brought them to a light-proof flight tent (8 × 7 × 4 m), located approximately 1 km from the trapping location. We illuminated the tent with visible light (head lamp) to provide owls with visual information from their surroundings during a one-night acclimation period before experiments began. All experimental trials were conducted in the absence of light visible to the owls. We illuminated the hunting arena with 5 infrared LED arrays (Wildlife Engineering). An owl perch (1.7 m high and 0.4 m wide) was placed 2.5 m from an elevated runway covered in soil and fir needles where a mouse was introduced individually through one of two randomly chosen entry tubes (Fig. 1C). We filmed all trials with infrared-sensitive Canon XA-10 and Sony CX-7 video cameras (high definition, 30 fps).

Trials took place at night and consisted of 4 consecutive hunting opportunities over 2–3 nights, each under a randomly selected noise condition (61–73 dBA in 2012, 46–55 dBA in 2013; Supplementary Table 1). We played files through Bose speakers (Freespace 51, 250 Hz–12 kHz ± 3 dB) powered by a Kicker (IX500.2) or Lepai amplifier (LP-2020A). The speakers produced an even sound field (±2 dBA) across the hunting area. We recorded playback files between the hours of 2100–0400 (temp. 10–12 °C) at distances of 50–500 m from a compressor station (Gobbler's Knob Compressor Station, WY) with a Sennheiser ME66 microphone (40–20,000 Hz; ±2.5 dB) and Roland R-05 recorder (sampling rate 96 kHz) while measuring sound pressure levels using a Larsen-Davis 824 implementing a 3-minute integration. Due to an inability to record at distances greater than 500 m, we used the ANSI Standard for Sound Attenuation (ISO 9613-2, 1996) to project the 50 m track to distances of 600 (49 dBA) and 800 m (46 dBA), respectively. Using a custom MatLab program (D. Mennit), we calibrated our playback system so that each 1/3rd octave frequency band within the range of owl hearing (Dooling, 2002) matched recorded levels.

To quantify owl and mouse behavior, we analyzed videos using Adobe Premiere Pro (CS6). Mouse detection was recorded when the owl's facial disc was oriented toward the mouse for at least one video frame. We also noted whether the owl left the perch in pursuit of the mouse (strike) and if the strike was successful (capture). Mouse movement was quantified and recorded as the proportion of the trial that the mouse was physically moving on the runway. We conducted all analyses in R, version 3.1.3, and used package lme4 (Bates et al., 2014) to build generalized linear mixed models with binomial distributions and logit links. Overall hunting success was determined by analyzing all trials. We also examined three behaviors independently. We determined strike odds using the subset of trials during which the mouse was initially detected. We quantified the odds of an owl capturing a mouse using the subset of trials during which the owl struck at the mouse. In this way, the effect of noise could be assessed for each step in the attack sequence, independent of the prior step. For each dependent variable (overall hunting success, detection, strike, and capture odds), we compared the two hypotheses (dose–response vs. threshold) with each other, with models only containing extraneous variables (described below), and with a null (intercept-only) model. The dose–response hypothesis was tested using a model with a covariate indicating the decibel level and the threshold hypothesis was tested using a model with a binary factor indicating whether noise was played or not. To control for repeated sampling, we set individual owl as a random intercept. We then ranked and compared models using Akaike's Information Criterion (Akaike, 1974). The covariates within all models $\Delta AIC < 2$ were considered useful for inference if the 85% confidence intervals of their coefficients excluded zero. We used 85% confidence intervals instead of 95% because they are more appropriate under an AIC model selection framework (Arnold, 2010), although we note that use of 95% confidence intervals would not have affected the inference from our study.

In addition to the variables of interest, there were extraneous variables that we included in the models if they were independently determined to have had an effect on owl hunting behavior (Table 1). These variables were order of trial, night of trial, mouse movement, and year. We determined the effect of each of these covariates by regressing them against the hunting behaviors of interest (overall success, detection, strike, and capture) using generalized linear mixed models with binomial distributions and retaining the variables where the 85% confidence intervals of the coefficients excluded zero. We used linear regression to analyze the relationship between sound level and mouse movement.

Table 1
Coefficients (β) for the extraneous variables that independently affected owl hunting behavior. Variables were included in the subsequent analyses of noise on owl hunting behavior when the 85% confidence interval of their coefficients excluded zero.

Hunting behavior	Extraneous variable	β	SE	CI −	CI +
Success	Night	0.71	0.427	0.10	1.33
	Movement	1.33	0.878	0.06	2.59
	Order	0.19	0.003	0.19	0.20
Detection	Night	0.85	0.421	0.25	1.46
	Movement	1.38	0.723	0.34	2.42
	Year	0.15	0.003	0.15	0.16
Strike	Movement	2.41	0.855	1.18	3.64
	Year	−1.00	0.535	−1.77	−0.23
Capture	Night	2.01	0.86	0.77	3.25
	Year	1.51	0.72	0.46	2.55

3. Results

Twelve owls completed a total of 32 trials in 2012 and 18 owls completed a total of 152 trials in 2013. The extraneous variables (order of trial, night of trial, mouse movement, and year) and their independent effect on owl hunting behavior are summarized in Table 1. No relationship between noise level and mouse movement was detected ($p = 0.97$). Models containing noise covariates were the only models within $\Delta AIC < 2$ for all steps of the hunting process (Table 2). The only model within $\Delta AIC < 2$ for overall hunting success contained the dose–response parameter (Table 2). The inclusion of the dose–response parameter in the top model indicates that the odds of hunting success decreased as noise increased; the odds of a successful hunt decreased by 8% (CI 4%–11%) for each decibel increase in noise (Fig. 2). For mouse detection and strike odds, the dose–response model was the only model within $\Delta AIC < 2$, whereas the dose–response and threshold models were nearly tied for the AIC-best model of capture success (Table 2). The odds of an owl detecting a mouse during an experimental trial decreased by 11% (CI 7%–16%) for each decibel increase in noise and, likewise, the odds of a strike decreased by 5% (CI 5%–6%) for each decibel increase in noise (Fig. 2). The threshold and dose–response models were both competitive for capture. The threshold model indicated that the odds of a mouse capture under treatment conditions were 11 times less likely (CI 9–12; Movie S1) than in control conditions (Movie S2) while the dose–response model suggested that the odds of a mouse capture decreased by 9% (CI 2%–16%) for each decibel increase in noise.

Table 2
Model results for overall hunting success (calculated from all trials), detection, strike, and capture (calculated from trials where strikes occurred) odds. Extraneous variables (mouse *movement*, *night* of trial, *order* of trial, and *year*) were included if they had an independent effect.

Hunting success model	AIC	ΔAIC	k	wi
dose–response + movement + night	149.38	0	4	0.84
threshold + movement + night	152.68	3.3	4	0.16
movement + night	163.05	13.67	3	0
null	167.48	18.10	1	0
Detection model	AIC	ΔAIC	k	wi
dose–response + movement + night + order + year	165.58	0	6	0.97
threshold + movement + night + order + year	172.53	6.95	5	0.03
mouse movement + night + order + year	189.30	23.72	5	0
null	191.13	25.55	1	0
Strike model	AIC	ΔAIC	k	wi
dose–response + movement + year	170.10	0	4	0.86
threshold + movement + year	174.11	4.01	4	0.12
movement + year	177.67	7.57	3	0.02
null	189	18.90	2	0
Capture model	AIC	ΔAIC	k	wi
threshold + year + night	66.77	0	4	0.52
dose–response + year + night	67.23	0.46	4	0.41
year + night	70.96	4.19	3	0.06
null	75.59	8.82	1	0.01

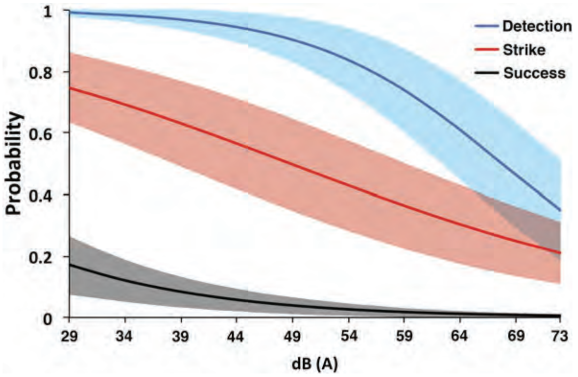


Fig. 2. The probability of an owl detecting, striking, and successfully capturing a mouse by sound level (dBA). The control averaged 29 dB(A); the loudest playback file was presented at 73 dB(A). Curves are plotted from the AIC-best model for each component of the attack sequence. Shading represents standard errors.

4. Discussion

The odds of an owl detecting prey, striking at prey, and overall hunting success decreased as noise level and spectral bandwidth increased, supporting a dose–response mechanism. The presence of added noise, regardless of amplitude, negatively impacted the odds of mouse capture, provided that the owl had struck. In this case, the dose–response hypothesis was also competitive and could not be rejected. Overall hunting success was progressively compromised in increasing noise up to 61 dB(A); above this sound level, no mice were captured. The deficits we observed likely resulted from the interference of noise with the gathering and/or processing of auditory information critical to successful hunting.

Though the hearing ability of saw-whet owls has yet to be quantified, data from 13 owls indicate that owl hearing is most sensitive between 0.5 and 8 kHz (Dooling, 2002). Compressor noise, and anthropogenic noise broadly, is primarily below 10 kHz (Fig. 1A). Noise treatments equivalent to 50–200 m from a compressor station overlapped substantially in spectrum with the sounds produced by mouse footsteps (Fig. 1B) and across these acoustic conditions owls did not successfully capture mice. The 500–800 m noise tracks produced progressively less overlap in frequency with mouse footsteps, due to excess attenuation of high frequencies at these distances, which might explain the improved hunting success we observed in these conditions. Masking of prey-generated sounds is a likely mechanism underlying our results; however, we cannot dismiss attentional distraction (Chan et al., 2010). Co-varying with an increasing overlap in frequency between playback stimuli and prey-generated sounds was an increase in noise amplitude. Increasing sound levels increase distraction in hermit crabs (*Coenobita clypeatus*) (Chan et al., 2010). Regardless of mechanism, we observed deficits at every stage of the attack sequence.

An average of 50,000 new gas wells were drilled per year from 2000 to 2012 in the US and Canada (Allred et al., 2015). Owl distributions around noisy infrastructure are unstudied, but we suggest that acoustically specialized owls might be absent from otherwise suitable habitat or suffer reduced condition if they remain (Ware et al., 2015). Our results clearly indicate that noise should be managed by dose of the pollutant and mitigation strategies, such as noise walls surrounding compressor stations (Francis et al., 2011), are likely to benefit acoustically specialized predators. Understanding owl distributions and fitness in relation to environmental sound levels are clear next steps. Environmental perturbations have a cumulative impact on ecosystem integrity, so the maintenance of natural acoustic environments could lessen the burden faced by many species. Further, we suggest that the trophic connections between many predators and prey are particularly vulnerable to being severed by noise.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.biocon.2016.04.009.

Acknowledgments

We thank G. Kaltenecker, J. Carlisle, A. Jensen, J. Butch, B. Leavell, J. Belthoff, I. Robertson, A. Dufty, K. Miner, E. Tyrell, D. Mennitt, J. Bunkley, and especially M. Beeken. Funding provided by Osher Institute, Animal Behaviour Society, Raptor Research Foundation, NSF GK-12 fellowship to JTM and NSF-CNH 1414171 to JRB.

Data accessibility: Dryad

We have no competing interests.

Author contributions: JTM and JRB designed the research, JTM performed research, CJM and JTM conducted analyses. All authors wrote the paper.

References

Akaike, H., 1974. A new look at the statistical model identification. IEEE Trans. Autom. Control 19. http://dx.doi.org/10.1109/TAC.1974.1100705.

Allred, B.W., Smith, W.K., Twidwell, D., Haggerty, J.H., Running, S.W., Naugle, D.E., Fuhlendorf, S.D., 2015. Ecosystem services lost to oil and gas in North America. Science 348, 401–402 (80-.).

Arnold, T.W., 2010. Uninformative parameters and model selection using Akaike's information criterion. J. Wildl. Manag. 74, 1175–1178. http://dx.doi.org/10.2193/2009-367.

Bates, D., Maechler, M., Bolker, B., Walker, S., 2014. lme4: linear mixed-effects models using S4 classes. R package version 1.1-6. R. http://CRAN.R-project.org/package=lme4 (doi:).

Bayne, E.M., Habib, L., Boutin, S., 2008. Impacts of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. Conserv. Biol. 22, 1186–1193. http://dx.doi.org/10.1111/j.1523-1739.2008.00973.x.

Beckett, S.R., Proudfoot, G.A., 2011. Large-scale movement and migration of northern saw-whet owls in eastern North America. Wilson J. Ornithol. 123, 521–535. http://dx.doi.org/10.1676/10-130.1.

Bunkley, J.P., Barber, J.R., 2015. Noise Reduces Foraging Efficiency in Pallid Bats (Antrozous pallidus) 121 pp. 1–6. http://dx.doi.org/10.1111/eth.12428.

Chan, A.A.Y.H., David Stahlman, W., Garlick, D., Fast, C.D., Blumstein, D.T., Blaisdell, A.P., 2010. Increased amplitude and duration of acoustic stimuli enhance distraction. Anim. Behav. 80, 1075–1079. http://dx.doi.org/10.1016/j.anbehav.2010.09.025.

Dooling, R., 2002. Avian hearing and the avoidance of wind turbines. Contract NREL/TP-50, p. 84.

Francis, C.D., Barber, J.R., 2013. A framework for understanding noise impacts on wildlife: an urgent conservation priority. Front. Ecol. Environ. http://dx.doi.org/10.1890/120183.

Francis, C.D., Kleist, N.J., Ortega, C.P., Cruz, A., 2012. Noise pollution alters ecological services: enhanced pollination and disrupted seed dispersal. Proc. R. Soc. B Biol. Sci. 279, 2727–2735. http://dx.doi.org/10.1098/rspb.2012.0230.

Francis, C.D., Ortega, C.P., Cruz, A., 2009. Noise pollution changes avian communities and species interactions. Curr. Biol. 19, 1415–1419. http://dx.doi.org/10.1016/j.cub.2009.06.052.

Francis, C.D., Paritsis, J., Ortega, C.P., Cruz, A., 2011. Landscape patterns of avian habitat use and nest success are affected by chronic gas well compressor noise. Landsc. Ecol. 26, 1269–1280. http://dx.doi.org/10.1007/s10980-011-9609-z.

ISO 9613-2, 1996. Acoustics—attenuation of sound during propagation outdoors—part 2: general method of calculation. Acoust. Soc. Am.

Konishi, M., 1973. How the owl tracks its prey. Am. Sci. http://dx.doi.org/10.1511/2012.99.494.

McClure, C.J.W., Ware, H.E., Carlisle, J., Kaltenecker, G., Barber, J.R., 2013. An experimental investigation into the effects of traffic noise on distributions of birds: avoiding the phantom road. Proc. Biol. Sci. 280, 20132290. http://dx.doi.org/10.1098/rspb.2013.2290.

Norberg, R.a., 1977. Occurrence and independent evolution of bilateral ear asymmetry in owls and implications on owl taxonomy. Philos. Trans. R. Soc. B Biol. Sci. 280, 375–408. http://dx.doi.org/10.1098/rstb.1977.0116.

Siemers, B.M., Schaub, A., 2011. Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. Proc. Biol. Sci. 278, 1646–1652. http://dx.doi.org/10.1098/rspb.2010.2262.

Ware, H.E., Mcclure, C.J.W., Carlisle, J.D., Barber, J.R., 2015. A Phantom Road Experiment Reveals Traffic Noise Is an Invisible Source of Habitat Degradation. http://dx.doi.org/10.1073/pnas.1504710112.

Exhibit 3

www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

Traffic noise reduces foraging efficiency in wild owls

Masayuki Senzaki[1], Yuichi Yamaura[2], Clinton D. Francis[3] & Futoshi Nakamura[1]

Received: 18 May 2016
Accepted: 04 July 2016
Published: 18 August 2016

Anthropogenic noise has been increasing globally. Laboratory experiments suggest that noise disrupts foraging behavior across a range of species, but to reveal the full impacts of noise, we must examine the impacts of noise on foraging behavior among species in the wild. Owls are widespread nocturnal top predators and use prey rustling sounds for localizing prey when hunting. We conducted field experiments to examine the effect of traffic noise on owls' ability to detect prey. Results suggest that foraging efficiency declines with increasing traffic noise levels due to acoustic masking and/or distraction and aversion to traffic noise. Moreover, we estimate that effects of traffic noise on owls' ability to detect prey reach >120 m from a road, which is larger than the distance estimated from captive studies with bats. Our study provides the first evidence that noise reduces foraging efficiency in wild animals, and highlights the possible pervasive impacts of noise.

Anthropogenic noise (hereafter "noise") is increasing globally and mounting evidence suggests that noise can negatively affect wild animals in many ways[1–3]. Of these impacts, masking from noise, where it interferes with an organism's ability to detect or discriminate biologically relevant signals, appears to be especially problematic[4–6]. Although several studies have examined impacts of masking using "quiet *versus* loud designs", to fully understand and reduce the severity of masking, quantifying wildlife responses to a range of noise exposure levels is critical[5–7].

Compromised foraging efficiency in animals, especially in acoustic predators such as owls and bats, is among the main concerns regarding impacts of novel acoustic environments created by noise[8–10]. This is because declines in foraging efficiency likely influence their distributions by altering behavior and reducing habitat suitability[11,12] and thereby may alter predator-prey interactions that have ecosystem-wide consequences[13]. Nevertheless, only a few laboratory experiments with limited sample sizes have examined noise impacts on foraging efficiency, and only in two bat species[8,11,12] and in a single owl species[14]. Thus, to clarify whether negative effects of noise on foraging efficiency in acoustic predators are widespread, we must understand the degree to which noise degrades foraging efficiency in acoustic predators in the wild[5,6].

The objective of this study was to experimentally determine the relationship between foraging efficiency of wild acoustic predators and noise levels common to many landscapes. We studied nocturnal owls because they are specialized acoustic predators, have cosmopolitan distributions, and have different audible ranges and hunting techniques than bats. We conducted novel field playback experiments using two types of sounds, traffic noise (hereafter "TN") and artificial prey rustling sound (hereafter "APRS") (Fig. 1). Playback of TN allowed us to isolate effects of noise from other confounding factors, such as habitat changes, visual disturbance of moving vehicles and lights, etc[15–17]. Because owls localize and attack prey using prey-generated rustling sounds at frequencies spanning 6–8.5 kHz[18], we digitally developed APRS (Fig. 2a) and found that owls in the wild are attracted to playback of these sounds (see supplementary Fig. S1), providing a method for quantifying prey detection among wild owls under a variety of acoustical conditions. In field experiments, we played back APRS at constant amplitude under various TN exposure levels at many locations in northern Japan, and thereby examined the effect of TN on owls' ability to detect APRS. Finally, we estimated the compromised foraging range by noise near roads. To the best of our knowledge, this is the first study to examine effects of different levels of TN on foraging efficiency in acoustic predators in the wild.

Results

We conducted 367 playback experiments in northern Japan (see supplementary Fig. S2), and recorded a total of 92 owls in 76 playback experiments (Table 1). After exclusion of owls that did not satisfy our analytical criteria

[1]Graduate School of Agriculture, Hokkaido University, Kita 9, Nishi 9, Kita-Ku, Sapporo, 060-8589, Japan. [2]Department of Forest Vegetation, Forestry and Forest Products Research Institute, 1 Matsunosato, Tsukuba, Ibaraki, 305-8687, Japan. [3]Department of Biological Sciences, California Polytechnic State University, San Luis Obispo, CA 93407, USA. Correspondence and requests for materials should be addressed to M.S. (email: bittern0412@yahoo.co.jp)

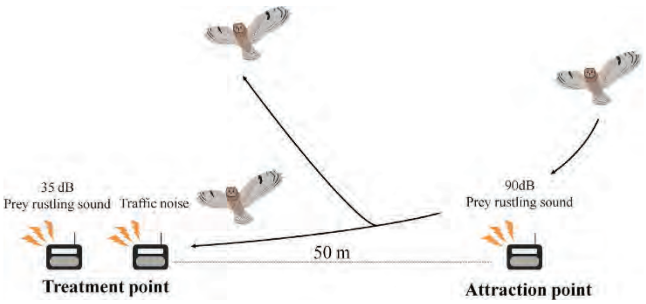
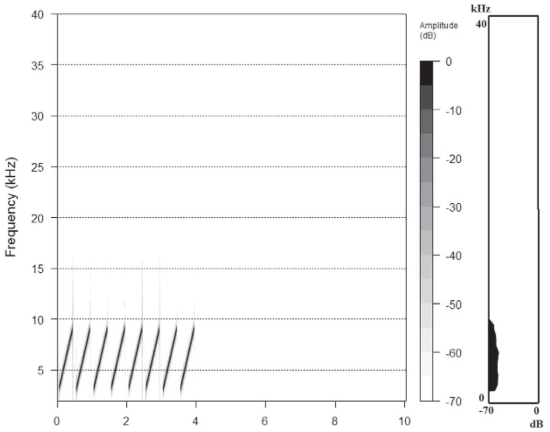


Figure 1. **Schematic of the playback experimental set up.**

a) Artificial prey rustling sound



b) Traffic noise

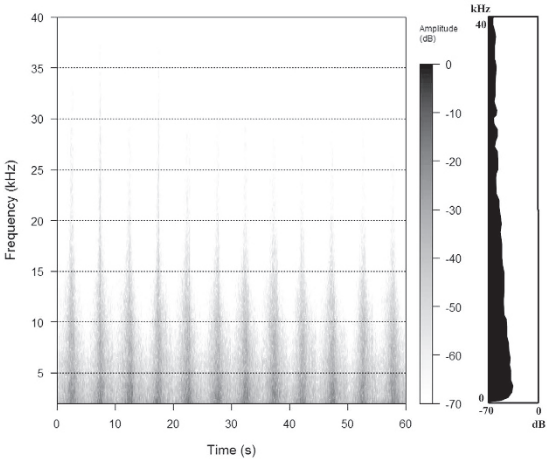


Figure 2. Spectral characters, relative amplitudes (left panel) and power spectra (right panel) of (**a**) ARPS and (**b**) TN.

	Yufutsu	Sendai	Total
Number of study plots	45	58	103
Number of experiments	210	157	367
Number of owls	21	71	92
long-eared owl	7	29	36
short-eared owl	14	39	53
ural owl	0	3	3

Table 1. **Summary of field experiments.**

Variables	Model rank				β	SE
	1	2	3	4		
Traffic noise level						
Distance from road	+	+			−0.30	0.01
Distance from road^2	+		+		0.00	0.00
df	4	3	3	2		
ΔAICc	0.00	115.80	199.44	295.71		
Weight	1.00	0.00	0.00	0.00		
Owls' prey detectability						
Trafic noise	+	+	+		−0.07	0.02
Species_ID		+	+			
TN X SP_ID			+			
df	4	5	6	3		
ΔAICc	0.00	2.28	4.60	17.07		
Weight	0.70	0.23	0.07	0.00		

Table 2. Results of GLM examining how TN decreases with distance from a road and GLMM examining effects of TN on owl's ability to detect prey. For GLM, we treated SPL as a response variable, and distance from a road (m) and its quadratic term as explanatory variables. For GLMM, we treated whether owls detected APRS at the treatment point as the response variable, SPL of TN, species ID and interaction of these variables as explanatory variables and plot ID and Study region (Yufutsu or Sendai) as random variables. Variables included in models are indicated with plus sign. "TN X SP_ID" indicates the interaction term between traffic noise and species ID and "Weight" refers to Akaike Weights. Parameter estimates (β) and its standard errors (SE) in the best models are also given.

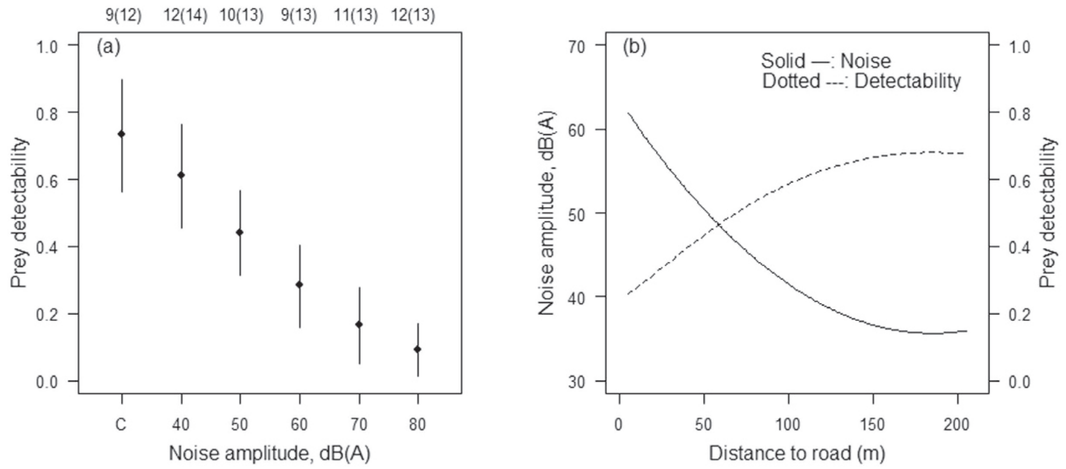


Figure 3. (**a**) Estimated owls' ability to detect prey under noise exposure levels (with 95% CI). "C" indicates control experiments. Detectability at C is estimated using average background sound level (32 dB). Top figures indicate number of experiments (number of owls analyzed). (**b**) Relationships between road distances and noise levels and owls' prey detectability. The owls' ability to detect prey was estimated based on linear regression equation presented in (**a**).

($n = 14$, see "Materials and Methods"), we analyzed 78 owls in 63 playback experiments (45 short-eared owls *Asio flammeus* and 33 long-eared owls *Asio otus*). The best model included sound pressure level (SPL) of TN and suggested owls' ability to detect prey was negatively associated with SPL of TN (Table 2, Fig. 3a). Species ID and the interaction term had no association with owls' ability to detect prey (Table 2).

In addition, to estimate relationship between road distances and owls' ability to detect prey, we also measured SPL of TN at various distances from road. Result of model selection showed SPL of TN attenuated quadratically with distance from road (Table 2, Fig. 3b), indicating impacts of traffic noise on owls' ability to detect prey has the potential to reach >120 m from a road (Fig. 3b). In other words, owls' ability to detect prey was impacted even at the lowest level of TN (40 dB[A]) and was approximately 17% lower than detections in ambient sound conditions (Fig. 3a).

Discussion

Using a novel field-based experimental approach, we show that owls' ability to detect prey is negatively impacted by increases in TN. Masking of the signal occurs when there is spectral and temporal overlap between the signal and noise[5]. Because APRS experience considerable spectral overlap by TN (Fig. 2a,b), reduction of owls' ability to detect prey could be caused by increasing acoustic masking with increasing amplitude of TN[11,12], although whether the signal was masked depends on the acoustic processing abilities of the owls and how they hear sound in noise. Additionally, it is not mutually exclusive that distraction and/or avoidance to TN play some role for explaining decreases in prey detection. For example, previous works with bats suggests that distraction/avoidance to noise had larger impact on bats' ability to detect prey than masking[8].

Owls' ability to detect prey was impacted even at the lowest level of TN (40 dB[A]) and was approximately 17% lower than that of ambient conditions (Fig. 3a). This corresponds to a distance of 120 m estimated from our model predicting noise levels from distance to the road and is twice the distance estimated for impacts on bats' prey detectability due to TN[9]. Methodological differences between laboratory and field studies could explain these differences. For example, laboratory experiments conducted in a restricted area could overestimate prey detectability of acoustic predators because in a confined laboratory setting they circle above the experimental foraging area in flight and may have more chances to detect their prey. In contrast, in the field acoustic predators typically forage in linear flight and would have fewer opportunities to detect prey sounds[11]. Alternatively, such difference may be, at least partially, due to differences of audible range and/or sensitivity to sounds between birds and bats (i.e., owls cannot detect sounds at frequencies above 15 kHz[18] while echolocating bats use sounds at frequencies up to 120 kHz)[11] and differences in prey-generated rustling sounds between the experiments.

Masking of real or artificial prey rustling sounds by traffic noise should invariably reduce foraging efficiency to some degree. However, hunting owls may be able to take advantage of directional masking release where rustling sounds and background noise propagate from different directions. Distraction, in which owls attend to traffic noise rather than rustling sounds, could also explain declines in prey detectability and could operate along side masking. However, it is also possible that distraction or compromised attention could decrease with habituation to traffic noise over time. Distinguishing among these potential mechanisms must be a next step. Additionally, it is also critical to understand whether declines in prey detection scale to responses most relevant to population persistence, such as site abandonment or impact actual foraging success, body condition and reproductive success of animals occupying noisy areas[11,19,20].

In addition, there are several differences between this study and natural conditions. First, omnidirectional TN used here differs from horizontal TN propagation from roadways that wild owls encounter in nature. Thus, future work evaluating how directional masking release changes detection of APRS is needed. Second, we used a representative TN sound recording in the experiments based on comparisons among several TN sounds. Although this isolates noise amplitude as a single factor that varied among treatment levels, it also does not reflect TN variation due to variable traffic speeds, densities and environmental conditions, indicating that future work should focus on how possible TN variation affects owls' ability to detect prey. Moreover, high frequency components of TN attenuate faster with distance from roads than lower frequency components, suggesting overestimation of the masking effects of TN playbacks at amplitudes reflective of 55, 105, 155, 205 m from the road. However, because APRS playbacks were louder than natural prey rustling sounds and APRS might be easier for owls to detect than actual prey rustling sounds with broadband energy, effects of TN on owls' prey detection may extend well-beyond our 120 m estimate.

Despite the need to parse the effects of how directional masking release, real versus artificial prey sounds and high frequency components simultaneously contribute to estimated impacts with respect to distance from roads, we provide the first evidence that noise reduces foraging efficiency in a wild predator in a natural situation. Additionally, our analysis of sound level attenuation with distance from the road suggests that declines in prey detection occur at distances twice that estimated for bats from lab studies[11], at least in our study region. Nevertheless, given our playback is representative of traffic noise propagating from other roadways (see supplementary Fig. S3), it is likely that impairment of foraging at similar distances is generalizable to other roadways. Moreover, a recently published captive study showed that experimental playback of compressor noise, which has similar power spectrum with traffic noise, negatively impacts hunting behavior of northern saw-whet owls (*Aegolius acadius*) at sound levels as low as 46 dB(A), which corresponds to approximately 800 m from compressor stations[14]. These potentially sizable footprints from energy-sector and traffic noise highlight the pervasive impacts of noise on acoustic predators because many sources of noise, including road densities, are high and increasing[4]. For example, 83% of the continental US is within 1061 m of a road[21], and globally, >25 million kilometers of new roads are anticipated by 2050[22]. Key to fully understanding noise-impacts on acoustic predators will require knowledge of how the magnitude of noise-impacts varies depending on road densities, arrangements and traffic volumes and speeds. Moreover, it is critical to understand how common prey species respond to roadways and traffic and determine whether the cumulative effects are additive, synergistic or even antagonistic, as some nocturnal small mammals appear to increase in noise exposed areas[23] and along roadways[24]. Regardless of the shape of these interactions, it is likely that wild owls and other acoustically-oriented predators will continue to be impacted by noise.

Methods

(a) Preparation of the traffic noise for playback experiments. Vehicle noise was recorded at the prefectural road #1046 in Yufutsu plain, central Hokkaido, late December 2014. The recording was conducted between 22:00 to 02:00 on a clear day when wind speeds were less than 1 m/s. We set a recorder (PCM-D100, Sony Corporation, Tokyo, Japan; frequency response ± 2 dB between 20 Hz and 45 kHz) with a sound pressure meter (Sound Level Meter TYPE 6236, ACO CO., LTD, Miyazaki, Japan) at a height of 1.5 m and 5 m distance from the road. Then, for each of 20 passing vehicles at constant speed (60 km/h), we recorded its noise and measured its sound pressure level (SPL) as the A-weighted equivalent continuous noise level during five seconds at nearest distance to a vehicle (L_{eq} [5 s], fast response time, re. 20 μPa, A-weighting). For these, we used the A-weighted filter because this filter provides better measurement of acoustic energy relevant to birds at frequencies between 1.0 and 9.5 kHz[25], which cover entire frequency range used by hunting owls[18]. Finally, we created a 1 min exemplar of TN sound consisting of 12 vehicle pass-by events, which contained energy up to 40 kHz, but had the most energy below 10 kHz (Fig. 2b). This traffic level was found along roads in many national parks, national forests, and protected areas globally[19]. Although it is better to use different TN sounds in each playback experiment to capture potential heterogeneity in traffic noise present in different locations or times, because our primary interest is to quantify effect of amplitude alone on owls' ability to detect prey, we used this single TN sound file in all playback experiments based on comparisons of frequency spectra among several TN sounds recorded at different locations (see supplementary Fig. S3). We also created a 1 min control sound file that had no acoustic energy. In addition, to understand how sound levels attenuate with distance from the roadway, for each of 20 passing vehicles at known speed (i.e., 60 km/h), we measured its sound pressure level (SPL) as the A-weighted equivalent continuous noise level during five seconds at nearest distance to a vehicle (e.g., LAeq [5 s]) at 5, 55, 105, 155, and 205 m from the road.

(b) Preparation of the artificial prey rustling sound for playback experiments. When small-mammals walk on the ground, they produce rustling sounds which are short and contain a wide range of frequencies[18]. Owls can precisely locate these rustling sounds, especially at frequencies between 6 and 8.5 kHz[18]. Because they respond strongly to stimuli at these frequencies, we created sound files consisting of an upsweeping element of 0.4 s in duration spanning 3.0–9.0 kHz separated by 0.1 s (sampling rate: 192 kHz). For each file, the elements were repeated eight times, followed by 6 s with no acoustic energy (Fig. 2a). This 10 s section was then repeated six times to create a one-minute artificial prey rustling sound, which is similar in structure to rustling sounds made by actual prey[18]. All sound analyses and clip generation were conducted in Sound Forge Audio Studio 10.0 (Sony, Tokyo, Japan).

(c) Study area and field playback experiments. To make certain that we could obtain sufficient sample sizes, we selected two study areas in northern Japan where many owls overwinter. Specifically, field experiments were conducted in Yufutsu plain, central Hokkaido and in Sendai plain, northern Honshu (see Supplementary Fig. S2). Both landscapes are predominantly agricultural fields and semi-natural grasslands (see Supplementary Fig. S2), providing suitable environments for our target study species. We established 103 playback experimental plots in these two areas (45 in Yufutsu plain and 58 in Sendai plain, northern Honshu) (see Supplementary Fig. S2). In the study area, an individual short-eared owl territory size was estimated to be approximately 5 ha (M. Senzaki, personal observations), which nearly equals an area with 130 m radius. Thus, to prevent double sampling, adjacent plots were spaced by >500 m. In addition, we did not establish plots in areas with tall trees or streetlights to prevent potential effects of these factors on sound propagation or owls' behaviors respectively. Playback experiments were conducted at least once in each plot between 1700–0500 h on both clear and cloudy nights, when wind speeds were <2 m/s, from December 2014 to March 2015, which corresponded with owls' wintering periods. The average number of playback experiments at each plot (±SD) was 3.56 ± 1.23. When owls were sampled in a plot, we did not conduct any additional playback experiments in the same plot three or more days to minimize effects of habituation.

A plot consisted of an attraction and treatment point spaced 50 m apart (Fig. 1) with one and two speakers (PDX-B11: Yamaha, Hamamatsu, Japan; frequency response ± 10 dB between 55–20 kHz) connected with players (WALKMAN NW-E080, Sony Corporation, Tokyo, Japan), respectively. Although traffic noise propagates horizontally across the landscape, and mimicking directional propagation can be carefully controlled in laboratory conditions[11,12], we set all speakers on the ground facing upwards to ensure omnidirectional propagation of attraction and treatment point sounds across the landscape. This ensures fairly equal amplitudes of playback sounds in all directions, which was important when owls could approach from any direction. On nights when background SPL ≤ 35 dB(LAeq[1 min]), we broadcasted TN or the silent sound file with no acoustic energy (hereafter "control sound") from one speaker at the treatment point until the end of the experiment. Amplitude of TN was randomly chosen to be approximately 40, 50, 60, 70, or 80 dB(LAeq [5 s]) at 1.5 m height above the speaker, representing sound levels measured at different distances from a roadway. After 1 min of TN broadcast at the treatment point, we first broadcast APRS at 90 max dB(A) at a height of 1.5 m above the attraction point speaker for 1 min to attract owls from the larger surrounding area. When the playback was finished, we immediately broadcast APRS at 35 max dB(A) at a height of 1.5 m above the second speaker at the treatment point for 1 min. Although 35 dB(A) is louder than natural prey sounds[11,12], we used the value to ensure that owls at attraction points could detect APRS at treatment points at least under control playback conditions. We tracked owls attracted to the attraction point and determined whether they could subsequently detect APRS at the treatment point. Owls that actively entered the range within 10 m from the attraction/treatment point (e.g., owls hovering and/or flying circular over the speaker) were determined to detect APRS in each point. When we observed attacks and/or chases between attracted owls and/or when we could not determine whether owls in attraction points were detecting APRS in treatment points because they landed on the ground, they were not included in subsequent analyses. We also excluded experiments with no owls detected from any analysis. Because flying owls could be observed at approximately 50 m distance from an observer, observations were conducted 30 m from both attraction and treatment points using a night scope (ATN Night Spirit XT, California, USA) and binoculars (MONARCH 8 × 42, NIKON CORPORATION, Tokyo, Japan).

(d) Data analysis. We used Generalized Linear Model (GLM) with Gaussian error to examine how TN decreases with distance from a road. We treated SPL as a response variable, and distance from a road (m) and its quadratic term (m^2) as explanatory variables.

We examined effects of TN on owl's ability to detect prey using Generalized Linear Mixed Model (GLMM) with Binomial error. We treated whether owls detected APRS at the treatment point as the response variable, SPL of TN, or ambient SPL measured prior to the start of control trials, species ID (long- or short-eared owl) and the interaction of these variables as explanatory variables. Plot ID and Study region (Yufutsu or Sendai) were treated as random variables. Although identifying whether the same individuals were recorded within a specific plot was difficult due to low light levels, treating plot ID as a random effect can account for possible repeated sampling of the same individuals. For experiments with control sound, SPL measured before the start of the experiments was used. We constructed models for the combinations of all possible covariates, ranked them by Akaike's information criterion for small sample size (AICc), and considered covariates in the best model as meaningful predictors. These analyses were conducted using "lme4" (v. 1.1–5)[26] and "MuMIn"(v. 1.9.13)[27] with R software (v. 2.15.3)[28].

(e) Ethical statement. All experiments were performed in accordance with relevant guidelines and regulations. All experimental protocols were approved by the Japanese Ministry of the Environment.

References

1. Francis, C. D. Vocal traits and diet explain avian sensitivities to anthropogenic noise. *Glob. Change. Biol.* **21,** 1809–1820 (2015).
2. Fuller, R. A., Warren, P. H. & Gaston, K. J. Daytime noise predicts nocturnal singing in urban robins. *Biol. Lett*. **3,** 368–370 (2007).
3. Halfwerk, W. *et al.* Low-frequency songs lose their potency in noisy urban conditions. *Proc. Natl. Acad. Sci*. **108,** 14549–14554 (2011).
4. Barber, J. R., Crooks, K. R. & Fristrup, K. M. The costs of chronic noise exposure for terrestrial organisms. *Trends. Ecol. Evol.* **25,** 180–189 (2010).
5. Francis, C. D. & Barber, J. R. A framework for understanding noise impacts on wildlife: an urgent conservation priority. *Front. Ecol. Environ.* **11,** 305–313 (2013).
6. Shannon, G. *et al.* A synthesis of two decades of research documenting the effects of noise on wildlife. *Biol. Rev.* (in press).
7. McLaughlin, K. E. & Kunc, H. P. Experimentally increased noise levels change spatial and singing behaviour. *Biol. Let*. **9,** 20120771 (2013).
8. Luo, J., Siemers, B. M. & Koselj, K. How anthropogenic noise affects foraging. *Glob. Change. Biol*. **29,** 3278–3289 (2015).
9. Purser, J. & Radford, A. N. Acoustic noise induces attention shifts and reduces foraging performance in three-spined sticklebacks (*Gasterosteus aculeatus*). *PLoS One*. **6,** e17478 (2011).
10. Wale, M. A., Simpson, S. D. & Radford, A. N. Noise negatively affects foraging and antipredator behaviour in shore crabs. *Anim Behav*. **86,** 111–118 (2013).
11. Siemers, B. M. & Schaub, A. Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. *Proc. R. Soc. B* **278,** 1646–1652 (2011).
12. Schaub, A., Ostwald, J. & Siemers, B. M. Foraging bats avoid noise. *J. Exp. Biol*. **211,** 3174–3180 (2008).
13. Estes, J. A. *et al.* Trophic downgrading of planet earth. *Science*. **333,** 301–306 (2011).
14. Mason, J. T., McClure, C. J. W. & Baber, J. Anthropogenic noise impairs owl hunting behavior. *Biol. Conserv.* **199,** 29–32 (2016).
15. Sun, J. W. & Narins, P. M. Anthropogenic sounds differentially affect amphibian call rate. *Biol. Conserv.* **121,** 419–427 (2005).
16. Lengagne, T. Traffic noise affects communication behavior in a breeding anuran, Hyla arborea. *Biol. Conserv*. **141,** 2023–2031 (2008).
17. Blickley, J. L., Blackwood, D. & Patricelli, G. L. Experimental evidence for the effects of chronic anthropogenic noise on abundance of greater sage-grouse at leks. *Conserv. Biol.* **26,** 461–471 (2012).
18. Konishi, M. How the owl tracks its prey. *Ame. Sci.* **61,** 414–424 (1973).
19. McClure, C. J., Ware, H. E., Carlisle, J., Kaltenecker, G. & Barber, J. R. An experimental investigation into the effects of traffic noise on distributions of birds: avoiding the phantom road. *Proc. R. Soc. B* **280,** 2013–2290 (2013).
20. Ware, H. E., McClure, C. J., Carlisle, J. D. & Barber, J. R. A phantom road experiment reveals traffic noise is an invisible source of habitat degradation. *Proc. Natl. Acad. Sci*. **112,** 12105–12109 (2015).
21. Ritters, K. H. & Wickham, J. D. How far to the nearest road? *Front. Ecol. Environ.* **1,** 125–129 (2003).
22. Laurance, W. F. *et al.* A global strategy for road building. *Nature.* **513,** 229–232 (2014).
23. Francis, C. D., Kleist, N. J., Ortega, C. P. & Cruz, A. Noise pollution alters ecological services: enhanced pollination and disrupted seed dispersal. *Proc. R. Soc. B* **279,** 2727–2735 (2012).
24. Fahrig, L. & Rytwinski, T. Effects of roads on animal abundance: an empirical review and synthesis. *Ecol. Soc.* **14,** 21 (2009).
25. Francis, C. D., Kleist, N. J., Davidson, B. J., Ortega, C. P. & Cruz, A. Behavioral responses by two songbirds to natural-gas-well compressor noise. *Ornithol. Monogr*. **74,** 36–46 (2012).
26. Bates, D., Maechler, M., Bolker, B. & Walker, S. *lme4: Linear mixed-effects models using Eigen and S4, version 1.0–4.* R Foundation for Statistical Computing, Vienna, Austria. Available at: https://cran.r-project.org/web/packages/lme4/index.html. (Accessed: 15th September 2015) (2013).
27. Barton, K. *MuMIn: Multi-model inference. R package version 1.0. 0.*, R Foundation for Statistical Computing, Vienna, Austria. Available at: https://cran.r-project.org/web/packages/MuMIn/index.html. (Accessed: 15th September 2015) (2011).
28. R. Core Team. *R: A language and environment for statistical computing*, R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.R-project.org/ (Accessed: 15th September 2015) (2013).

Acknowledgements

Research was supported by JSPS KAKENHI grant number 14J05368.

Author Contributions

M.S. designed the study, carried out the field experiments and drafted the manuscript. Y.Y. participated in the design of the study and helped draft the manuscript. C.D.F. and F.N. helped draft the manuscript. All authors gave final approval for publication.

Additional Information

Supplementary information accompanies this paper at http://www.nature.com/srep

Competing financial interests: The authors declare no competing financial interests.

How to cite this article: Senzaki, M. *et al.* Traffic noise reduces foraging efficiency in wild owls. *Sci. Rep.* **6**, 30602; doi: 10.1038/srep30602 (2016).

Exhibit 4

Declaration of Douglas J. Tempel

I, Douglas J. Tempel, declare as follows:

1. I am a wildlife ecologist and a resident of Tucson, Arizona.

2. My academic training includes a Bachelor of Science degree in chemical engineering from the University of Notre Dame in 1987, a Master's of Science degree in wildlife conservation from the University of Minnesota in 2002, and a Ph.D. in natural resources science and management (wildlife ecology and management track) from the University of Minnesota in 2014.

3. I have nearly 30 years of diverse work experience in natural resource fields including wildlife ecology, wilderness management, and fire ecology.

4. Importantly, I have participated in scientific research on California spotted owls for more than 20 years. Spotted owls were the subject of both my Master's thesis and Ph.D. dissertation. As part of my Master's thesis, I studied the effects of chainsaw noise on spotted owl behavior and stress hormone levels, which is directly relevant to the subject of this declaration. While completing my dissertation on spotted owl population ecology, I served for 7 years as the Project Leader for a long-term population study in California's Sierra Nevada. In subsequent years, I continued to study spotted owls as a research associate at the University of Wisconsin with a primary focus on how wildfires affect spotted owl populations. I have published 16 peer-reviewed journal articles related to spotted owl population dynamics, habitat use, and physiology. Finally, I served as a member on a U.S. Forest Service conservation assessment team for the California spotted

owl during 2015-16 in which we summarized the current state of knowledge about the owl and made management recommendations for owl conservation.

5. A copy of my curriculum vitae is attached to this declaration.

6. As a result of my training and experiences, I have extensive knowledge of the biology, management, and conservation of spotted owl populations.

7. I have reviewed documents describing and analyzing the proposed Sunnyside Exploration Drilling Project and Flux Canyon Exploration Drilling Project in the Patagonia Mountains region of the Coronado National Forest. Specifically, I have reviewed the following: (1) Biological Assessment for Sunnyside Exploration Drilling Project, prepared by Logan Simpson (August 2020); (2) U.S. Fish and Wildlife Service Biological Opinion for the Sunnyside Exploration Drilling Project (December 1, 2022); (3) U.S. Forest Service Environmental Assessment for the Sunnyside Exploration Drilling Project (January 2023); (4) U.S. Forest Service Decision Notice and Finding of No Significant Impact for the Sunnyside Exploration Drilling Project (June 16, 2023); (5) Biological Assessment for Flux Canyon Exploration Drilling Project (May 10, 2022); (6) U.S. Fish and Wildlife Service Letter concerning Proposed Flux Canyon Exploration Drilling Project (September 23, 2022); and (7) U.S. Forest Service Decision Memo for Flux Canyon Exploration Drilling Project (May 30, 2023). I reviewed these documents for the specific purpose of assessing these Projects' likely impact on Mexican spotted owls.

8. Implementation of the Sunnyside Exploration Drilling Project threatens a significant impact to affected Mexican spotted owls due to chronic noise effects from

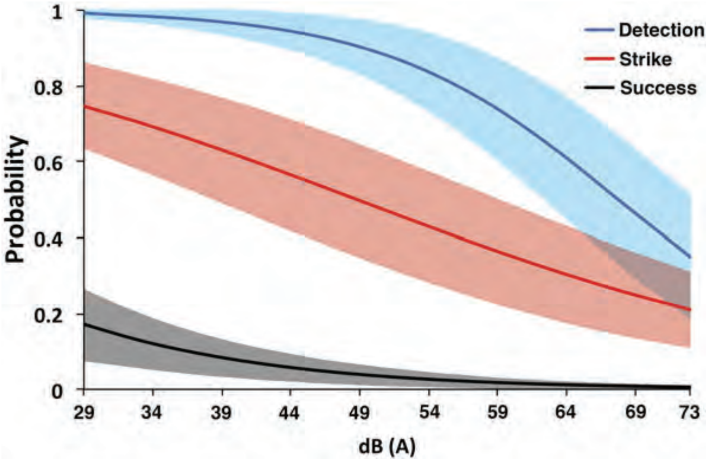
Project activities. Portions of five Mexican spotted owl protected activity centers (PACs) occur within the action area for this proposed Project. Surveying history indicates long-term Mexican spotted owl occupancy with frequent nesting at one of these PACs (#03-020), with repeated observations at another PAC (#03-025) as well. This survey history indicates that at least PAC #03-020 is likely a very important PAC for this species in the Patagonia Mountains area.

9. Project activities are proposed to occur primarily within and adjacent to PACs #03-020 and #03-025, along with PAC #03-024. During drilling operations, up to two drill rigs will be active at any one time and they will be operated 24 hours per day for seven days a week for up to seven years, followed by a reclamation period of at least five additional years. It is anticipated that drilling activities and other proposed activities in the project area, such as road construction and reclamation, will produce elevated levels of noise that are likely to affect the behavior and activities of Mexican spotted owls in the affected area. Planned mitigation measures include a prohibition on drilling activities within the "core area" of a Mexican spotted owl PAC from March 1 through August 31 unless it has been determined through surveys that the PAC is unoccupied or the owls are not nesting, and requirements for lighting to be pointed downward and all internal combustion engines to be fitted with a properly operating muffler.

10. The chronic noise impacts caused by this proposed round-the-clock Project activity are likely to significantly impair the affected Mexican spotted owls' ability to successfully forage for their prey species. These owls rely on hearing to hunt at night and have highly sensitive, directional hearing that enables them to locate their prey. Chronic

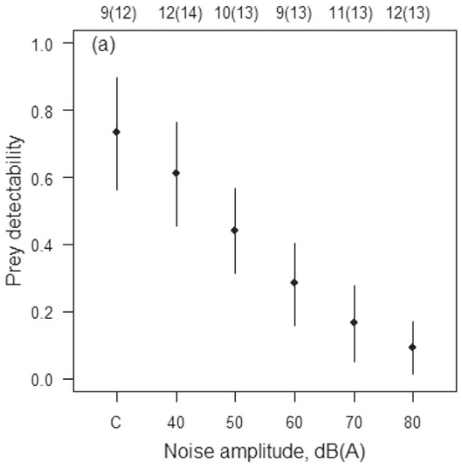
noise disturbance in proximity to their roosting and nesting sites threatens to mask the sounds that owls rely upon to successfully hunt. This would reduce the owls' hunting success and thereby impair their ability to obtain sufficient food to sustain themselves within the affected habitat. There would be no break in the Project's interference with the owls' foraging ability given Project plans for round-the-clock drilling.

11. In fact, two papers published in reliable scientific journals indicate that owls' ability to hunt successfully becomes significantly impaired due to interference from chronic noise at levels well below the noise impacts associated with the proposed Sunnyside Project. One paper—Mason, et al., Anthropogenic noise impairs owl hunting behavior, *Biological Conservation* 199 (2016) 29-32—determined that members of a different owl species, the Northern saw-whet owl, suffered decreased ability to detect and successfully capture a mouse only 2.5 meters away when exposed to chronic noise levels of about 50 dB(A), and these owls were unable to capture any mice at all when exposed to chronic noise levels above 61 dB(A). The second paper—Senzaki, et al., Traffic noise reduces foraging efficiency in wild owls, *Scientific Reports* 6, 3002; doi: 10.1038/srep30602 (2016)—determined that members of two other owl species, long-eared owls and short-eared owls, suffered a reduced ability to detect their prey even at 40 dB(A) of persistent traffic noise, with increasing impacts as noise levels amplified up to 80 dB(A), where prey detectability was near zero. These scientific research results are depicted in the following two figures from these two papers:



The probability of an owl detecting, striking, and successfully capturing a mouse by sound level (dBA). The control averaged 29 dB(A); the loudest playback file was presented at 73 dB(A). Curves are plotted from the AIC-best model for each component of the attack sequence. Shading represents standard errors.

Source: Mason, et al. (2016), page 31, Figure 2.



Estimated owls’ ability to detect prey under noise exposure levels (with 95% CI). “C” indicates control experiments. Detectability at C is estimated using average background sound level (32 dB). Top figures indicate number of experiments (number of owls analyzed).

Source: Senzaki, et al. (2016), page 3, Figure 3(a).

12. These findings are likely to be representative of chronic noise impacts on Mexican spotted owls because, like the owl species involved in the cited papers, Mexican spotted owls rely heavily upon auditory cues when hunting. These findings therefore indicate that chronic noise impacts from the proposed Sunnyside Project would seriously compromise the affected spotted owls' ability to hunt in the Project area and surrounding vicinity. In fact, the noise attenuation projections for the Sunnyside Project that were utilized in the Biological Assessment for this Project (Table 5-1) indicate that, even up to 1,600 feet from drilling and construction equipment, noise from the Project is expected to exceed the 61 dB(A) threshold that was associated with no owl hunting success in Mason, et al. (2016). These attenuation projections further indicate that Project noise is expected to reach Senzaki, et al. (2016)'s documented threshold for impacts on owls' ability to detect prey—40 dB(A)—as far as 12,800 feet (more than two miles) from the noise source.

13. Because of the likelihood that the Sunnyside Project's chronic noise impacts will extensively interfere with the affected Mexican spotted owls' ability to forage throughout a large area surrounding the proposed drilling and construction activity, there is also a high likelihood that the affected owls will permanently abandon territories in the impacted area for at least the full duration of proposed drilling activities (i.e., up to seven years), and potentially longer depending on the extent of disturbance associated with subsequent reclamation activities. Successful foraging is essential for the resident owls to feed themselves. The PACs where owls have recently been documented in the Project area would appear to provide productive habitat based on long-term owl

occupancy, indicating sufficient prey populations to enable successful owl foraging. However, the chronic noise impacts that would be caused by the Sunnyside Project threaten to convert this currently productive habitat into unproductive habitat by interfering with the owls' ability to successfully locate their prey in this area. Simply put, if the owls cannot successfully hunt in the affected area, they will have to go elsewhere.

14. The Forest Service's analysis of the Sunnyside Project does not dispel these threats. The Forest Service determined that the Sunnyside Project would cause no significant impact to Mexican spotted owls by relying on the determinations contained in the U.S. Fish and Wildlife Service Biological Opinion dated December 1, 2022 (Forest Service Decision Notice at 19-20). The Biological Opinion (at page 35) determined that "[n]oise levels in the project vicinity are expected to attenuate below the threshold level for injury of owls (92 dBA per Delaney *et al.* 1999) at approximately 100 feet from any drill area or area of heavy equipment use." The Biological Opinion (at page 40) further determined that owls "experiencing short-term harm" from the proposed Project "may fail to successfully rear young or may depart in one or more breeding seasons, but will not likely permanently desert the area because of the disturbance (Delaney *et al.* 1999)."

15. This analysis does not dispel the threat posed by the Sunnyside Project's chronic noise impacts because the threshold noise level that the Biological Opinion used to identify injury to owls—92 dB(A)—is well above the thresholds at which both Mason, et al. (2016) and Senzaki, et al. (2016) documented that chronic noise caused complete or near-complete preclusion of successful hunting by owls. Further, the Biological Opinion's repeated citations to Delaney, et al. (1999) do not support its conclusions.

These citations refers to a paper—Delaney, et al., Effects of Helicopter Noise on Mexican Spotted Owls, *Journal of Wildlife Management* 63(1):60-76 (1999)—that documented specific responses by Mexican spotted owls to less than 10 minutes of helicopter disturbance and 5 minutes of chain saw disturbance per day. Comparing these relatively short, time-limited disturbances to the chronic round-the-clock noise impacts of the proposed Sunnyside Project is like comparing apples to oranges. In fact, Delaney, et al. (1999) cautioned against using their findings to infer how spotted owls would respond to more frequent disturbances. As for the 92 dB(A) injury threshold that the Biological Opinion attributed to Delaney, et al. (1999), that paper identified the 92 dB(A) sound level as a threshold only for the studied owls' response of flushing from a roost when exposed to helicopter disturbance. It did not purport to identify that noise level as a threshold for any other type of injury to owls, and specifically did not attempt to assess or identify a threshold for the impacts of chronic noise on owl foraging success. Further, although the Biological Opinion again cited Delaney, et al. (1999) to support its determination that owls might seasonally depart the Sunnyside Project area but were not likely to permanently desert the area, the Delaney, et al. (1999) paper did not examine any questions about owl desertion of territories in response to noise disturbance.

16. The Forest Service also determined (at page 33 of the Environmental Assessment) that the Sunnyside Project might cause temporary avoidance of habitats by owls, but "it is more likely that owls would shift their activities within their existing home ranges to avoid areas with increased human activities." This supposition also does not dispel the threat posed to Mexican spotted owls by the Sunnyside Project because it

does not acknowledge the potential for cumulative disturbance effects. It appears that the Sunnyside Project would operate simultaneously with other development activities that are ongoing or proposed in nearby areas, including the Flux Canyon Exploratory Drilling Project, which also involves round-the-clock drilling with associated chronic noise. The ability of owls affected by the Sunnyside Project to move elsewhere will be constrained by disturbance from these other projects. Moreover, a critical feature of a suitable territory for spotted owls is the presence of appropriate roosting and nesting habitat. Even if owls affected by the Sunnyside Project were able to successfully forage in areas that are distant from that Project, there is no indication that they could find suitable roosting habitat if they had to abandon the PACs that will be disturbed by that Project. In fact, the owls' long-term occupancy of some of the PACs that will be disturbed by the Sunnyside Project likely indicates that suitable nesting and roosting habitat is in limited supply in surrounding areas. If alternative such habitats were readily available, it is likely that owls would already be occupying them. For all these reasons, the threat that affected owls would permanently abandon currently occupied territories in the Sunnyside Project area is not dispelled by speculation that they could shift their activities elsewhere.

17. Finally, for many of the same reasons already discussed, the mitigation measures relied upon in the Environmental Assessment (at page 34) and Biological Opinion (at page 38) will not reduce the impact that the Sunnyside Project's chronic noise would have on the owls' foraging ability. These mitigation measures appear largely to be focused on reducing disturbances that might cause a roosting owl to flush. However, as discussed, the primary impact of the Sunnyside Project on Mexican spotted

owls will be chronic noise that interferes with the owls' ability to forage within their territory. The mitigation measures discussed in the Environmental Assessment and Biological Opinion do not meaningfully mitigate that impact. For instance, even if mitigation measures were taken to prohibit drilling and other activities within the "core area" of a PAC during the owls' breeding season, chronic noise from Project activities would continue to interfere with the owls' ability to procure food during the remainder of the year, at least. Their reduced ability to hunt prey at all times of the year may cause them to permanently abandon their territories in the impacted area for at least the full duration of proposed drilling activities.

Pursuant to 28 U.S.C. § 1746, I declare under penalty of perjury that the foregoing is true and correct.

Executed on June 26, 2023 in Nevada City, California.

Douglas Tempel

Douglas J. Tempel

Douglas J. Tempel Declaration
Exhibit 1

Douglas J. Tempel

Current Position

Research Technician, University of Wisconsin-Madison

Contact Information

455 West Kelso Street
Apt. 129
Tucson, AZ 85705

E-mail: djtempel1965@gmail.com
Telephone (mobile): 608-658-4599

Education

Ph.D.: January 2014, University of Minnesota, Saint Paul, MN
Major: Natural Resources Science and Management (Wildlife Ecology and Management track)
Thesis Title: California Spotted Owl Population Dynamics in the Central Sierra Nevada: an Assessment Using Multiple Types of Data
Major Advisor: Dr. R. J. Gutiérrez
Other Committee Members: Dr. David Andersen, Dr. Alan Franklin, Dr. James Nichols
GPA: 4.00

M.S.: November 2002, University of Minnesota, Saint Paul, MN
Major: Wildlife Conservation
Thesis Title: Fecal Corticosterone Levels in a California Spotted Owl Population: Implications for Assessing Chronic Stress
Major Advisor: Dr. R. J. Gutiérrez
Other Committee Members: Dr. David Andersen, Dr. Patrick Redig
GPA: 4.00

B.S.: May 1987, University of Notre Dame, Notre Dame, IN
Major: Chemical Engineering
GPA: 3.41

Additional Coursework: 2004-05, Cal Polytechnic, San Luis Obispo, CA
Subjects: General Botany, Vascular Plant Taxonomy.
GPA: 4.00

Additional Coursework: 1998-99, Utah State University, Logan, UT
Subjects: General Biology, General Ecology, Introduction to Genetics, Biometry, Wildlife Behavior, Conservation Genetics, Ecosystem Concepts and Management, Predator Ecology and Management.
GPA: 4.00

Work History and Field Experience

Research Technician, University of Wisconsin, Madison, WI
April 2023-present
40 hours/week
$22/hour
Supervisor: William Berigan, 775-686-9735, wberigan@wisc.edu
Conducting field research to determine California spotted owl (*Strix occidentalis occidentalis*) occupancy and habitat use in territories that will be impacted by fuel-reduction treatments within the next several years. Duties include surveying owl territories; capturing and GPS-tagging owls; assessing owl reproduction following a mousing protocol; clearing roads of fallen trees and brush; operating 4-wheel-drive trucks on rugged roads.

Associate Researcher, University of Wisconsin, Madison, WI
July 2020-June 2021
40 hours/week
$60,000/year
Supervisor: Dr. M. Zachariah Peery, 608-890-2766, mpeery@wisc.edu
Conducted research and data analyses to estimate the effects of habitat, timber harvest, climate, and wildfire on California spotted owl (*Strix occidentalis occidentalis*) occupancy and reproduction dynamics in southern California. Duties included collaboration with other researchers and U.S. Forest Service personnel; use of software including MARK, PRESENCE, R, SAS, ArcMap 10, Microsoft Office 2010, and EndNote.

Contract Researcher
January 2017-April 2018 (3 months total during this period)
40 hours/week
$5,000/month
Performed contract work with the University of Wisconsin. Duties including data analyses and writing of annual reports to the funding agency (U.S. Forest Service) for the Eldorado Spotted Owl Demography Study; collaboration on peer-reviewed manuscripts; use of software including MARK, SAS, and Microsoft Office.

Post-doctoral Research Associate, University of Wisconsin, Madison, WI
April 2013-April 2016
40 hours/week
$54,000/year
Supervisor: Dr. M. Zachariah Peery, 608-890-2766, mpeery@wisc.edu
Conducted research and data analyses to estimate the effects of habitat, timber harvest, climate, and wildfire on California spotted owl population dynamics. Duties included participation on an interdisciplinary Science Team for the Sierra Nevada Adaptive Management Project that assessed the impacts of forest fuel treatments on Sierra Nevada ecosystems; presentation of research results to agency personnel and stakeholders at public meetings within a collaborative adaptive management framework;); use of software including MARK, PRESENCE, R *marked*, WinBUGS, SAS, ArcMap 10, Microsoft Office 2010, and EndNote. Served as member of U.S. Forest Service conservation assessment team for the California spotted owl.

Project Leader (Eldorado Spotted Owl Demography Study and the Sierra Nevada Adaptive Management Project), University of Minnesota, Saint Paul, MN
November 2006-April 2013

$44,000/year
40 hours/week including nighttime fieldwork
Supervisor and advisor: Dr. R. J. Gutiérrez, 612-916-1987, gutie012@umn.edu
Conducted research to estimate long-term demographic parameters for a California spotted owl population on the Eldorado and Tahoe National Forests, to assess the influence of habitat, forest disturbance, and other variables on owl demography, and participation on an interdisciplinary Science Team for the Sierra Nevada Adaptive Management Project. Duties included data analyses and writing of annual reports to the funding agency (U.S. Forest Service); supervising and managing two Assistant Project Leaders and a field crew; assessing owl survival by resighting, capturing, and banding owls; assessing owl reproduction following a mousing protocol; collecting vegetation data on forest structure; clearing roads of fallen trees and brush; operating 4-wheel-drive trucks on rugged roads; using global positioning system units (GPS; Garmin XL12, Garmin 60CSx); using software including MARK, PRESENCE, WinBUGS, SAS, ArcMap 10, Microsoft Office 2007, and EndNote.

Project Manager, BioResources Consultants, Big Bear Lake, CA
March 2005-November 2006
40 hours/week including nighttime fieldwork
$28/hour
Supervisor: Richard Tanner, 805-636-1806, Richard@tannerenvironmental.com
Conducted presence/absence and reproductive surveys for California spotted owls on the San Bernadino, Cleveland, and Angeles National Forests. Duties include supervising field technicians; assessing owl reproduction following a mousing protocol; clearing roads of fallen trees and brush; operating 4-wheel-drive trucks on rugged roads; using global positioning system units (GPS; Garmin XL12). Worked 45 hours/week, variable schedule but mostly nighttime work.

Project Manager, UC-Berkeley Cooperative Extension, Integrated Hardwood Range Management Program, San Luis Obispo, CA
October 2003-March 2005
40 hours/week
$27,000/year
Supervisor: Dr. William Tietje, 805-781-5938, tietje@berkeley.edu
Conducted research on small vertebrates (mammals, herpetofauna) in coast live oak (*Quercus agrifolia*) woodlands, with an emphasis on oak woodlands at risk to Sudden Oak Death infection. Duties included live-trapping and ear-marking of small mammals; performing coverboard surveys for herpetofauna; collecting vegetation data on habitat structure; using software including CAPTURE, SAS, Microsoft 2003, and ArcView 3.2.

Ecology Specialist, U.S. Forest Service, Aldo Leopold Research Institute, Missoula, MT
September 2002-October 2003
40 hours/week
$22,000/year
Supervisor: Vita Wright, 406-758-3547, vwright@fs.fed.us
Worked within the Research Application Program to make wilderness research results readily available to managers, policymakers, and other interested parties. Duties included writing an annotated bibliography on backcountry recreation impacts to wildlife; writing a summary report on non-native species present within U.S. Fish and Wildlife Service wilderness areas; writing a non-native species research agenda for the Institute; compiling a database of fire research conducted in wilderness areas.

Research Assistant, University of Minnesota, Saint Paul, MN
April 2000-September 2002
40 hours/week including nighttime fieldwork
$14,000/year
Supervisor and advisor: Dr. R. J. Gutiérrez, 612-916-1987, gutie012@umn.edu
Worked on a research project to estimate long-term demographic parameters for a California spotted owl population on the Eldorado and Tahoe National Forests Duties include completing a research project on owl fecal corticosterone levels for my M.S. degree; supervising two field technicians; assessing owl survival by resighting, capturing, and banding owls; assessing owl reproduction following a mousing protocol; collecting vegetation data on forest structure; clearing roads of fallen trees and brush; operating 4-wheel-drive trucks on rugged roads; using global positioning system units (GPS; Garmin XL12); using software including ArcView 3.2, SAS, Microsoft Office 2003, WordPerfect, and Reference Manager.

Research Technician, Utah State University, Logan, UT
May 1999-September 1999
40 hours/week
$13/hour
Supervisor: Dr. Mark Ritchie, 315-443-2479, meritchi@syr.edu
Worked on ecological research projects conducted at Cedar Creek Natural History Area, a Long-Term Ecological Research site near Bethel, MN. Duties included maintenance of experimental vegetation plots; collecting data from the experimental plots on photosynthetic rates, plant growth and biomass, and insect herbivory; conducting insect surveys using net sweeps; trapping for small mammals; conducting an independent research project on the effects of ant mounds on soil nitrogen, soil moisture, and plant diversity.

Life Skills Instructor, Northeastern Services, Logan, UT
November 1997-April 1999
20 hours/week
$10/hour
Worked for a non-profit company that assisted mentally disabled adults with integration into the community. Duties included teaching mentally disabled adults basic living and social skills (e.g., shopping for food and cooking, appropriate interactions with other people); assisting them with identification and achievement of personal goals (e.g., saving money, participating in recreational activities).

Wilderness Ranger, U.S. Forest Service, Roosevelt, UT
May 1995-October 1997 (summers only)
40 hours/week
$20/hour
Worked in the High Uintas Wilderness on the Ashley National Forest in northeastern Utah. Duties included enforcement of Forest Service wilderness regulations; educating wilderness users about minimum impact camping techniques, wilderness ethics, and natural history; maintenance of hiking trails; using horses and llamas as pack animals; performance of fire-fighting duties on two wildfires.

Biological Technician, U.S. Fish and Wildlife Service, Yuma, AZ
October 1995-April 1996
40 hours/week

$15/day
Worked on the Kofa National Wildlife Refuge in southwestern Arizona as a volunteer (received a daily stipend). Duties included conducting surveys on foot for desert bighorn sheep (*Ovis canadensis nelsoni*); performing breeding bird surveys within designated quadrats; collecting field locations for radiomarked desert tortoises (*Gopherus agassizii*) using global positioning system units.

Production Supervisor/Process Engineer, Elf Atochem North America, Carrollton, KY
March 1991-April 1994
40 hours/week
$44,000/year
Managed two production areas at a major chemical manufacturing plant. Duties included the supervision and training of hourly employees; completing annual evaluations for employees; ensuring that conditions in the production areas complied with OSHA and EPA regulations; improving the manufacturing process through technical and procedural changes.

Production Foreman, American Cyanamid Company, Kalamazoo, MI
October 1988-March 1991
40 hours/week
$35,000/year
Supervised hourly employees in three production areas at a major chemical plant. Duties included the supervision of employees; ensuring that conditions in the production areas complied with OSHA and EPA regulations; troubleshooting equipment and process malfunctions; scheduling and coordination of routine and emergency maintenance of process equipment.

Production Foreman, American Cyanamid Company, Wallingford, CT
July 1987-October 1988
40 hours/week
$32,000/year
Supervised hourly employees in two production areas at a major chemical plant. Duties included the supervision of employees; ensuring that conditions in the production areas complied with OSHA and EPA regulations; troubleshooting equipment and process malfunctions; scheduling and coordination of routine and emergency maintenance of process equipment.

References

Dr. R. J. Gutiérrez, Professor and Gordon Gullion Endowed Chair
Department of Fisheries, Wildlife, and Conservation Biology
University of Minnesota
Mailing address: 539 Old Roundhouse Rd., McKinleyville, CA, 95519
Email: gutie012@umn.edu
Phone: 612-916-1987

Dr. M. Zachariah Peery, Associate Professor
Department of Forest and Wildlife Ecology
University of Wisconsin-Madison
Mailing address: 1630 Linden Drive, University of Wisconsin-Madison, Madison, WI 53706
Email: mpeery@wisc.edu
Phone: 831-706-5059

Dr. James D. Nichols, Wildlife Biologist/Senior Scientist
Patuxent Wildlife Research Center
U.S. Geological Survey
Mailing address: 12100 Beech Forest Rd., Laurel, MD 20708
Email: jnichols@usgs.gov
Phone: 301-497-5660

Peer-Reviewed Publications

Tempel, D.J., H.A. Kramer, G.M. Jones, R.J. Gutiérrez, S.C. Sawyer, A. Koltunov, M. Slaton, R. Tanner, B.K. Hobart, and M.Z. Peery. 2022. Population decline in California spotted owls near their southern range boundary. Journal of Wildlife Management 86:e22168.

Jones, G.M., H.A. Kramer, S.A. Whitmore, W.J. Berigan, **D.J. Tempel**, C.M. Wood, B.K. Hobart, T. Erker, F.A. Atuo, N.F. Pietrunti, R. Kelsey, R.J. Gutiérrez, and M.Z. Peery. 2020. Habitat selection by spotted owls after a megafire reflects their adaptation to historical frequent-fire regimes. Landscape Ecology 35:1199-1213.

Fountain, E.D., J.K. Kang, **D.J. Tempel**, P.J. Palsbøll, J.N. Pauli, and M.Z. Peery. 2018. Genomics meets applied ecology: characterizing habitat quality for sloths in a tropical agroecosystem. Molecular Ecology 27:41-53.

Tempel, D.J., J.J. Keane, R.J. Gutiérrez, J.D. Wolfe, G.M. Jones, A. Koltunov, C.M. Ramirez, W.J. Berigan, C.V. Gallagher, T.E. Munton, P.A. Shaklee, S.A. Whitmore, and M.Z. Peery. 2016. Meta-analysis of California spotted owl (*Strix occidentalis occidentalis*) territory occupancy in the Sierra Nevada: habitat associations and their implications for forest management. Condor: Ornithological Applications 118:747-765.

Jones, G.M., R.J. Gutiérrez, **D.J. Tempel,** S.A. Whitmore, W.J. Berigan, and M.Z. Peery. 2016. Megafires: an emerging threat to old-forest species. Frontiers in Ecology and the Environment 14:300-306.

Jones, G.M., R.J. Gutiérrez, **D.J. Tempel,** B. Zuckerberg, and M.Z. Peery. 2016. Using dynamic occupancy models to inform climate change adaptation strategies for California Spotted Owls. Journal of Applied Ecology 53:895-905.

Tempel, D.J., R.J. Gutiérrez, J.J. Battles, D.L. Fry, Y. Su, Q. Guo, M.J. Reetz, S.A. Whitmore, G.M. Jones, B.M. Collins, S.L. Stephens, M. Kelly, W.J. Berigan, and M.Z. Peery. 2015. Evaluating short- and long-term impacts of fuels treatments and simulated wildfire on an old-forest species. Ecosphere 6:Article 261.

Tempel, D. J., R. J. Gutiérrez, S. A. Whitmore, M. J. Reetz, R. E. Stoelting, W. J. Berigan, M. E. Seamans, and M. Z. Peery. 2014. Effects of forest management on California spotted owls: implications for reducing wildfire risk in fire-prone forests. Ecological Applications 24:2089-2106.

Tempel, D. J., M. Z. Peery, and R. J. Gutiérrez. 2014. Using integrated population models to improve conservation monitoring: California spotted owls as a case study. Ecological Modelling 289:86-95.

Tempel, D. J., and R. J. Gutiérrez. 2013. Relation between occupancy and abundance for a territorial species, the California spotted owl. Conservation Biology 27(5): 1087-1095.

Berigan, W. J., R. J. Gutiérrez, and **D. J. Tempel**. 2012. Evaluating the efficacy of protected habitat areas for the California spotted owl using long-term monitoring data. Journal of Forestry 110(6): 299-303.

Popescu, V. D., P. de Valpine, **D. Tempel**, and M. Z. Peery. 2012. Estimating population impacts via dynamic occupancy analysis of Before–After Control–Impact studies. Ecological Applications 22(4): 1389-1404.

García-Feced, C., **D. J. Tempel**, and M. Kelly. 2011. LiDAR as a tool to characterize wildlife habitat: California spotted owl nesting habitat as an example. Journal of Forestry 108(8): 436-443.

Phillips, C.E., **D. J. Tempel**, and R. J. Gutiérrez. 2010. Do California spotted owls select nest trees close to forest edges? Journal of Raptor Research 44(4): 311-314.

Tempel, D. J., A. B. Cilimburg, and V. Wright. 2004. The status and management of exotic and invasive species in National Wildlife Refuge wilderness areas. Natural Areas Journal 24(4): 300-306.

Tempel, D. J., and R. J. Gutiérrez. 2004. Factors related to fecal corticosterone levels in California spotted owls: implications for assessing chronic stress. Conservation Biology 18(2): 538-547.

Washburn, B. E., **D. J. Tempel**, J. J. Millspaugh, R. J. Gutiérrez, and M. E. Seamans. 2004. Factors related to fecal estrogens and fecal testosterone in California spotted owls. Condor 106(3): 567-579.

Tempel, D. J., and R. J. Gutiérrez. 2003. Fecal corticosterone levels in California spotted owls exposed to low-intensity chainsaw sound. Wildlife Society Bulletin 31(3): 698-702.

Non-Peer-Reviewed Publications

Tempel, D., V. Wright, J. Neilson, and T. Mildenstein. 2008. Linking wilderness research and management—volume 5. Understanding and managing backcountry recreation impacts on terrestrial wildlife: an annotated reading list. (Wright, Vita, series ed.) Gen. Tech. Rep. RMRS-GTR-79-Vol 5. U.S. Forest Service, Rocky Mountain Research Station, Fort Collins, CO. 70 p.

Tempel, D. J., and R. J. Gutiérrez. 2008. Fecal corticosterone levels in spotted owls: implications for management. Research summary, U.S. Forest Service, Pacific Southwest Research Station, Albany, CA. 2 p.

Tempel, D. J., and W. D. Tietje. 2006. Potential effects of sudden oak death on small mammals and herpetofauna in coast live oak (*Quercus agrifolia*) woodlands. Pages 233-236 in "Proceedings of the sudden oak death second science symposium: the state of our knowledge." PSW-GTR-196, U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Tempel, D. J., W. D. Tietje, and D. E. Winslow. 2006. Vegetation and small vertebrates of oak woodlands at low and high risk for sudden oak death in San Luis Obispo County, California. Pages 211-232 in "Proceedings of the sudden oak death second science symposium: the state of our knowledge." PSW-GTR-196, U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Presentations

D. J. Tempel, R. J. Gutiérrez, and M. Z. Peery. Forest Fuel Reduction, Spotted Owls, and Adaptive Management: Where Are We? Oral presentation at The Ecological Society of America Annual Meeting, Sacramento, CA. August 13, 2014.

D. J. Tempel, R. J. Gutiérrez, and M. Z. Peery. Research Update from the California Spotted Owl Science Team. Oral presentation at the Spotted Owl Integration Team Meeting, Sierra Nevada Adaptive Management Project, Davis, CA. June 20, 2014.

Tempel, D. J. California Spotted Owl (*Strix occidentalis occidentalis*) Population Dynamics in the Central Sierra Nevada. Oral presentation of thesis research to the Department of Fisheries, Wildlife, and Conservation Biology, Saint Paul, MN, September 2014.

D. J. Tempel, R. J. Gutiérrez, and M. Z. Peery. Research Update from the California Spotted Owl Science Team. Oral presentation at the Spotted Owl Integration Team Meeting, Sierra Nevada Adaptive Management Project, Sacramento, CA. August 23, 2012.

D. J. Tempel, and R. J. Gutiérrez. Site Occupancy Dynamics of a California Spotted Owl (*Strix occidentalis occidentalis*) Population in the Central Sierra Nevada. Oral presentation at the Raptor Research Foundation Annual Conference, Duluth, MN. October 8, 2011.

D. J. Tempel, R. J. Gutiérrez, M. Z. Peery, S. Whitmore, and V. Berigan. California Spotted Owl Research on the Eldorado Study Area. Oral presentation at the U.S. Forest Service Spotted Owl Workshop, Sacramento, CA. February 24, 2011.

D. J. Tempel, R. J. Gutiérrez, M. Z. Peery, S. Whitmore, and V. Berigan. Annual Update from the California Spotted Owl Science Team. Oral presentation at the Sierra Nevada Adaptive Management Project Annual Meeting, Sacramento, CA. October 21, 2010.

D. J. Tempel, R. J. Gutiérrez, S. Whitmore, and V. Berigan. Annual Update from the California Spotted Owl Science Team. Oral presentation at the Sierra Nevada Adaptive Management Project Annual Meeting, Sacramento, CA. November 5, 2008.

Seamans, M. E., W. J. Berigan, S. A. Whitmore, **D. J. Tempel**, R. J. Gutiérrez, and A. H. Chatfield. Ecology of the California Spotted Owl (*Strix occidentalis occidentalis*) in the Central Sierra Nevada. Poster presentation at the Blodgett Forest Research Workshop, Georgetown, CA, February 8, 2008.

Tempel, D. J., and W. D. Tietje. The Potential Effects of Sudden Oak Death on Small Vertebrates in Coast Live Oak Woodlands of San Luis Obispo County. Oral presentation at the Sudden Oak Death Second Science Symposium, Monterey, CA, January 20, 2005.

Tietje, W. D., D. E. Winslow, and **D. J. Tempel**. The Effects of Sudden Oak Death on Wildlife—Can Anything Be Learned from the American Chestnut Blight? Poster presentation at the Sudden Oak Death Second Science Symposium, Monterey, CA, January 20, 2005.

Tempel, D. J., and W. D. Tietje. Assessing the Impacts of Sudden Oak Death on Wildlife. Oral presentation at the Western Section of The Wildlife Society Annual Meeting, Rohnert Park, CA, February 27, 2004.

Tempel, D. J., and V. Wright. Backcountry Recreation Impacts to Wildlife: An Application of the Montana TWS Bibliography. Oral presentation at the Montana Chapter of The Wildlife Society Annual Meeting, Lewistown, MT, January 24, 2003.

Tempel, D. J. Fecal Corticosterone Levels in a California Spotted Owl Population. Oral presentation of thesis research to the Department of Fisheries, Wildlife, and Conservation Biology, Saint Paul, MN, October 2002.

Money Received for Master’s Research:

U.S. Fish and Wildlife Service, May 2001: $15,000.

Scholarships and Awards from Undergraduate Studies:

Collegiate Engineering Award, National Society of Engineers, 1987.
John and Mary Boyle-Dailey Memorial Scholarship, 1986: $2,000.
John and Mary Boyle-Dailey Memorial Scholarship, 1985: $2,000.
John and Mary Boyle-Dailey Memorial Scholarship, 1984: $2,000.

Professional Activities

Attended the ArcFuels Workshop, U.S. Forest Service and University of California, Berkeley, CA, May 1-2, 2008.
Attended the Communication Tools for Adaptive Management Workshop, Sierra Nevada Adaptive Management Project, Auburn, CA, April 29, 2008.
Completed the Wildlife Capture, Immobilization, and Handling Course (FW5620), University of Minnesota, Wildlife Science Center, Forest Lake, MN, March 17-21, 2008.
Attended the Intermediate-Level Program MARK Workshop, Colorado State University, Fort Collins, CO, June 3-8, 2007.
Attended the Biometrics Workshop, Western Section of The Wildlife Society Annual Meeting, Rohnert Park, CA, February 25, 2004.
Attended Wilderness Stewardship in the Rockies: Let’s Talk! Workshop, Glacier National Park, MT, January 22-24, 2003.

Volunteered as a Scientist-in-Residence, Crossroads Elementary School, Saint Paul, MN, March 2002. Spoke to second-grade students about bats and remote sensing.
Member of Seminar Committee and Social Committee, Department of Fisheries, Wildlife, and Conservation Biology, Saint Paul, MN, September 2001-August 2002.
Graduate Student Representative, Department of Fisheries, Wildlife, and Conservation Biology, Saint Paul, MN, March-August 2002.
Served on the Board of Directors, Cache Valley Audubon Society, Logan, UT, August 1998-May 1999.

Professional Societies

The Wildlife Society

Exhibit 5

17 January 2022

South32 Limited
(Incorporated in Australia under the *Corporations Act 2001* (Cth))
(ACN 093 732 597)
ASX / LSE / JSE Share Code: S32 ADR: SOUHY
ISIN: AU000000S320
south32.net

HERMOSA PROJECT UPDATE

Conference call at 11.00am Australian Western Standard Time, details overleaf.

South32 Limited (ASX, LSE, JSE: S32; ADR: SOUHY) (South32) is pleased to provide an update following completion of a pre-feasibility study (PFS) for the Taylor Deposit, which is the first development option at our 100% owned Hermosa project located in Arizona, USA.

The PFS results support Taylor's potential to be the first development of a multi-decade operation, establishing Hermosa as a globally significant producer of metals critical to a low carbon future, delivering attractive returns over multiple stages. An initial development case demonstrates a sustainable, highly productive zinc-lead-silver underground mine and conventional process plant, in the first quartile of the industry cost curve[1].

The Taylor Deposit will progress to a feasibility study, including work streams designed to unlock additional value by optimising operating and capital costs, extending the life of the resource and further assessing options identified to target a carbon neutral operation. Completion of the feasibility study and a final investment decision to construct Taylor are expected in mid CY23.

Separately, a scoping study[a] for the spatially linked Clark Deposit has confirmed the potential for a separate, integrated underground mining operation producing battery-grade manganese, as well as zinc and silver. Clark has the potential to underpin a second development stage at Hermosa, with future studies to consider the opportunity to integrate its development with Taylor, potentially unlocking further operating and capital efficiencies.

While exploration drilling to date has been focused on the Taylor and Clark Deposits, we have continued to complete surface geophysics, soil sampling and other exploration programs across our land package. This work has resulted in the definition of a highly prospective corridor including Taylor and Clark as well as the Peake and Flux exploration targets[b] which will be prioritised for drill testing in CY22.

Further details of the Taylor PFS are contained in the attached report and accompanying presentation.

South32 Chief Executive Officer, Graham Kerr said: "The Taylor Deposit provides an important first development option for our Hermosa project in Arizona, USA. The project has the potential to sustainably produce the metals critical for a low carbon future across multiple decades from different deposits.

"Completing the pre-feasibility study for the Taylor Deposit is an important milestone that demonstrates its potential to be a globally-significant and sustainable producer of base and precious metals in the industry's first cost quartile. Beyond Taylor, Clark offers the potential to realise further value from our investment in Hermosa through the production of battery-grade manganese, a mineral designated as critical in the United States.

"Additional exploration targets around Taylor and Clark are indicative of further upside while the broader land package contains highly prospective areas for polymetallic and copper mineralisation.

"We are designing the Taylor Deposit to be our first 'next generation mine', using automation and technology to minimise our impact on the environment and to target a carbon neutral operation in line with our goal of achieving net zero operational carbon emissions by 2050.

"The future development of Taylor provides a platform from which to realise Hermosa's immense potential. It will further strengthen our portfolio and align with the already substantial growth in production of metals critical to a low carbon future that we have embedded in the portfolio over the past six months."

---

[a] The references to the scoping study in respect of the Clark Deposit are to be read in conjunction with the cautionary statement in footnote 2 on page 18 of this announcement.

[b] The references to the Exploration Target for the Hermosa project (including Peake) are to be read in conjunction with the cautionary statement in footnote 3 on page 18 of this announcement.

Conference call

South32 will hold a conference call at 11.00am Australian Western Standard Time (2.00pm Australian Eastern Daylight Time) on 17 January 2022 to provide an update of the Hermosa project including Q&A, the details of which are as follows:

Conference ID

Please pre-register for this call at link.

Website

A replay of the conference call will be made available on the South32 website.

HERMOSA PROJECT

Hermosa is a polymetallic development option located in Santa Cruz County, Arizona, and is 100% owned by South32. It comprises the zinc-lead-silver Taylor sulphide deposit (Taylor Deposit), the zinc-manganese-silver Clark oxide deposit (Clark Deposit) and an extensive, highly prospective land package with the potential for further polymetallic and copper mineralisation. Hermosa is well located with excellent access to skilled people, services and transport logistics.

We have completed a PFS for the Taylor Deposit, our first development option at Hermosa. The Taylor Deposit is a large, carbonate replacement massive sulphide deposit which extends to a depth of approximately 1,200m over an approximate strike length of 2,500m and width of 1,900m. The Mineral Resource estimate for the Taylor Deposit is 138Mt, averaging 3.82% zinc, 4.25% lead and 81 g/t silver[4]. The deposit remains open at depth and laterally, offering further exploration potential.

The preferred mine design applied to the PFS is a dual shaft access mine which prioritises higher grade mineralisation early in the mine's life. The mining method is longhole open stoping, with the geometry of the orebody enabling the operation of multiple concurrent mining areas. This supports our assumption of an initial 22 year resource life[5] with high mining productivity. Ramp up to nameplate capacity(c) of up to 4.3 million tonnes per annum (Mtpa)[7] is expected to be achieved in a single stage. The process design applies a conventional sulphide ore flotation circuit producing separate zinc and lead concentrates with substantial silver credits.

In addition to the current Mineral Resource estimate for Taylor, we have defined an Exploration Target ranging from 10 to 95Mt[3] indicating the potential for further exploration upside. The exploration opportunity at Taylor includes depth and extensional opportunities as well as new prospects in proximity to the deposit. We have identified an Exploration Target at depth to the Taylor Deposit known as Peake, with initial drilling results returning copper and polymetallic mineralisation. Further drilling at Peake is planned in CY22.

Separately, we have completed a scoping study for the spatially linked Clark Deposit, confirming the potential for an underground mining operation producing battery-grade manganese, as well as zinc and silver. We are undertaking a PFS for Clark to increase our confidence in the mining and processing assumptions of a preferred development option and customer opportunities in the rapidly growing battery-grade manganese markets.

The Clark Deposit is interpreted as the upper oxidised, manganese-rich portion of the mineralised system that hosts Taylor. As we advance both our Taylor and Clark studies, we maintain the option to merge this work and assess an integrated underground mining operation. While such a scenario would require separate processing circuits to produce base and precious metals, and battery-grade manganese, an integrated development has the potential to unlock further operating and capital efficiencies.

Our third focus at Hermosa remains on unlocking value through exploration of our regional scale land package. Through the completion of surface geophysics, soil sampling, mapping and interpretation of recently acquired data, we have identified a highly prospective corridor which will be prioritised for future drilling. Within this corridor, we plan to drill the Flux prospect following receipt of required permits, anticipated in the second half of CY22. The Flux prospect is located down-dip of a historic mining area that has the potential for carbonate hosted, Taylor-like mineralisation[8].

STRATEGIC ALIGNMENT

We continue to actively reshape our portfolio for a low carbon future, investing in opportunities that increase our exposure to base and precious metals, with strong demand fundamentals and low carbon production intensity. The Taylor Deposit is our most advanced development option at the Hermosa project, which has the potential to provide a multi-decade platform at the operation that would further improve the Group's exposure to the metals required for the transition to a low carbon future.

---

[c] The references to all Production Targets and resultant financial forecast information in this announcement is to be read in conjunction with the cautionary statement in footnote 6 on page 18 of this announcement. The key facts and material assumptions to support the reasonable basis for this information is provided in Annexure 2 of this announcement.

SUSTAINABLE DEVELOPMENT

Sustainable development is at the heart of our purpose at South32 and forms an integral part of our strategy. The Taylor Deposit has been designed as our first "next generation mine" using automation and technology to drive efficiencies, minimise our impact and reduce carbon emissions. We have completed initial work programs and studies with respect to our communities, cultural heritage, environment and water, and any future development at Hermosa will be consistent with our approach to sustainable development.

The Taylor Deposit has been designed as a low-carbon operation, with the feasibility study to target the further potential to achieve carbon neutrality. This may be achieved through identified options to access 100% renewable energy from local providers, and the potential use of battery electric vehicles and underground equipment. The development of the Taylor Deposit would be consistent with our commitment to a 50% reduction in our operational carbon emissions by FY35 and net zero by 2050.

CAPITAL MANAGEMENT FRAMEWORK

A final investment decision for the Taylor Deposit and its potential tollgate to construction will be assessed within our unchanged capital management framework. Our framework, which prioritises investment in safe and reliable operations, an investment grade credit rating and returns to shareholders via our ordinary dividends, also seeks to establish and pursue options that create enduring value for shareholders, such as capital investments in new projects. Our preferred funding mechanism for any future developments at Hermosa will be consistent with our commitment to an investment grade credit rating through the cycle that supports our strong balance sheet.

PFS HIGHLIGHTS

The PFS results demonstrate Taylor's potential to be a globally significant producer of green metals critical to a low carbon future, in the first quartile of the industry cost curve. Taylor has the potential to underpin a regional scale opportunity at Hermosa, with ongoing activities to unlock additional value from the Clark Deposit and exploration opportunities across the regional land package.

- **Our initial development scenario outlines the potential for a large scale, highly productive underground mine**
  - Dual shaft access which prioritises higher grade ore in early years
  - Proposed mining method is low technical risk, employing longhole open stoping with paste backfill
  - Single stage ramp-up to nameplate production of up to 4.3Mtpa
  - Conventional sulphide ore flotation circuit

- **Potential to be a globally significant producer of metals for a low carbon future**
  - PFS estimates annual average production ~111kt zinc, ~138kt lead and ~7.3Moz silver (~280kt zinc equivalent (ZnEq)[9], with output ~20% higher across the years of steady state production[10]
  - Zinc is used in renewable energy infrastructure such as solar and wind for energy conversion and to protect against corrosion; silver is a key element used in solar panels; while lead demand is expected to be supported by its use in renewable energy storage systems

- **Potential for a low cost operation in the industry's first quartile**
  - Average Operating unit costs ~US$81/t ore milled (all-in sustaining cost (AISC)[11] ~US$(0.05)/lb ZnEq) benefitting from high underground productivity

- **Directs capital to establish a multi-decade base metals operation and platform for growth at Hermosa**
  - Project capital of ~US$1,230M (direct) and ~US$470M (indirect) to establish the first development option
  - Low sustaining capital ~US$40M per annum
  - Potential to realise capital efficiencies through an integrated development of Taylor and Clark

- **A large Mineral Resource with substantial exploration potential**
  - Taylor Deposit supports an initial resource life of ~22 years, and remains open at depth and laterally
  - 10 to 95Mt Exploration Target identified, indicating the potential for further exploration upside
  - Copper-lead-zinc-silver mineralisation intercepted at the proximal Peake prospect

- **Pursues the sustainable development of critical metals**
  - We are investing in local programs and partnerships that reflect the priorities of our communities
  - We are committed to working with Native American tribes to protect cultural resources
  - We have completed key biodiversity, ecosystem and water studies
  - We are pursuing a pathway to net zero carbon emissions with identified options for renewable energy

FURTHER OPPORTUNITIES TO UNLOCK VALUE

Reflecting the early stage nature of the project we have identified numerous opportunities to unlock further value at Taylor that will be pursued prior to a final investment decision. Opportunities identified include the potential to:

- Extend the resource life, which is underpinned by the current Taylor Mineral Resource estimate and does not include the further potential identified in our Exploration Target.
- Reduce operating costs through:
  - Further optimisation of the mining schedule, power consumption and comminution circuit;
  - Supplying smelters in the Americas to realise a material reduction in transport costs; and
  - Adopting emerging technologies and further automation opportunities, targeting enhanced productivity.
- Reduce capital costs through further optimisation of the shaft design, construction and procurement.
- Achieve a carbon neutral operation through access to 100% renewable energy from local suppliers.
- Integrate the underground development with the Clark Deposit.

NEXT STEPS

Taylor will now progress to a feasibility study which is targeted for completion in mid CY23. To maintain the preferred development path in the PFS, critical path items including construction and installation of infrastructure to support additional orebody dewatering is planned to commence in H2 FY22. Total pre-commitment capital expenditure associated with dewatering of approximately US$55M is expected in H2 FY22, with further investment expected in FY23. This expenditure is included in the growth capital estimate in Table 1 below.

The PFS assumes a single stage ramp-up to the nameplate production rate. Based on the PFS schedule, and subject to a final investment decision and receipt of required permits, shaft development is expected to commence in FY24. First production is targeted in FY27 with surface infrastructure, orebody access, initial production and tailings storage expected on patented lands which require state-based approvals. Surface disturbance and additional tailings storage on unpatented land will require completion of the National Environmental Policy Act (NEPA) process with the United States Forest Service (USFS). The project may benefit from the classification of metals found at Hermosa as critical minerals in the United States. Zinc is proposed to be added as a critical mineral by the U.S. Geological Survey while manganese (found at the Clark Deposit) already has this designation.

PFS SUMMARY RESULTS

Key PFS outcomes are summarised below. Given the project's early stage nature, the accuracy level in the PFS for operating costs and capital costs is -15% / +25%. The cost estimate has a base date of H1 FY22. Unless stated otherwise, currency is in US dollars (real) and units are in metric terms.

Table 1: Key PFS outcomes

Production	Nameplate production capacity	Mtpa	~4.3
	Resource life	Years	~22
	Head grades (average)	%, g/t	4.1% Zn, 4.5% Pb, 82 g/t Ag
	Annual payable zinc production (average / steady state[10])	kt	~111 / ~130
	Annual payable lead production (average / steady state)	kt	~138 / ~166
	Annual payable silver production (average / steady state)	Moz	~7.3 / ~8.7
	Annual payable ZnEq production[9] (average / steady state)	kt	**~280 / ~340**
Operating costs	Operating unit costs (per tonne ore milled)	US$/t	~81
	Operating unit costs (per lb ZnEq)	US$/lb ZnEq	~(0.71)
Capital expenditure	Direct growth capital	US$M	~1,230
	Indirect growth capital	US$M	~470
	Sustaining capital (annual average)	US$M	~40

TAYLOR DEPOSIT PFS

The PFS for the Taylor Deposit provides confirmation that it is a technically robust project that has the potential to deliver an attractive return on investment. The PFS is based on an underground zinc-lead-silver mine development using longhole open stoping and a conventional sulphide ore flotation circuit producing separate zinc and lead concentrates, with silver by-product credits. The preferred development scenario is based on a mining and processing rate of up to 4.3Mtpa, with a resource life of approximately 22 years.

The PFS was completed with input from consultants including Fluor for the process plant and on-site infrastructure, SRK Consulting for geological and technical reviews, Stantec for mining studies, NewFields for hydrogeology, Montgomery & Associates for dewatering and tailings, Black and Veatch, and BQE for water treatment design and CPE for off-site roads. The PFS has been subject to an independent peer review.

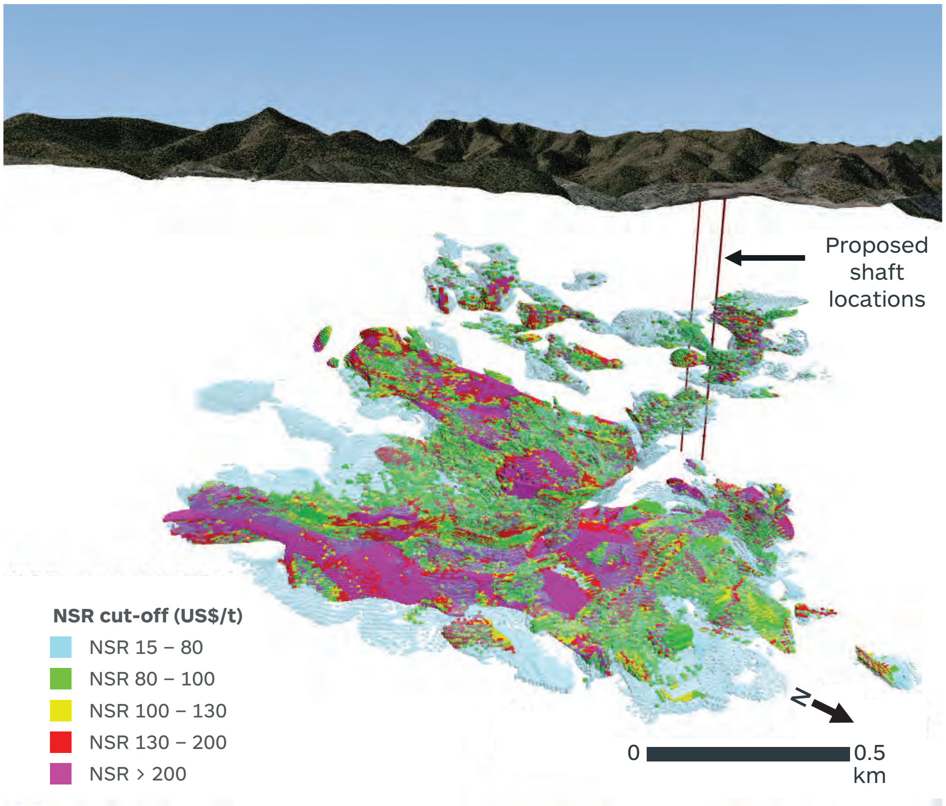
Mineral Resource estimate

The Taylor Deposit is a carbonate replacement style zinc-lead-silver massive sulphide deposit. It is hosted in Permian carbonates of the Pennsylvanian Naco Group of south-eastern Arizona. The Taylor Deposit comprises the upper Taylor sulphide (Taylor Mains) and lower Taylor deeps (Taylor Deeps) domains that have a general northerly dip of 30° and are separated by a low angle thrust fault.

The Taylor Mineral Resource estimate is reported in accordance with the JORC Code (2012) at 138Mt, averaging 3.82% zinc, 4.25% lead and 81 g/t silver with a contained 5.3Mt of zinc, 5.9Mt of lead and 360Moz of silver. The Mineral Resource estimate is reported using a net smelter return (NSR) cut-off value of US$80/t for material considered extractable by underground open stoping methods.

The Taylor Deposit has an approximate strike length of 2,500m and a width of 1,900m. The stacked profile of the thrusted host stratigraphy extends 1,200m from near-surface and is open at depth and laterally. It is modelled as one of the first carbonate replacement deposit occurrences in the region, with all geological and geochemical information acquired to date being consistent with this model.

Figure 1: Taylor Mineral Resource



Exploration Target

The Taylor Mineral Resource is within a highly prospective mineralised system and is open at depth and laterally, offering the potential for further exploration upside.

We have completed work aimed at developing an unconstrained, spatial view of the Exploration Target at the Taylor Deposit, considering extensional and near-mine exploration potential.

The Hermosa project has sufficient distribution of drill data to support evaluation of the size and quality of Exploration Targets. Tables of individual drill hole results are provided in Annexure 1 of this announcement, as well as a listing of the total number of holes and metres that support the assessment of the Exploration Target size and quality.

The tonnage represented in defining Exploration Targets is conceptual in nature. There has been insufficient exploration to define a Mineral Resource and it is uncertain if further exploration will result in the determination of a Mineral Resource. It should not be expected that the quality of the Exploration Targets is equivalent to that of the Mineral Resource.

Estimations were performed using resource range analysis, in which deterministic estimates of potential volumes and grades are made over a range of assumptions on continuity and extensions that are consistent with available data and generic models of carbonate replacement, skarn and vein styles of mineralisation.

The estimates are supported by exploration results from prospects in and around the Taylor Mineral Resource. These results are all of carbonate replacement, skarn, and vein styles of mineralisation and are currently explored at varying degrees of maturity and exploration drilling density.

Outcomes for the Exploration Target are provided in Table 2 below. The mid case Exploration Target is approximately 45Mt.

Table 2: Ranges for the Exploration Target for Taylor sulphide mineralisation (as at 31 December 2021)

	Low Case				Mid Case				High Case			
	Mt	% Zn	% Pb	g/t Ag	Mt	% Zn	% Pb	g/t Ag	Mt	% Zn	% Pb	g/t Ag
Sulphide	**10**	**3.8**	**4.2**	**81**	**45**	**3.4**	**3.9**	**82**	**95**	**3.6**	**4.0**	**79**

Notes:

a) Net smelter return cut-off (US$80/t): Input parameters for the NSR calculation are based on South32's long term forecasts for zinc, lead and silver pricing, haulage, treatment, shipping, handling and refining charges. Metallurgical recovery assumptions are 90% for zinc, 91% for lead, and 81% for silver.

b) All masses are reported as dry metric tonnes (dmt). All tonnes and grade information have been rounded to reflect relative uncertainty of the estimate, hence small differences may be present in the totals.

Peake prospect

Our drilling programs at the Taylor Deposit have focused on improving confidence in the mine plan for the potential development, extending the resource and testing near-mine exploration prospects.

As part of our work on near-mine exploration targets, we have intersected the skarn hosted copper-lead-zinc-silver Peake prospect, located south of the Taylor Deposit at a depth of approximately 1,300-1,500m. To date, 13 drill holes have been completed at Peake, a deeper zone prospective for copper mineralisation, returning results that intersected copper, lead, zinc and silver. The geological model interpreted from these results and other recently acquired data indicates the potential for a continuous structural and lithology-controlled system connecting Taylor Deeps and Peake. Further exploration drilling is planned in CY22.

Selected exploration drilling results from the Peake prospect are shown in Table 3 below.

Table 3: Selected Peake drilling results

Hole ID	From (m)	To (m)	Cut off	Width (m)	Zinc (%)	Lead (%)	Silver (ppm)	Copper (%)
HDS-540	1279.2	1389.0	0.2% Cu	109.7	0.1	0.3	15	0.62
	Including							
	1303.6	1309.7	0.2% Cu	6.1	0.2	0.4	61	3.48
HDS-552	1308.2	1384.7	0.2% Cu	76.5	0.2	0.4	25	1.52
	Including							
	1309.9	1328.6	0.2% Cu	18.8	0.1	0.2	40	2.77
	And							
	1364.3	1384.7	0.2% Cu	20.4	0.1	0.3	37	2.44
HDS-661	1322.2	1374.6	0.2% Cu	52.4	0.1	1.1	105	1.73
	Including							
	1322.2	1346.0	0.2% Cu	23.8	0.1	0.8	81	3.32
	Including							
	1322.2	1330.1	0.2% Cu	7.9	0.1	0.4	81	7.89
	1386.8	1460.6	0.2% Cu	73.8	0.5	0.7	67	1.06
	Including							
	1399.6	1410.3	0.2% Cu	10.7	0.7	1.5	227	2.84
HDS-717	1456.6	1466.7	0.2% Cu	10.1	0.5	1.0	78	2.57

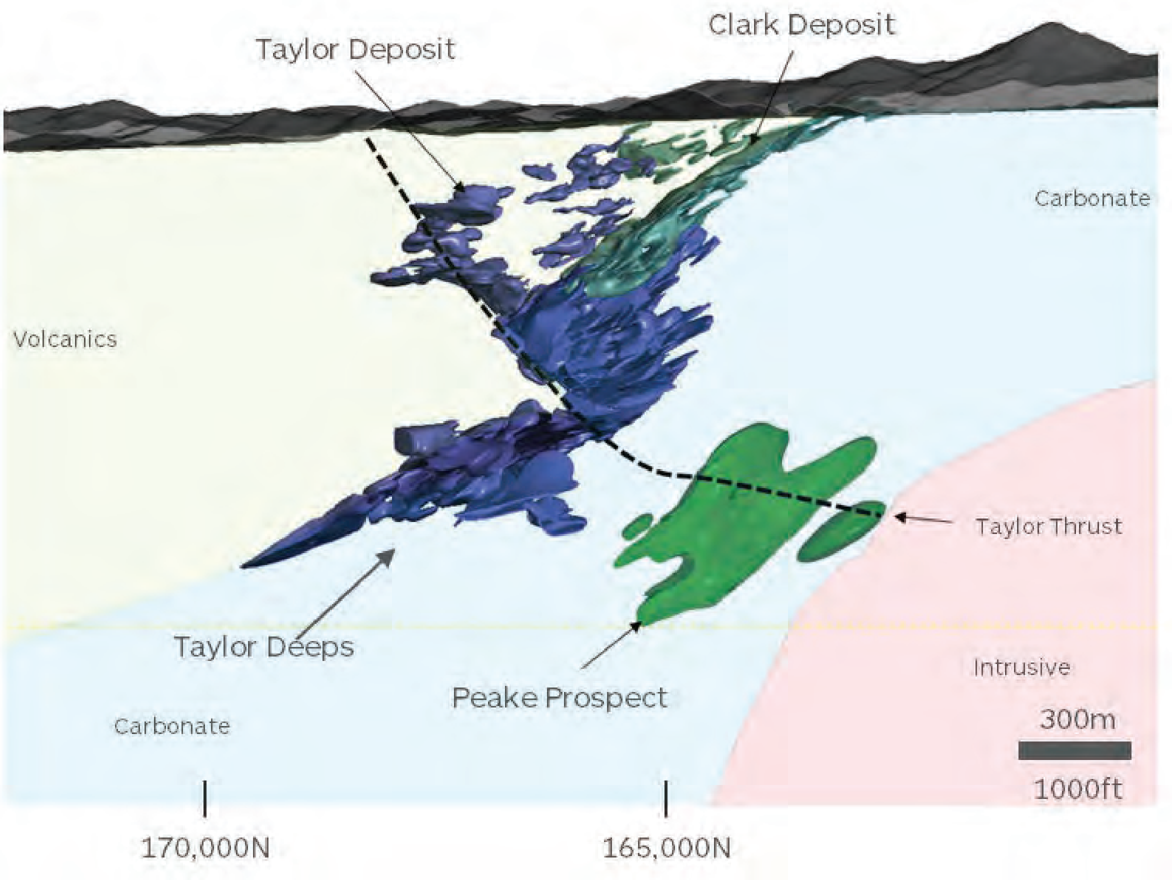
All exploration drilling results from the Peake prospect are shown in Table 4 below. All drill intersections used to define the Exploration Target are included in Annexure 1 of this announcement.

Table 4: All Peake drilling results

Hole ID	From (m)	To (m)	Cut off	Width (m)	Zinc (%)	Lead (%)	Silver (ppm)	Copper (%)
HDS-535	No significant intersection							
HDS-540	1279.2	1389.0	0.2% Cu	109.7	0.1	0.3	15	0.62
	Including							
	1303.6	1309.7	0.2% Cu	6.1	0.2	0.4	61	3.48
	1469.7	1488.0	0.2% Cu	18.3	0.0	0.0	10	0.63
HDS-545	No significant intersection							
HDS-549	1169.5	1175.6	0.2% Cu	6.1	1.5	1.6	312	1.92
HDS-551	1100.6	1111.6	0.2% Cu	11.0	0.0	0.2	10	0.39
	1254.9	1280.8	0.2% Cu	25.9	0.0	0.0	10	0.54
	1294.5	1372.8	0.2% Cu	78.3	0.0	0.1	10	0.51
HDS-552	1265.8	1273.9	0.2% Cu	8.1	0.2	0.5	27	0.39
	1308.2	1384.7	0.2% Cu	76.5	0.2	0.4	25	1.52

Hole ID	From (m)	To (m)	Cut off	Width (m)	Zinc (%)	Lead (%)	Silver (ppm)	Copper (%)
	Including							
	1309.9	1328.6	0.2% Cu	18.8	0.1	0.2	40	2.77
	And							
	1364.3	1384.7	0.2% Cu	20.4	0.1	0.3	37	2.44
	1478.9	1484.8	0.2% Cu	5.9	1.0	1.5	57	0.41
HDS-557	No significant intersection							
HDS-661	1298.4	1305.2	2% ZnEq	6.7	0.6	3.4	249	0.89
	1322.2	1374.6	0.2% Cu	52.4	0.1	1.1	105	1.73
	Including							
	1322.2	1346.0	0.2% Cu	23.8	0.1	0.8	81	3.32
	Including							
	1322.2	1330.1	0.2% Cu	7.9	0.1	0.4	81	7.89
	1386.8	1460.6	0.2% Cu	73.8	0.5	0.7	67	1.06
	Including							
	1399.6	1410.3	0.2% Cu	10.7	0.7	1.5	227	2.84
	And							
	1424.0	1446.9	0.2% Cu	22.9	0.5	0.6	45	1.24
	1555.1	1573.1	0.2% Cu	18	3.2	1.4	87	0.37
HDS-662	1316.4	1329.2	0.2% Cu	12.8	3.4	4.4	137	0.95
	1540.8	1546.7	2% ZnEq	5.9	5.9	2.1	250	0.45
HDS-663	1580.1	1591.8	0.2% Cu	11.7	0.1	0.0	16	0.95
	1615.9	1651.1	0.2% Cu	35.2	1.1	0.1	27	0.56
HDS-691	1343.6	1353.6	2% ZnEq	10.1	3.8	3.5	61	0.47
	1384.7	1395.4	0.2% Cu	10.7	2.7	2.9	38	1.03
	1405.9	1415.2	0.2% Cu	9.3	0.5	0.7	11	0.26
	1421.3	1452.1	0.2% Cu	30.8	0.7	0.8	22	0.59
	1463.6	1509.7	0.2% Cu	46.0	0.4	0.5	21	0.43
	1540.6	1549.3	0.2% Cu	8.7	0.3	0.9	51	0.61
	1563.9	1581.3	0.2% Cu	17.4	0.2	0.2	23	0.55
	1662.7	1677.9	0.2% Cu	15.2	2.8	1.1	155	1.19
	1683.4	1692.6	2% ZnEq	9.1	1.5	0.3	45	0.13
	1732.0	1735.2	2% ZnEq	3.2	6.2	0.3	107	0.18
	1994.6	1997.4	2% ZnEq	2.7	1.7	0.3	54	0.08
HDS-717	1065.3	1072.4	0.2% Cu	7.2	3.5	2.7	22	0.21
	1306.1	1318.3	0.2% Cu	12.2	1.8	1.8	63	0.82
	1444.1	1466.7	0.2% Cu	22.6	1.7	1.7	46	1.38
	Including							
	1456.6	1466.7	0.2% Cu	10.1	0.5	1.0	78	2.57
	1517.9	1522.2	2% ZnEq	4.3	3.0	1.8	49	0.03
	1718.6	1727.0	0.2% Cu	8.4	1.0	0.1	39	1.99
	1754.1	1763.3	2% ZnEq	9.1	1.4	0.5	42	0.13
HDS-763	1429.8	1439.6	2% ZnEq	9.8	2.3	0.1	3	0.02

Figure 2: Peake prospect



Mining

The PFS design for Taylor is a dual shaft mine which prioritises early access to higher grade mineralisation, supporting ZnEq average grades of approximately 12%[9] in the first five years of the mine plan. The proposed mining method, longhole open stoping, maximises productivity and enables a single stage ramp-up to our preferred development scenario of up to 4.3Mtpa. In the PFS schedule, shaft development is expected to commence in FY24 with first production targeted in FY27 and nameplate production in FY30.

Ore is expected to be mined in an optimised sequence concurrently across four independent mining areas, crushed underground and hoisted to the surface for processing. The mine design contemplates two shaft stations, one for logistics and access, and the other for material handling. The primary haulage material handling level is expected to be located at a depth of approximately 800m.

The operation would be largely resourced with a local owner-operator workforce, with a mining fleet consisting of jumbo drills, rock bolters, production drills, load, haul and dump machines and haulage trucks. Taylor's feasibility study will evaluate the potential use of battery electric underground equipment and trucks within the mining fleet, bringing further efficiency benefits, reducing diesel consumption and carbon emissions.

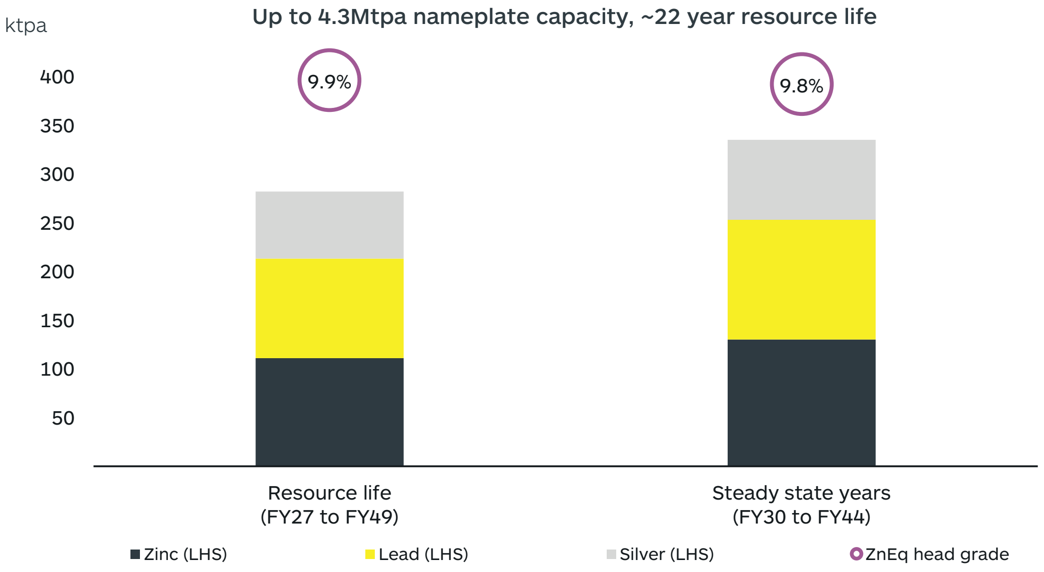
Processing

The PFS process plant design is based on a sulphide ore flotation circuit to produce separate zinc and lead concentrates, with silver by-product credits. The flowsheet adheres to conventional principles with a primary crusher, crushed ore bins, comminution circuit, sequential flotation circuit, thickening and filtration. Tailings are processed by either filtration and drystacking, or by converting to paste and returning them underground. Approximately half of the planned tailings will be sent underground as paste fill, reducing the surface environmental footprint.

Pre-flotation and pre-float concentrate cleaning steps have been included in the plant design to prevent magnesium oxide and talc from affecting flotation performance and concentrate quality. Jameson cell technology is proposed to be used in place of some traditional mechanical flotation cells to enhance recoveries. Once filtered, concentrate would be loaded directly into specialised bulk containers.

The PFS processing facility has design recoveries of 90% for zinc and 91% for lead, and target concentrate grades of 53% for zinc and 70% for lead. Silver primarily reports to the lead concentrate, with a design recovery of 81%. The zinc concentrate is considered mid-grade with relatively high silver content for zinc, and the lead concentrate is considered high-grade. Indicative production rates in the PFS are shown in Figure 3.

Figure 3: Payable ZnEq production and head grade



The PFS mine ramp-up enables nameplate capacity to be reached in FY30. Annual average payable production is ~111kt zinc, ~138kt lead and ~7.3Moz silver (~280kt ZnEq[9]). Production over the steady state years (FY30 to FY44) is expected to be approximately 20% higher, averaging ~130kt zinc, ~166kt lead and ~8.7Moz silver (~340kt ZnEq[9]).

Site infrastructure

PFS capital includes estimates for non-processing infrastructure, including required tailings, power and water infrastructure.

Figure 4: Site infrastructure

The tailings storage facilities (TSF) have been designed in accordance with South32's Dam Management Standard, with our approach being consistent with the International Council on Mining and Metals (ICMM) Tailings Governance Framework. We are also progressing work on compliance with the Global Industry Standard on Tailings Management. Approximately half of the tailings produced will be thickened and filtered and sent back underground as paste backfill, reducing the surface environmental footprint. The remaining filtered tailings will be placed in one of two dry stack TSFs. The first facility is located on patented land and is an expansion to the existing TSF which was constructed as part of the voluntary remediation program completed in CY20. This already completed work established a state-of-the-art dry stack facility which will provide initial tailings capacity to support the commencement of operations. The PFS contemplates a second purpose-built facility on unpatented land, requiring Federal permits.

Future site power needs are expected to be met through transmission lines connecting to the local grid. Grid power is currently generated from a combination of coal, natural gas and renewables including solar, hydro and wind power. We have commenced discussions in relation to securing 100% renewable energy for the project, with options for grid-based renewable energy as well as new solar power projects to be advanced through the feasibility study.

Orebody dewatering is a critical path activity in the PFS schedule and capital expenditure has been committed to support construction and the installation of its related infrastructure, commencing from H2 FY22. The hydrogeological studies completed in the PFS and the design of the required water wells and infrastructure have been completed to feasibility-stage standards to support the execution of these early works.

Water treatment requirements are expected to met through two proposed water treatment plants (WTP). WTP1 is already installed and treatment upgrades are expected to be commissioned in Q3 FY22, while WTP2 is expected to be commissioned in Q4 FY23.

Logistics

Hermosa is well located with existing nearby infrastructure for both bulk rail and truck shipments to numerous North American ports. The transportation of concentrates is expected to be a combination of trucking to a rail transfer facility (for subsequent rail transfer to port) and directly to port, for shipping to Asian and European smelters. Specialised bulk containers will be used to eliminate dust exposure from the time of load out until discharge to the ocean vessel. The expected trucking route in the PFS includes the construction of a connecting road to a state highway and other upgrades to road infrastructure.

PFS shipping costs assume transportation of concentrate to Asia and Europe. During feasibility we will continue to investigate the potential to supply smelters in the Americas, substantially lowering our assumed transport logistics and shipping costs.

Operating cost estimates

The PFS includes estimates for mining, processing, general and administrative operating costs.

Mining costs (~US$35/t ore processed) include all activities related to underground mining, including labour, materials, utilities and maintenance. Processing costs (~US$13/t ore processed) include consumables, labour and power. General and administrative costs (~US$10/t ore processed) include head office corporate costs and site support staff. Other costs (~US$23/t ore processed) include shipping and transport (~US$16/t ore processed), marketing and royalties, with private net smelter royalties averaging 2.4% (~US$4/t ore processed).

Average PFS operating unit costs of ~US$81/t ore processed (~US$77/t at steady state production) reflect the high productivity rates expected from concurrently mining multiple independent underground areas and the benefit from access to local, skilled service providers.

Average PFS Operating unit costs expressed on a zinc equivalent basis of ~US$(0.71)/lb and AISC[11] of ~US$(0.05)/lb place the Taylor Deposit in the first quartile of the industry cost curve[1].

Table 5: Operating unit costs – $t/ore processed

Item	US$/t ore processed
Mining	~35
Processing	~13
General and administrative	~10
Other (including royalties)	~23
Total	**~81**

Table 6: Operating unit costs – $/lb ZnEq

Item	$/lb ZnEq
Mining	~0.51
Processing	~0.19
General and administrative	~0.15
Other (including royalties)	~0.33
Operating unit costs	**~1.18**
Lead and silver credits	~(1.89)[12]
Zinc equivalent operating unit costs	**~(0.71)**

Capital cost estimates

Direct PFS capital expenditure estimates to construct Taylor are shown below. The construction period following a final investment decision is expected to be approximately four years. Indirect costs include contingency, owner's and engineering, procurement, and construction management (EPCM) costs to support the project. The Group will also continue to incur ongoing costs for work being undertaken across the broader Hermosa project that will be separately guided.

Table 7: Growth capital expenditure (from 1 January 2022)

Item	US$M
Mining	~565
Surface facilities	~440
Dewatering	~225
Direct costs	**~1,230**
Indirect costs (including contingency)	~470
Total	**~1,700**

Mining capital expenditure includes the shafts (~US$310M), development, mobile equipment and infrastructure. Surface facilities includes the processing plant (~US$350M), tailings and utilities. The capital estimate reflects assumptions for key inputs including steel, cement and labour as at H1 FY22.

Additional capital is included in the PFS estimates for critical path orebody dewatering. The direct capital expenditure estimate of US$225M includes expenditure directly attributable to water wells and a second required water treatment plant. A further ~US$140M of owner's costs across the period of dewatering are included within indirect costs (~US$470M).

Further value engineering work in the feasibility study will target a potential reduction in capital costs through further optimisation of the shaft design, construction and procurement.

Sustaining capital expenditure is expected to average approximately US$40M per annum and primarily relates to mine development.

Development approvals

The Hermosa project's mineral tenure is secured by 30 patented mining claims totaling 228 hectares that have full surface and mineral rights owned by South32. The patented land is surrounded by 1,957 unpatented mining claims totaling 13,804 hectares. The surface rights of the unpatented mining claims are administered by the USFS under multiple-use regulatory provisions.

The initial PFS mine development and surface infrastructure, including the processing plant, on-site power and the first TSF are designed to be located on patented mining claims. As a result, construction and mining of the Taylor Deposit can commence with approvals and permits issued by the State of Arizona. Several required permits for dewatering are already held, with the timeframe to receive the remaining State-based approvals expected to take up to approximately two years. Surface disturbance and additional tailings storage on unpatented land will require completion of the NEPA process with the USFS, in order to receive a Record of Decision (RoD). The ramp-up to nameplate production assumed in the PFS could take longer than contemplated if the RoD was delayed, as production may need to be slowed so tailings capacity could be restricted to patented lands until the RoD is received.

Our approach to sustainability at Hermosa

Sustainable development is at the heart of our purpose at South32 and forms an integral part of our strategy. Our commitment to sustainable development is embedded in the approach we are adopting at Taylor.

We have developed a comprehensive stakeholder identification, analysis and engagement plan. Our key stakeholders include local communities within Santa Cruz County, Native American tribes with historic affiliation around the project area, and county, state and federal government agencies.

Partnering with local communities

We have developed a community investment plan for Hermosa. Key investment initiatives include a South32 Hermosa Community Fund developed in partnership with the Community Foundation for South Arizona, community sponsorships and grants to community programs that reflect the priorities of the communities around Hermosa. In addition to community investment programs, we have established local procurement and employment plans designed to provide direct economic benefits for our communities.

Preserving cultural heritage

We are committed to working with Native American tribes who have a historic affiliation with the area around the Hermosa project. While there are no Native American trust lands near Hermosa, historic habitation or use of the region by Indigenous Peoples may establish culturally significant connections. We have completed initial surveys for cultural resources on both our patented lands and unpatented mining claims and will continue to engage with Native American tribes who have historic affiliations to gain a more thorough understanding of sensitive cultural resources.

Managing our environmental impact

An environmental management plan (EMP) has been developed for Hermosa that is consistent with the South32 Environment Standard. Key aspects of the EMP include baseline studies, risk assessments and mapping of key features with respect to biodiversity, ecosystems and water. The baseline studies have included several biological studies and surveys, including for species listed under the *Endangered Species Act* (ESA) and USFS sensitive species, as well as monitoring of surface water, ground water and air quality. The ongoing collection, analysis and modelling of baseline information and survey data will align with the South32 Environment Standard and support the required permits and approvals for Hermosa.

Hermosa is in a semi-arid environment, with most rainfall occurring in the “monsoon” season of July through October. Water resource monitoring and management plans have been developed to support an understanding of the baseline conditions and numerical modelling of surface and groundwater resources. Additional studies are planned for completion as part of the Taylor feasibility study.

Targeting net zero carbon operational emissions

Taylor has been designed as a low carbon operation, with the primary sources of carbon emissions being residual diesel consumption and grid power. We have identified several opportunities to improve this starting position, with active discussions to secure 100% renewable energy for site power and the feasibility study to include further evaluation of the potential use of battery electric vehicles and underground mining equipment. We are testing technology solutions to support this, with a trial of electric vehicles planned at our Cannington zinc-lead-silver mine during FY22 and our ongoing participation in the Electric Mine Consortium[13].

Commodities for a low carbon future

The proposed development of Taylor is consistent with our focus on reshaping our portfolio for a low carbon future, increasing our exposure to base and precious metals and reducing our carbon intensity.

The metals produced at Taylor are expected to play a role in supporting global decarbonisation. Zinc demand is expected to benefit from an increase in renewable energy infrastructure such as solar, where it allows for higher energy conversion, and wind, given its use in protecting key elements from corrosion. Silver is used in solar panels due to its superior electrical conductivity and has higher intensity of use in electric vehicles compared to internal combustion engine (ICE) cars. In the medium term, the ongoing growth in ICE vehicles sales will continue to see demand for lead-acid batteries grow, with lead demand also expected to be supported by its use in renewable energy storage systems.

Taylor project summary

Key PFS assumptions and outcomes are summarised below.

Table 8: Taylor PFS assumptions

Mining	
Mineral Resource estimate	138Mt averaging 3.82% zinc, 4.25% lead and 81g/t silver
Resource life	~22 years
Mining method	Longhole open stoping with paste backfill
Mined ore grades	Zinc 4.1%, Lead 4.5%, Silver 82g/t
Processing	
Mill capacity	~4.3Mtpa
Concentrates	Separate zinc and lead concentrates with silver credits
Zinc recoveries (in zinc concentrate)	~90%
Lead recoveries (in lead concentrate)	~91%
Silver recoveries (in lead concentrate)	~81%
Metal payability	Zinc ~85%, Lead ~95%, Silver ~95% (in lead concentrate)
Zinc concentrate grade	~53%
Lead concentrate grade	~70%
Payable metal production	
Zinc	~2.4Mt (~111kt annual average)
Lead	~3.0Mt (~138kt annual average)
Silver	~160Moz (~7.3Moz annual average)
Zinc equivalent[9]	~6.2Mt (~280kt annual average)
Capital costs	
Direct capital expenditure	~US$1,230M
Indirect capital expenditure	~US$470M
Sustaining capital expenditure	~US$40M annual average
Schedule	
First production	FY27
Steady state production	FY30-FY44
Operating costs	
Mining costs	~US$35/t ore processed
Processing costs	~US$13/t ore processed
General and administrative costs	~US$10/t ore processed
Other operating unit costs	~US$23/t ore processed (incl. royalties)
Operating unit costs	~US$81/t ore processed
Zinc equivalent operating unit cost	~(US$0.71/lb) ZnEq (incl. lead and silver credits)
All-in sustaining cost[11]	~(US$0.05)/lb ZnEq (incl. lead and silver credits)
Fiscal terms	
Corporate tax rate[14]	~26%
Royalties	Average 2.4% private net smelter royalties

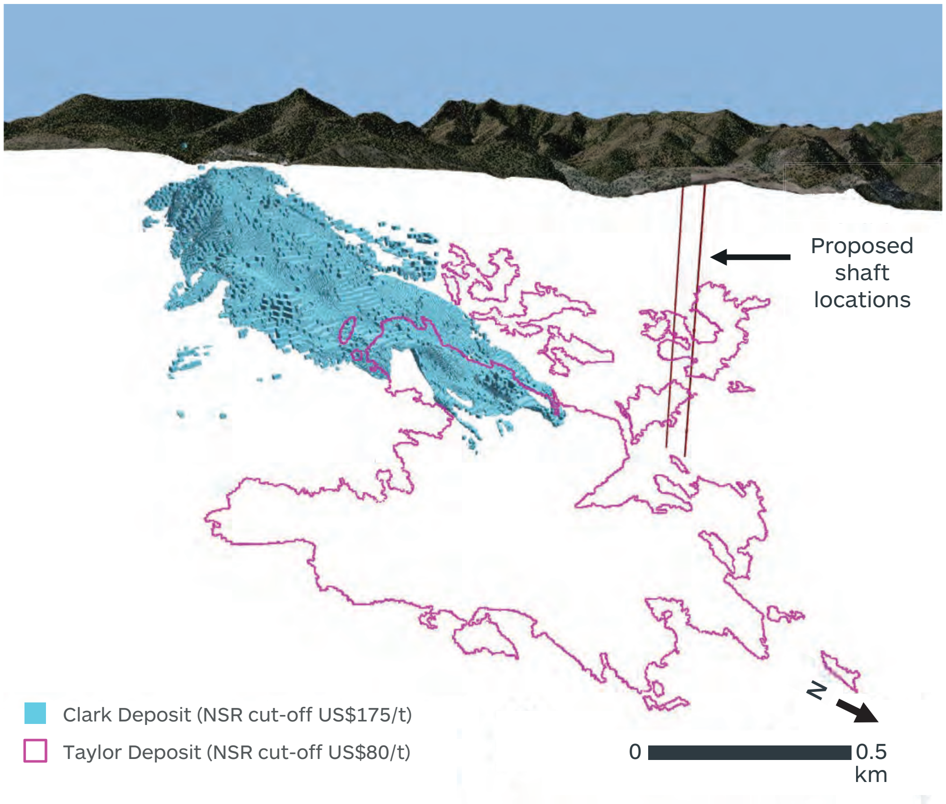
CLARK DEPOSIT SCOPING STUDY

Clark is a manganese-zinc-silver oxide deposit located adjacent, and up-dip of the Taylor Deposit, which has a Mineral Resource estimate of 55 million tonnes, averaging 9.08% manganese, 2.31% zinc and 78 g/t silver using a NSR cut-off of US$175/t[4] in accordance with the JORC Code. The Clark Deposit is interpreted as the upper oxidised, manganese-rich portion of the mineralised system, with the resource extending from near surface to a depth of approximately 600m.

The Clark Deposit has the potential to underpin a second development at Hermosa. We recently completed a scoping study[2] for the Clark Deposit which has confirmed viable flowsheets to produce battery-grade manganese, in the form of electrolytic manganese metal (EMM) or high purity manganese sulphate monohydrate (HPMSM). Clark has advanced to a PFS for a potential underground mine development using longhole open stoping accessed from existing patented mining claims. The PFS is designed to increase confidence in our technical and operating assumptions and customer opportunities in the rapidly growing battery-grade manganese markets. The first phase of the PFS is expected to be completed in late CY22, at which point a preferred development pathway will be selected. Many areas of the PFS, including mine planning, hydrogeology, infrastructure, sustainability and permitting will benefit from work completed in the Taylor PFS.

Our study work will also review the potential to pursue an integrated development of Taylor and Clark. An integrated development would comprise underground mining operations for Taylor and Clark with separate processing circuits to produce base and precious metals, and battery-grade manganese. An integrated development has the potential to realise operating and capital efficiencies.

Figure 5: Clark and Taylor deposits

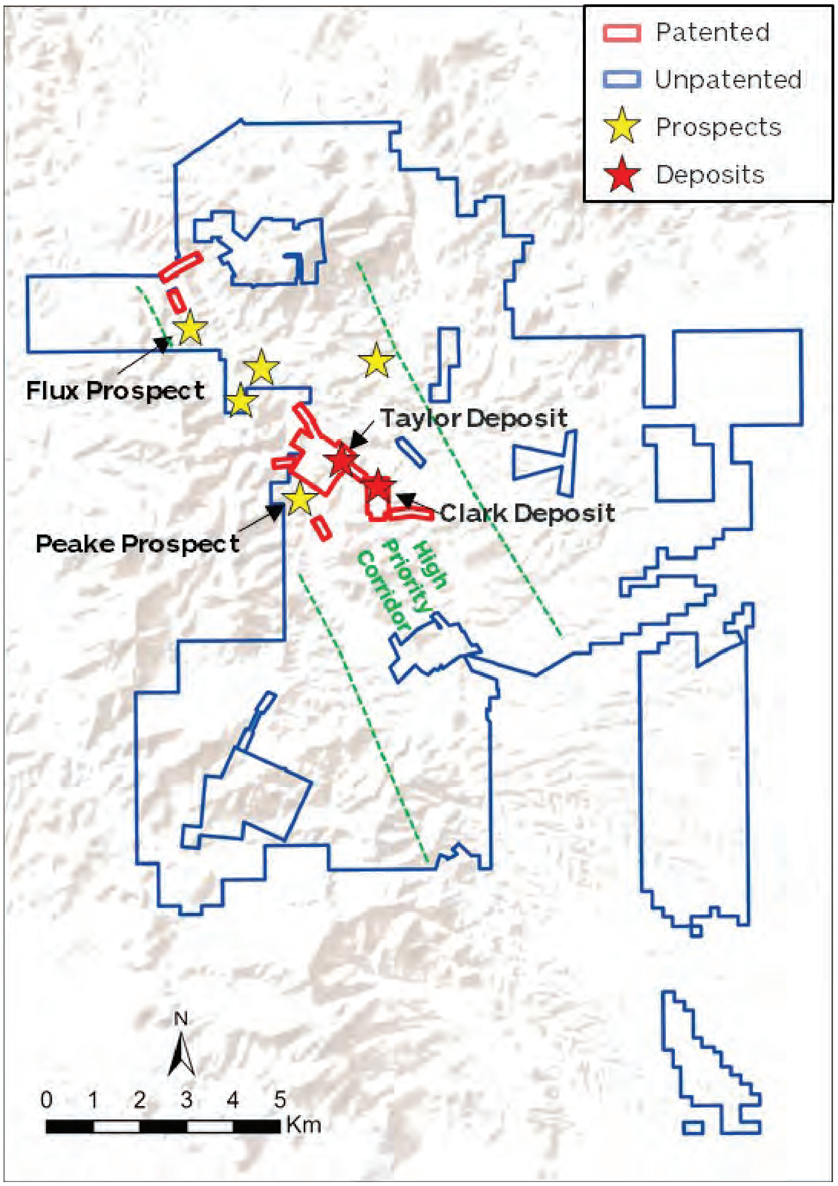


REGIONAL EXPLORATION

Our third area of focus at Hermosa is unlocking value through exploration of our highly prospective regional land package. Since our initial acquisition, we have increased our tenure by 66%, consolidating our position in the most prospective areas. We have completed surface geophysics, soil sampling, mapping and other exploration activity, resulting in the definition of a highly prospective corridor across our land package which will be prioritised for future testing.

Within this highly prospective corridor, we plan to drill test the Flux prospect in the second half of CY22 following the receipt of required permits. The Flux prospect is located down-dip of an historic mining area in carbonates that could host Taylor-like mineralisation[8]. Our ongoing exploration strategy will focus on identifying, permitting and drilling new exploration targets across the land package while continuing to refine our understanding of the regional geology.

Figure 6: Regional exploration



FOOTNOTES

1. Based on Taylor's estimated all-in sustaining costs (AISC) in the PFS and the Wood Mackenzie Lead/Zinc Asset Profiles. AISC includes operating unit costs (including royalties), treatment and refining charges (TCRCs), and sustaining capital expenditure.
2. Clark Deposit scoping study cautionary statement: The scoping study referred to in this announcement is based on low-level technical and economic assessments and is insufficient to support estimation of Ore Reserves or to provide assurance of an economic development case at this stage, or to provide certainty that the conclusions of the scoping study will be realised. The study is based on 60% Indicated and 40% Inferred Mineral Resources (refer to footnote 4 for the cautionary statement).
3. Competent Persons Statement and cautionary statement – Exploration Results and Exploration Target: The information in this announcement that relates to Exploration Results and Exploration Targets for Hermosa (including Peake) is based on information compiled by David Bertuch, a Competent Person who is a Member of The Australasian Institute of Mining and Metallurgy and is employed by South32. Mr Bertuch has sufficient experience that is relevant to the style of mineralisation and type of deposit under consideration and to the activity being undertaken to qualify as a Competent Person as defined in the 2012 Edition of the 'Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves'. Mr. Bertuch consents to the inclusion in the report of the matters based on his information in the form and context in which it appears. The JORC Table 1 (sections 1 and 2) related to the Exploration Results and Exploration Targets is included in Annexure 1. In respect of those Exploration Targets, the potential quantity and grade is conceptual in nature. There has been insufficient exploration to determine a Mineral Resource and there is no certainty that further exploration work will result in the determination of Mineral Resources.
4. Mineral Resource Statements for the Taylor and Clark deposits: The information in this announcement that relates to Mineral Resources for the Taylor and Clark deposits is extracted from South32's FY21 Annual Report (www.south32.net) published on 3 September 2021. The information was prepared by a Competent Person in accordance with the requirements of the JORC Code. South32 confirms that it is not aware of any new information or data that materially affects the information included in the original market announcement, and that all material assumptions and technical parameters underpinning the estimates in the relevant market announcement continue to apply and have not materially changed. South32 confirms that the form and context in which the Competent Person's findings are presented have not been materially modified from the original market announcement.
5. Resource life is estimated using Mineral Resources (extracted from South32's FY21 Annual Report published on 3 September 2021 and available to view on www.south32.net) and Exploration Target (details of which are available in this announcement) converted to a run-of-mine basis using conversion factors, divided by the nominated run-of-mine production rate on a 100% basis. Whilst South32 believes it has a reasonable basis to reference this resource life and incorporate it within its Production Targets, it should be noted that resource life calculations are indicative only and do not necessarily reflect future uncertainties such as economic conditions, technical or permitting issues. Resource life is based on our current expectations of future results and should not be solely relied upon by investors when making investment decisions.
6. Production Targets Cautionary Statement: The information in this announcement that refers to the Production Target and forecast financial information is based on Measured (20%), Indicated (62%) and Inferred (14%) Mineral Resources and Exploration Target (4%) for the Taylor Deposit. All material assumptions on which the Production Target and forecast financial information is based is available in Annexure 1. The Mineral Resources underpinning the Production Target have been prepared by a Competent Person in accordance with the JORC Code (refer to footnote 4 for the cautionary statement). All material assumptions on which the Production Target and forecast financial information is based is available in Annexure 2. There is low level of geological confidence associated with the Inferred Mineral Resources and there is no certainty that further exploration work will result in the determination of Indicated Mineral Resources or that the Production Target will be realised. The potential quantity and grade of the Exploration Target is conceptual in nature. In respect of the Exploration Target used in the Production Target, there has been insufficient exploration to determine a Mineral Resource and there is no certainty that further exploration work will result in the determination of Mineral Resources or that the Production Target itself will be realised. The stated Production Target is based on South32's current expectations of future results or events and should not be solely relied upon by investors when making investment decisions. Further evaluation work and appropriate studies are required to establish sufficient confidence that this target will be met. South32 confirms that inclusion of 18% tonnage (14% Inferred Mineral Resources and 4% Exploration Target) is not the determining factor of the project viability and the project forecasts a positive financial performance when using 82% tonnage (20% Measured and 62% Indicated Mineral Resources). South32 is satisfied, therefore, that the use of Inferred Mineral Resources and Exploration Target in the Production Target and forecast financial information reporting is reasonable.
7. Preferred case design capacity based on Taylor PFS outcomes.
8. Flux Exploration Target: The information in this announcement that relates to the Exploration Target for Flux is extracted from "South32 Strategy and Business Update" published on 18 May 2021 and is available to view on www.south32.net. The information was prepared by a Competent Person in accordance with the requirements of the JORC Code. South32 confirms that it is not aware of any new information or data that materially affects the information included in the original market announcement. South32 confirms that the form and context in which the Competent Person's findings are presented have not been materially modified from the original market announcement.
9. Payable zinc equivalent was calculated by aggregating revenues from payable zinc, lead and silver, and dividing the total revenue by the price of zinc. Average metallurgical recovery assumptions are 90% for zinc, 91% for lead and 81% for silver in lead concentrate. FY21 average index prices for zinc (US$2,695/t), lead (US$1,992/t) and silver (US$25.50/oz) (excluding treatment and refining charges) have been used.
10. Based on steady state production years (FY30 to FY44).
11. AISC includes Operating unit costs (including royalties), TCRCs and sustaining capital expenditure.
12. Lead and silver credits are calculated using FY21 average index prices for lead (US$1,992/t) and silver (US$25.50/oz).
13. South32 is a founding member of the Electric Mine Consortium, which aims to accelerate progress towards a fully electrified zero carbon, zero particulates, mine. More information is available at www.electricmine.com.
14. Federal tax of 21.0% and Arizona state tax of 4.9% of taxable income, subject to applicable allowances. Hermosa has an opening tax loss balance of approximately US$83M as at 30 June 2020. Property and severance taxes are also expected to be paid. Based on the PFS schedule, we expect to commence paying income taxes from FY29.

About us

South32 is a globally diversified mining and metals company. Our purpose is to make a difference by developing natural resources, improving people's lives now and for generations to come. We are trusted by our owners and partners to realise the potential of their resources. We produce bauxite, alumina, aluminium, metallurgical coal, manganese, nickel, silver, lead and zinc at our operations in Australia, Southern Africa and South America. With a focus on growing our base metals exposure, we also have two development options in North America and several partnerships with junior explorers around the world.

Investor Relations

Alex Volante		Tom Gallop	
T	+61 8 9324 9029	T	+61 8 9324 9030
M	+61 403 328 408	M	+61 439 353 948
E	Alex.Volante@south32.net	E	Tom.Gallop@south32.net

Media Relations

James Clothier		Jenny White	
M	+61 413 391 031	T	+44 20 7798 1773
E	James.Clothier@south32.net	M	+44 7900 046 758
		E	Jenny.White@south32.net

Further information on South32 can be found at www.south32.net.

Approved for release by Graham Kerr, Chief Executive Officer
JSE Sponsor: UBS South Africa (Pty) Ltd
17 January 2022

Forward-looking statements

This release contains forward-looking statements, including statements about trends in commodity prices and currency exchange rates; demand for commodities; production forecasts; plans, strategies and objectives of management; capital costs and scheduling; operating costs; anticipated productive lives of projects, mines and facilities; and provisions and contingent liabilities. These forward-looking statements reflect expectations at the date of this release, however they are not guarantees or predictions of future performance. They involve known and unknown risks, uncertainties and other factors, many of which are beyond our control, and which may cause actual results to differ materially from those expressed in the statements contained in this release. Readers are cautioned not to put undue reliance on forward-looking statements. Except as required by applicable laws or regulations, the South32 Group does not undertake to publicly update or review any forward-looking statements, whether as a result of new information or future events. Past performance cannot be relied on as a guide to future performance. South32 cautions against reliance on any forward looking statements or guidance, particularly in light of the current economic climate and the significant volatility, uncertainty and disruption arising in connection with COVID-19.

Annexure 1: JORC Code Table 1

HERMOSA PROJECT – EXPLORATION RESULTS

The following table provides a summary of important assessment and reporting criteria used for the reporting of Taylor sulphide exploration results for the Hermosa project, which is located in southern Arizona, USA (Figure 1), in accordance with the Table 1 checklist in The Australasian Code for the Reporting of Exploration Results, Mineral Resources and Ore Reserves (The JORC Code, 2012 Edition) on an 'if not, why not' basis.

Section 1 Sampling Techniques and Data

(Criteria in this section apply to all succeeding sections.)

Criteria	Commentary
Sampling techniques	• The drilling that supports the exploration results is located outside of the current Taylor Mineral Resource estimate declared as at 30 June 2021 in the South32 Annual Report. A total of 53 diamond drill holes (HQ/NQ) totalling 73,632 metres have been drilled across the Taylor sulphide mineralisation. In order to define mineralisation continuity, the drilling information used to inform the resource is used for geological interpretation of the exploration results. In addition, the geological model also reflects input from near-surface reverse circulation (RC) drilling. All drilling is at predominantly 1.5m (5') intervals on a half core basis. • A heterogeneity study is yet to be concluded to determine sample representivity. • Core is competent and sample representivity is monitored using predominantly quarter or half core field duplicates submitted at a rate of approximately 1:40 samples. Field duplicates located within mineralisation envelopes demonstrate 70–90% performance to within 30% of original sample splits. • Core assembly, interval mark-up, recovery estimation (over the 3m drill string) and photography all occur prior to sampling and follow documented procedures. • Sample size reduction during preparation involves crushing and splitting of HQ (95.6mm) or NQ (75.3mm) half-core.
Drilling techniques	• Data used for exploration results is based on logging and sampling of HQ diamond core, reduced to NQ in areas of difficult drilling. Triple and split-tube drilling methods were also employed in cases where conditions required these mechanisms to improve recovery. • All drill core has been oriented using the Boart Longyear 'Trucore' system since mid-August 2018. In Q3 FY20, acoustic televiewer data capture was implemented for downhole imagery for the majority of drilling to improve orientation and geotechnical understanding. Structural measurements from oriented drilling have been incorporated in geological modelling to assist with fault interpretation.
Drill sample recovery	• Prior to October 2018, core recovery was determined by summation of individual core pieces within each 3m drill string. Recovery for the drill string has since been measured after oriented core alignment and mark-up. • Core recovery is recorded for all diamond drill holes. Recovery of holes for the ranging and targeting exercise exceeds 96%. • Poor core recovery can occur when drilling overlying oxide material and in major fault zones. To maximise recovery, drillers vary speed, pressure and composition of drilling muds, reduce HQ to NQ core size and use triple tube and '3 series' drill bits. • When core recovery is compared to Zn, Pb and Ag grades for both a whole data set and within individual lithology, there is no discernible relationship. • Correlation analysis suggests there is no relationship between core recovery and depth except where structure is considered. There are isolated cases where lower recovery is localised at intersections of the Taylor sulphide carbonates with a major thrust structure.
Logging	• The entire length of core is photographed and logged for lithology, alteration, structure, rock quality designation (RQD), and mineralisation. • Logging is both quantitative and qualitative; there are a number of examples including estimation of mineralisation percentages and association of preliminary interpretative assumptions with observations. • All logging is peer reviewed against core photos and in the context of current geological interpretation and surrounding drill holes during geological model updates. • Logging is to a level of detail to support the exploration results.

Criteria	Commentary
Sub-sampling techniques and sample preparation	• Sawn half core and barren whole core samples are taken on predominantly 1.5m intervals for the entire drill hole after logging. Mineralisation is highly visual. Sampling is also terminated at litho-structural and mineralogical boundaries to reduce the potential for boundary/dilution effects at a local scale. • Sample lengths can vary between 0.75m and 2.3m. The selection of the sub-sample size is not supported by sampling studies. • Sample preparation has occurred offsite at an ISO17025-certified laboratory since the Taylor sulphide deposit discovery. This was initially undertaken by Skyline until 2012, then by Australian Laboratory Services (ALS). Samples submitted to ALS are generally 4–6kg in weight. Sample size reduction during preparation involves crushing of HQ (95.6mm) or NQ (75.3mm) half or whole core, splitting of the crushed fraction, pulverisation, and splitting of the sample for analysis. A detailed description of this process is as follows: o The entire half or whole core samples are crushed and rotary split in preparation for pulverisation. Depending on the processing facility, splits are done via riffle or rotary splits for pulp samples. o Fine crushing occurs until 70% of the sample passes 2mm mesh. A 250g split of finely crushed sub-sample is obtained via rotary or riffle splitter and pulverised until 85% of the material is less than 75µm. These 250g pulp samples are taken for assay, and 0.25g splits are used for digestion. • ALS protocol requires 5% of samples to undergo a random granulometry QC test. Samples are placed on 2 micron sieve and processed completely to ensure the passing mesh criteria is maintained. Pulps undergo similar tests with finer meshes. Results are loaded to an online portal for review to client. • Sample preparation precision is also monitored with blind laboratory duplicates assayed at a rate of 1:50 submissions. • Coarse crush preparation duplicate pairs show that 80% of all Zn and Ag pairs for sulphide mineralisation report within +/-20% of original samples. Performance drops off for Pb mineralisation, with less than 70% of duplicates reporting within the +/-20% limits. • More than 85% of pulp duplicates report within a 10% variance for Zn and Ag within all pulp duplicates. Performance for Pb is demonstrably poorer, similar to the preparation duplicates, with less than 80% of all pulp duplicates reporting within this tolerance. • Sub-sampling techniques and sample preparation are adequate for providing quality assay data for declaring exploration results but will benefit from planned studies to optimise sample selectivity and quality control procedures.
Quality of assay data and laboratory tests	• Samples of 0.25g from pulps are processed at ALS Vancouver using ME-ICP61, where these are totally digested using a four-acid method followed by analysis with a combination of Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) and Inductively Coupled Plasma – Atomic Emission Spectroscopy (ICP-AES) determination for 33 elements. Overlimit values for Ag, Pb, Zn, and Mn utilise OG-62 analysis. In November 2020, Hermosa switched to the analytical method ME-MS61 for the four acid 48 element assay for additional elements and improved detection limits alongside the addition of overlimit packages of S-IR07 for S and ME-ICP81 for Mn. Digestion batches of 36 samples plus four internal ALS control samples (one blank, two CRM, and one duplicate) are processed using a four-acid digestion. Analysis is done in groups of three larger digestion batches. Instruments are calibrated for each batch prior to and following the batch. • ALS internal QA/QC samples are continuously monitored for performance. In the case of a blank failure, for example, the entire batch is redone from the crushing stage. If one CRM fails, data reviewers internal to ALS examine the location of the failure within the batch and determine how many samples around the failure should be reanalysed. If both CRMs fail, the entire batch is rerun. No material failures have been observed from the data. • Coarse and fine-grained certified silica blank material submissions, inserted at the beginning and end of every work order of approximately 200 samples, indicate a lack of systematic sample contamination in sample preparation and ICP solution carryover. While systematic contamination issues are not observed for the blanks, the nature of the blanks themselves and suitability for use in QA/QC for polymetallic deposits is in question. o Failures for blanks are noted at greater than ten times detection limit or recommended upper limit for the certified blank material for each analyte, failures range from 0% for Ag (>5ppm), 1% for Cu (>10ppm), 3.5% for Pb (>20ppm), and 7.5% for Zn (>20ppm), and indicate that the blanks themselves are not truly suited for

Criteria	Commentary
	polymetallic deposits. In particular, a coarse blank submitted from 2017–2018 demonstrated consistent contamination above detection limits for Zn, Cu, Mn, and other elements. This has since been replaced with a better performing coarse blank of the end of 2018. o The nature of the blanks and the failures observed are very low for Ag and Cu, and failures for blanks for Zn and Pb are in the hundreds of ppm. No consistent bias has been observed and the magnitude of impacts at the low end for the blanks are very limited. It is not likely to impact the exploration results. • A range of certified reference materials (CRM) are submitted at a rate of 1:40 samples to monitor assay accuracy. The CRM failure rate is very low, ranging from 0.1% to 1.3% depending on analyte, demonstrating reliable laboratory accuracy. • External laboratory pulp duplicates and CRM checks have been submitted to the Inspectorate (Bureau Veritas) laboratory in Reno from November 2017 to 2018 and resumed in March 2021 at a rate of 1:100 to monitor procedural bias. Between 84% and 89% of samples for Zn, Pb and Ag were within expected tolerances of +/-20% when comparing three-acid (Inspectorate) and four-acid (ALS) digest methods. No significant bias was determined. • The nature and quality of assaying and laboratory procedures are appropriate for supporting disclosure of exploration results.
Verification of sampling and assaying	• Core photos of the entire hole are reviewed by alternative company personnel (modelling geologists) to verify significant intersections and finalise geological interpretation of core logging. • Sampling is recorded digitally and uploaded to an Azure SQL project customised database (Plexer) via an API provided by the ALS laboratory and the external laboratory information management system (LIMS). Digital transmitted assay results are reconciled upon upload to the database. • No adjustment to assay data has been undertaken.
Location of data points	• Drill hole collar locations are surveyed by registered surveyors using a GPS Real Time Kinematic (RTK) rover station correlating with the Hermosa project RTK base station and Global Navigation Satellite Systems with up to 1cm accuracy. • Downhole surveys prior to mid-August 2018 were taken with a 'TruShot' single shot survey tool every 76m and at the bottom of the hole. From 20 June 2018 to 14 August 2018, surveys were taken at the same interval with both the single shot and a Reflex EZ-Gyro, before the Reflex EZ-Gyro was used exclusively. • The Hermosa project uses the Arizona State Plane (grid) Coordinate System, Arizona Central Zone, International Feet. The datum is NAD83 with the vertical heights converted from the ellipsoidal heights to NAVD88 using GEOID12B. • All drill hole collar and downhole survey data was audited against source data. • Survey collars have been compared against a one-foot topographic aerial map. Discrepancies exceeding 1.8m were assessed against a current aerial flyover and the differences attributed to surface disturbance from construction development and/or road building. • Survey procedures and practices result in data location accuracy suitable for mine planning.
Data spacing and distribution	• Drill hole spacing ranges from 60m to 600m. The spacing supplies sufficient information for assessment of exploration results. • Geological modelling has determined that drill spacing is sufficient to establish the degree of geological and grade continuity necessary to support review of exploration results.
Orientation of data in relation to geological structure	• For geological modelling, mineralisation varies in dip between 30°NW in the upper Taylor Sulphide domain and between 20°N and 30°N in the lower Taylor Deeps and the Peake Copper-Skarn prospect. Most drilling is oriented vertically and at a sufficiently high angle to allow for accurate representation of grade and tonnage using three-dimensional modelling methods. • There is indication of sub-vertical structures, possibly conduits for or offsetting mineralisation, which have been accounted for at a regional scale through the integration of mapping and drilling data. Angled, oriented core drilling introduced from October 2018

Criteria	Commentary
	is designed to improve understanding of the relevance of these structures to mineralisation.
Sample security	• Samples are tracked and reconciled through a sample numbering and dispatch system from site to the ALS sample distribution and preparation facility in Tucson. The ALS LIMS assay management system provides an additional layer of sample tracking from the point of sample receipt. Movement of sample material from site to the Tucson distribution and preparation facility is a combination of ALS dedicated transport and project contracted transport. Distribution to other preparation facilities and Vancouver is managed by ALS dedicated transport. • Assays are reconciled and results processed in an Azure SQL project customised database (Plexer) which has password and user level security. • Core is stored in secured onsite storage prior to processing. After sampling, the remaining core, returned sample rejects and pulps are stored at a purpose-built facility that has secured access. • All sampling, assaying and reporting of results are managed with procedures that provide adequate sample security.
Audits or reviews	• CSA Global audited the sampling methodology and database for the FY21 Mineral Resource estimate and noted that the sampling and QA/QC measures showed the database to be adequate. • An internal database audit was undertaken in February 2019 for approximately 10% of all drilling intersecting sulphide mineralisation (24 of 242 holes). Data was validated against original data sources for collar, survey, lithology, alteration, mineralisation, structure, RQD and assay (main and check assays). The overall error rates across the database were found to be very low. Isolated issues included the absence of individual survey intervals and minor errors in collar survey precision. All were found to have minimal impact on resource estimation. • Golder and Associates completed an independent audit of the exploration results including QA/QC of reported drillholes outside the FY21 Taylor Sulphide Mineral Resource estimate, adherence to the Resource Range Analysis process, inputs, assumptions and outcomes. Outcomes are considered appropriate for public reporting of exploration results.

Section 2 Reporting of Exploration Results

(Criteria listed in the preceding section also apply to this section.)

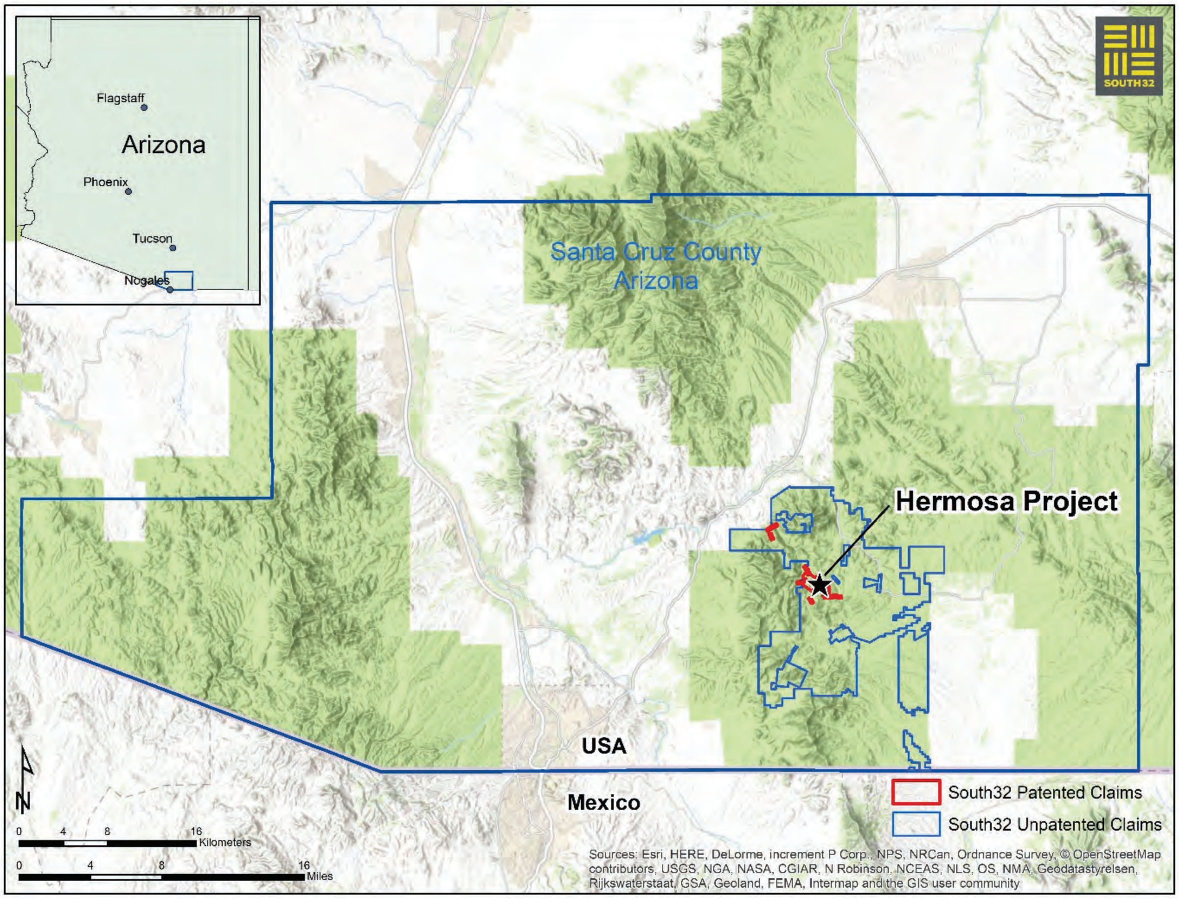
Criteria	Commentary
Mineral tenement and land tenure status	• The Hermosa project mineral tenure (Figure 2) is secured by 30 patented mining claims totalling 228 hectares that have full surface and mineral rights owned fee simple. These claims are retained in perpetuity by annual real property tax payments to Santa Cruz County in Arizona and have been verified to be in good standing until 31 August 2022. • The patented land is surrounded by 1,957 unpatented lode mining claims totalling 13,804 hectares. These claims are retained through payment of federal annual maintenance fees to the Bureau of Land Management (BLM) and filing record of payment with the Santa Cruz County Recorder. Payments for these claims have been made for the period up to their annual renewal on or before 1 September 2022. • Title to the mineral rights is vested in South32's wholly owned subsidiary Arizona Minerals Inc. (AMI). No approval is required in addition to the payment of fees for the claims.
Exploration done by other parties	• ASARCO LLC (ASARCO) acquired the Property in 1939 and completed intermittent drill programs between 1940 and 1991. ASARCO initially targeted silver and lead mineralisation near historical workings of the late 19th century. ASARCO identified silver-lead-zinc bearing manganese oxides in the manto zone of the overlying Clark Deposit between 1946 and 1953. • Follow-up rotary air hammer drilling, geophysical surveying, detailed geological, and metallurgical studies on the manganese oxide manto mineralisation between the mid-1960s and continuing to 1991 defined a heap leach amenable, low-grade manganese

Criteria	Commentary
	and silver resource, reported in 1968 and updated in 1975, 1979 and 1984. The ASARCO drilling periods account for 98 drill holes from the database. • In March 2006, AMI purchased the ASARCO property and completed a re-assay of pulps and preliminary SO_2 leach tests on the manto mineralisation to report a Preliminary Economic Assessment (PEA) in February 2007. Drilling of RC and diamond holes between 2006 and 2012 focused on the Clark Deposit (235 holes) and early definition of the Taylor Deposit sulphide mineralisation (16 holes), first intersected in 2010. Data collected from the AMI 2006 campaign is the earliest information contributing to estimation of the Taylor Deposit Mineral Resource. • AMI drill programs between 2014 and August 2018 (217 diamond holes) focused on delineating Taylor Deposit sulphide mineralisation, for which Mineral Resource estimates were reported in compliance to NI 43-101 (Foreign Estimate) in November 2016 and January 2018.
Geology	• The regional geology is set within Lower-Permian carbonates, underlain by Cambrian sediments and Proterozoic granodiorites. The carbonates are unconformably overlain by Triassic to late-Cretaceous volcanic rocks (Figures 3 and 4). The regional structure and stratigraphy are a result of late-Precambrian to early-Palaeozoic rifting, subsequent widespread sedimentary aerial and shallow marine deposition through the Palaeozoic Era, followed by Mesozoic volcanism and late batholitic intrusions of the Laramide Orogeny. Mineral deposits associated with the Laramide Orogeny tend to align along regional NW structural trends. • Cretaceous-age intermediate and felsic volcanic and intrusive rocks cover much of the Hermosa project area and host low-grade disseminated silver mineralisation, epithermal veins and silicified breccia zones that have been the source of historic silver and lead production. • Mineralisation styles in the immediate vicinity of the Hermosa project include the carbonate replacement deposit (CRD) style zinc-lead-silver base metal sulphides of the Taylor Deposit and deeper skarn-style copper-zinc-lead-silver base metal sulphides of the Peake prospect and an overlying manganese-silver oxide manto deposit of the Clark Deposit. • The Taylor Deposit comprises the overlying Taylor Sulphide, and Taylor Deeps domains that are separated by a thrust fault. Approximately 600–750m lateral and south to the Taylor Deeps domain, the Peake copper-skarn sulphide mineralisation is identified in older lithological stratigraphic units along the interpreted continuation of the thrust fault (Figures 5 and 6). • The Taylor Sulphide Deposit extends to a depth of around 1,000m and is hosted within approximately a 450m thickness of Palaeozoic carbonates that dip 30°NW, identified as the Concha, Scherrer and Epitaph Formations. • Taylor Sulphide mineralisation is dominantly constrained within a tilted and thrusted carbonate stratigraphy and to a lesser degree the overlying volcanic stratigraphy. The mineralising system is yet to be fully drill tested in multiple directions. At Taylor, the sulphide mineralisation is constrained up-dip where it merges into the overlying oxide manto mineralisation of the Clark Deposit, representing a single contiguous mineralising system. • The north-bounding edge of the thrusted carbonate rock is marked by a thrust fault where it ramps up over the Jurassic/Triassic 'Older Volcanics' and 'Hardshell Volcanics'. This interpreted pre-mineralising structure that created the sequence of carbonates also appears to be a key mineralising conduit. The thrust creates a repetition of the carbonate formations below the Taylor Sulphide domain, which host the Taylor Deeps mineralisation. • The Taylor Deeps mineralisation dips 10°N to 30°N, is approximately 100m thick, and primarily localised near the upper contact of the Concha Formation and the unconformably overlying 'Older Volcanics'. Some of the higher-grade mineralisation is also accumulated along a westerly plunging lineation intersection where the Concha Formation contacts the Lower Thrust. Mineralisation has not been closed off down-dip or along strike. • Lateral to the Taylor Deeps mineralisation, skarn sulphide mineralisation is identified in older lithological stratigraphic units along the interpreted continuation of the thrust fault. This creates an interpreted continuous structural and lithological controlled system from the deeper skarn Cu domain into Taylor Deeps, Taylor Sulphide, and associated volcanic hosted mineralisation and the Clark oxide Deposit.

Criteria	Commentary
Drill hole Information	• A drill hole plan (Figure 4) provides a summary of drilling collar locations that support the exploration results and surface geology. Figure 5 provides a drill hole plan relative to the Taylor FY21 and Clark FY20 Mineral Resource domains, and the Peake copper-skarn prospect. Figure 6 shows a cross section relative to key inputs in Figure 5 alongside the Taylor thrust and simplified geology. • Table 1 summarises all the drill holes that support Exploration Targets. • Table 2 summarises all significant intersections. • All drill hole information, including tabulations of drill hole positions and depths is stored within project data files on a secure company server. • Hole depths vary between 550m and 2,000m.
Data aggregation methods	• Mineralisation domains were created within bounding litho-structural zones using both manually interpreted volumes and Radial Based Function (RBF) indicator interpolation of the cumulative in-situ value of metal content. The metal content descriptor, "Metval", is calculated by summing the multiplication of economic analyte grades for Zn, Pb, Ag and Cu, price and recovery. Metval cut-off ranges for mineralisation domains range from US$5-7.5 for the different litho-structural domains. Material above the Metval cut-off was modelled utilising the indicator numerical model function in Leapfrog Geo™ to create volumes. • Significant assay intercepts are reported as length-weighted averages exceeding either 2% ZnEq or 0.2% Cu. • No top cuts are applied to intercept calculations. • ZnEq (%) is zinc equivalent which accounts for combined value of zinc, lead and silver. Metals are converted to ZnEq via unit value calculations using long term consensus metal price assumptions and relative metallurgical recovery assumptions. For the Exploration Target, overall metallurgical recoveries differ for geological domains and vary from 87% to 94% for zinc, 94% to 95% for lead, and 87% to 92% for silver. Exploration Target tonnage and grade is reported above an NSR that accounts for payability of metals in concentrate products, which depending on other factors, may decrease the total payable recovered metal. Average payable metallurgical recovery assumptions are zinc (Zn) 90%, lead (Pb) 91%, and silver (Ag) 81% and metals pricing assumptions are South32's prices for the December 2021 quarter. The formula used for calculation of zinc equivalent is ZnEq = Zn (%) + 0.718 * Pb (%) + 0.0204 * Ag (g/t).
Relationship between mineralisation widths and intercept lengths	• Near vertical drilling (75–90^{0}) amounts to the majority of holes used in the creation of the geology model. Where they intersect the low to moderately dipping (30°) stratigraphy the intersection length can be up to 15% longer than true-width. • Since August 2018, drilling has been intentionally angled, where appropriate, between 60° and 75° to maximise the angle at which mineralisation is intersected. • The mineralisation is modelled in 3D to appropriately account for sectional bias or apparent thickness issues which may result from 2D interpretation.
Diagrams	• Relevant maps and sections are included with this market announcement.
Balanced reporting	• Exploration results are reported considering drill holes completed outside the disclosed Mineral Resource estimate as at 30 June 2021. All drill hole intersections are considered in this assessment for balanced reporting. A list of drill holes is included as an annexure to this announcement.
Other substantive exploration data	• Aside from drilling, the geological model is compiled from local and regional mapping, geochemistry sampling and analysis, and geophysical surveys. • Magneto-telluric (MT) and induced polarisation surveys (IP) were conducted with adherence to industry standard practices by Quantec Geosciences Inc. In most areas, the MT stations were collected along N–S lines with a spacing of 200m. Spacing between lines is 400m. Some areas were collected at 400m spacing within individual lines. IP has also been collected, both as 2D lines and as 2.5D swaths, collected with a variable spacing of data receivers. IP surveying is ongoing over the project. • Quality control of geophysical data includes using a third-party geophysical consultant to verify data quality and provide secondary inversions for comparison to Quantec interpretations.
Further work	• The following work is planned to be conducted: o The deeper Peake Copper-skarn prospect will be assessed in detail.

Criteria	Commentary
	o Additional drilling of the Peake Copper-skarn prospect is planned to occur in CY22, guided by the outcomes of a detailed assessment in the area adjacent to Taylor Deeps where very little drilling is completed so far. o Additional ongoing drilling will assess Taylor and Taylor Deeps extensional opportunities. o Exploratory drilling underneath and downdip of the historic mine workings at the Flux prospect is planned to occur in CY22, pending permit approvals. o Additional geophysics over the project is ongoing.

Figure 1: Regional location plan



Sources: Esri, HERE, DeLorme, increment P Corp., NPS, NRCan, Ordnance Survey, © OpenStreetMap contributors, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community

Figure 2: Hermosa project tenement map

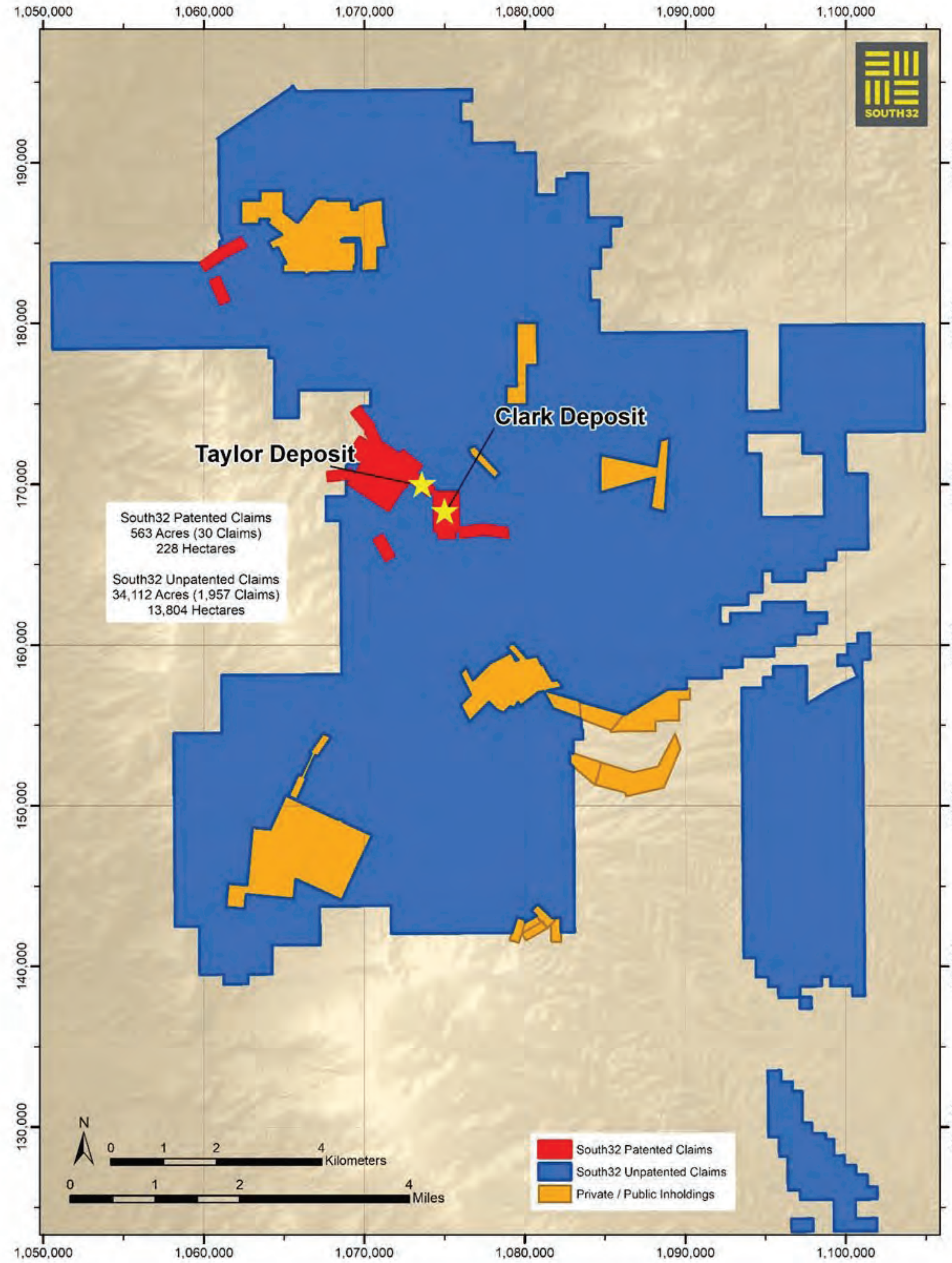
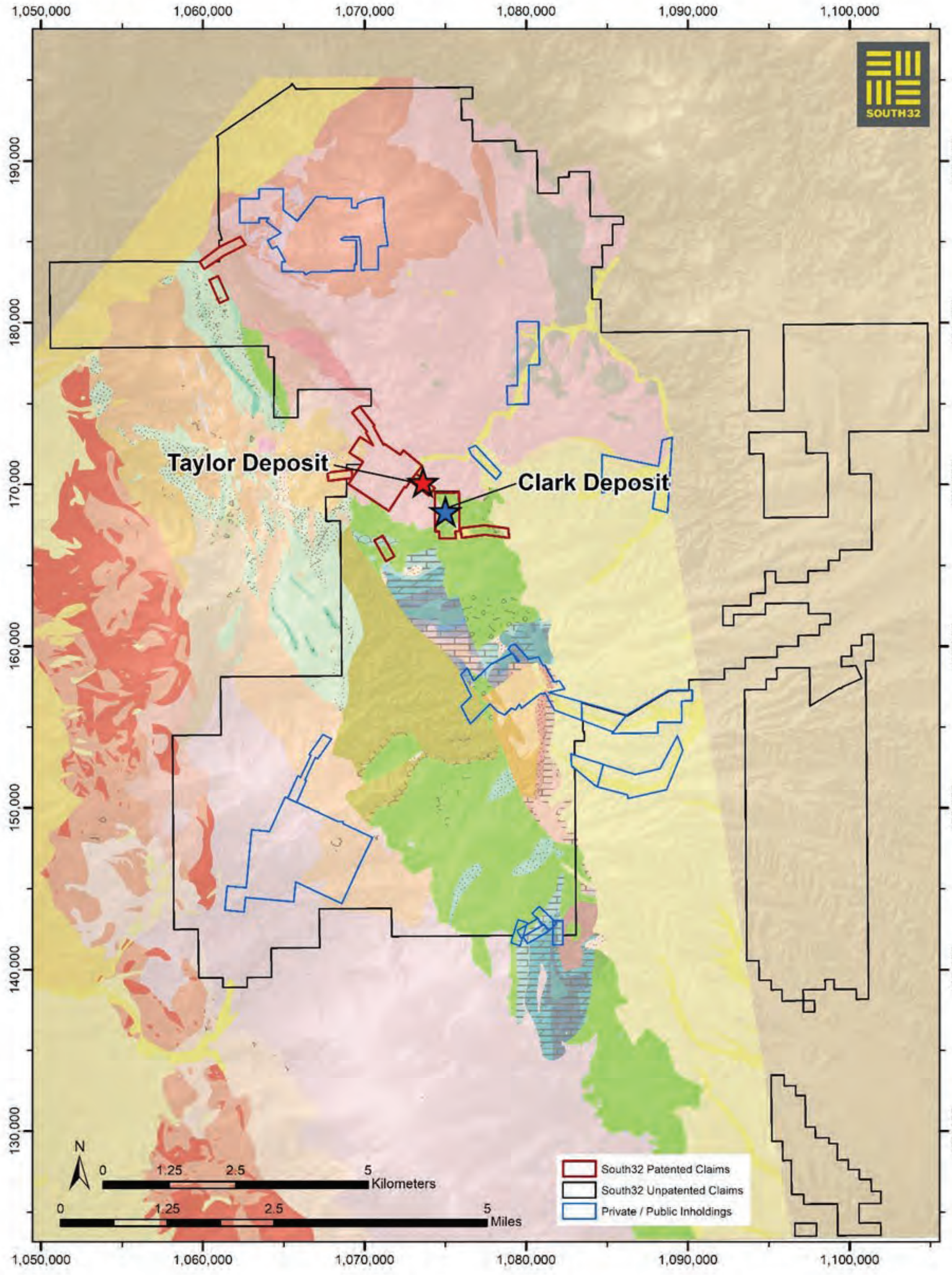


Figure 3: Hermosa project regional geology



Map units

Symbol, Unit name

Qal—Younger alluvium and talus
QTal—Older alluvium
QTg—Gravel and conglomerate
Tl—Limestone
Tt—Biotite rhyolite tuff
si—Silicification
Tv—Volcaniclastic rocks of middle Alum Gulch
Tib—Intrusive breccia of middle Alum Gulch
Tqp—Quartz feldspar porphyry of middle Alum Gulch
Tqpx—Xenolithic quartz feldspar porphyry of middle Alum Gulch
Tqmp—Quartz monzonite porphyry, in granodiorite of the Patagonia Mountains
Tqmpb—Breccia, in quartz monzonite porphyry (unit Tqmp) of granodiorite of the Patagonia Mountains
Tg—Granodiorite, in granodiorite of the Patagonia Mountains
Tgb—Breccia, in granodiorite (unit Tg) of granodiorite of the Patagonia Mountains
Tlp—Latite porphyry, in granodiorite of the Patagonia Mountains
Tbq—Biotite quartz monzonite, in granodiorite of the Patagonia Mountains
Tbqb—Breccia, in biotite quartz monzonite (unit Tbq) of granodiorite of the Patagonia Mountains
Tbg—Biotite granodiorite, in granodiorite of the Patagonia Mountains
Tibx—Intrusion breccia, in granodiorite of the Patagonia Mountains
Tsy—Syenodiorite or mangerite, in granodiorite of the Patagonia Mountains
Tag—Biotite augite quartz diorite, in granodiorite of the Patagonia Mountains
Tmp—Quartz monzonite porphyry of Red Mountain
TKr—Rhyolite of Red Mountain
TKggt—Gringo Gulch Volcanics
Ka—Trachyandesite
r—Rhyolite or latite, in trachyandesite (unit Ka)
Km—Pyroxene monzonite
Kl—Biotite quartz latite(?)
Kv—Silicic volcanics
la—Biotite latite(?), in silicic volcanics (unit Kv)
Kpg—Porphyritic biotite granodiorite
Kb—Bisbee Formation
Kbc—Conglomerate, in Bisbee Formation (unit Kb)
Jtg—Granite of Three R Canyon, in granite of Cumero Canyon
Jtgb—Breccia, in granite of Three R Canyon (unit Jtg) of granite of Cumero Canyon
Jcm—Porphyritic granite, in granite of Cumero Canyon
Jcs—Equigranular alkali syenite, in granite of Cumero Canyon
Jcsb—Breccia, in equigranular alkalik syenite (unit Jcs) of granite of Cumero Canyon
Jcg—Equigranular granite, in granite of Cumero Canyon
Jcgb—Breccia, in equigranular granite (unit Jcg) of granite of Cumero Canyon
Jhm—Hornblende monzonite of European Canyon
JTRv—Volcanic rocks, in silicic volcanic rocks
ha—Hornblende andesite dike and (or) plug, in volcanic rocks (unit JTRv)
b—Volcanic breccia, in volcanic rocks (unit JTRv)
s—Sedimentary rocks, in volcanic rocks (unit JTRv)
cg—Limestone conglomerate, in volcanic rocks (unit JTRv)
qz—Quartzite, in volcanic rocks (unit JTRv)
ls—Exotic blocks of upper Paleozoic limestone, in volcanic rocks (unit JTRv)
w—Rhyolitic welded(?) tuff, in volcanic rocks (unit JTRv)
lp—Latite(?) porphyry, in volcanic rocks (JTRv)
JTRvs—Volcanic and sedimentary rocks, in silicic volcanic rocks
TRm—Mount Wrightson Formation
q—Quartzite, in Mount Wrightson Formation (unit TRm)
a—Biotite(?)-albite andesite lava(?), in Mount Wrightson Formation (unit TRm)
t—Coarse volcaniclastic beds, in Mount Wrightson Formation (unit TRm)
TRms—Sedimentary rocks, in the Mount Wrightson Formation (unit TRm)
Pcn—Concha Limestone
Ps—Scherrer Formation
Pe—Epitaph Dolomite
Pc—Colina Limestone
PPe—Earp Formation
Ph—Horquilla Limestone
Me—Escabrosa Limestone
Dm—Martin Limestone
Ca—Abrigo Limestone
Cb—Bolsa Quartzite
pCq—Biotite or biotite-hornblende quartz monzonite
pCh—Hornblende-rich metamorphic and igneous rocks
pCm—Biotite quartz monzonite
pCd—Hornblende diorite

Figure 4: Taylor Deposit local geology and Exploration Target collar locations

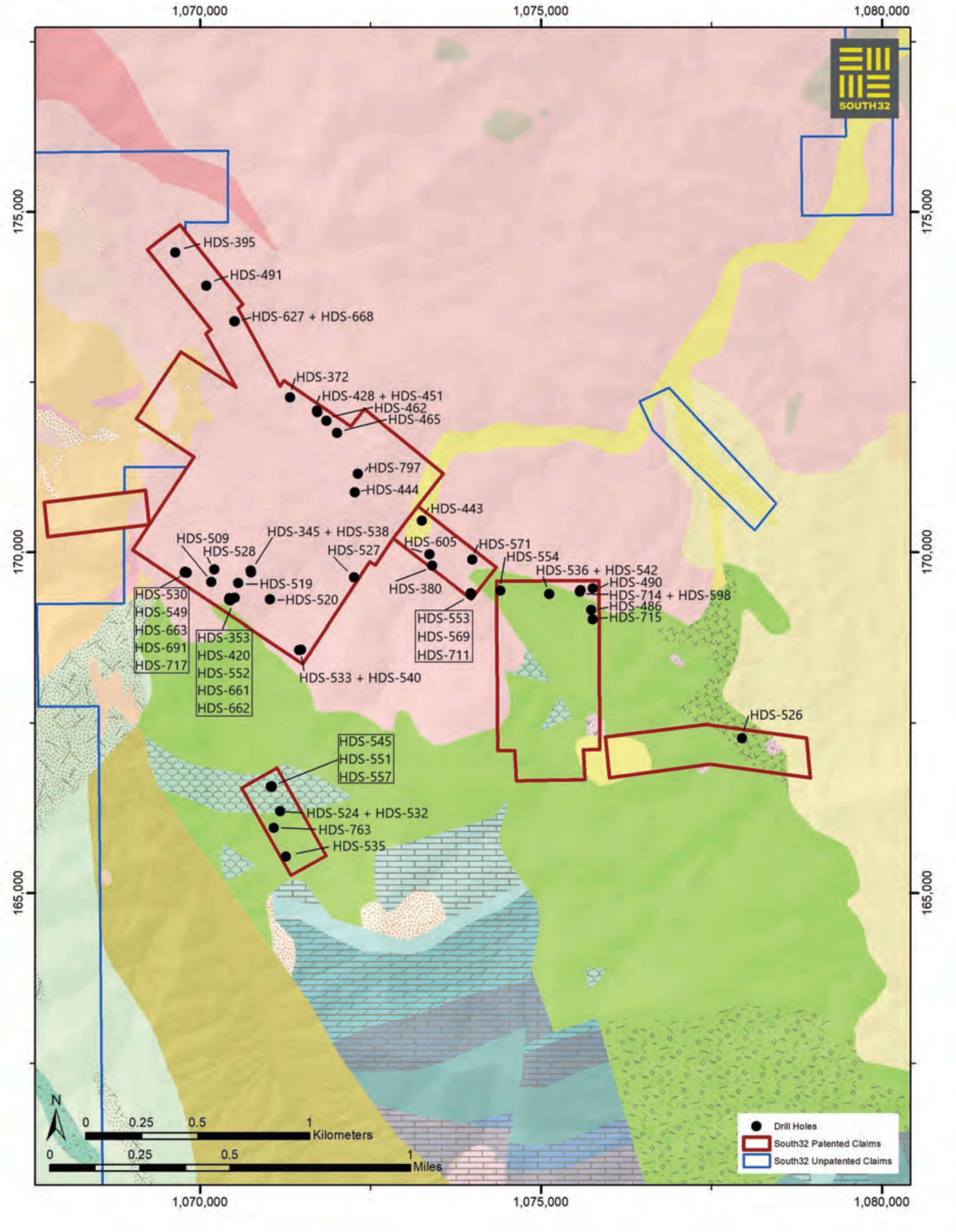


Figure 5: Plan view of the Taylor and Clark Mineralisation Domains with exploration drill holes and the Peake Copper-Skarn Prospect

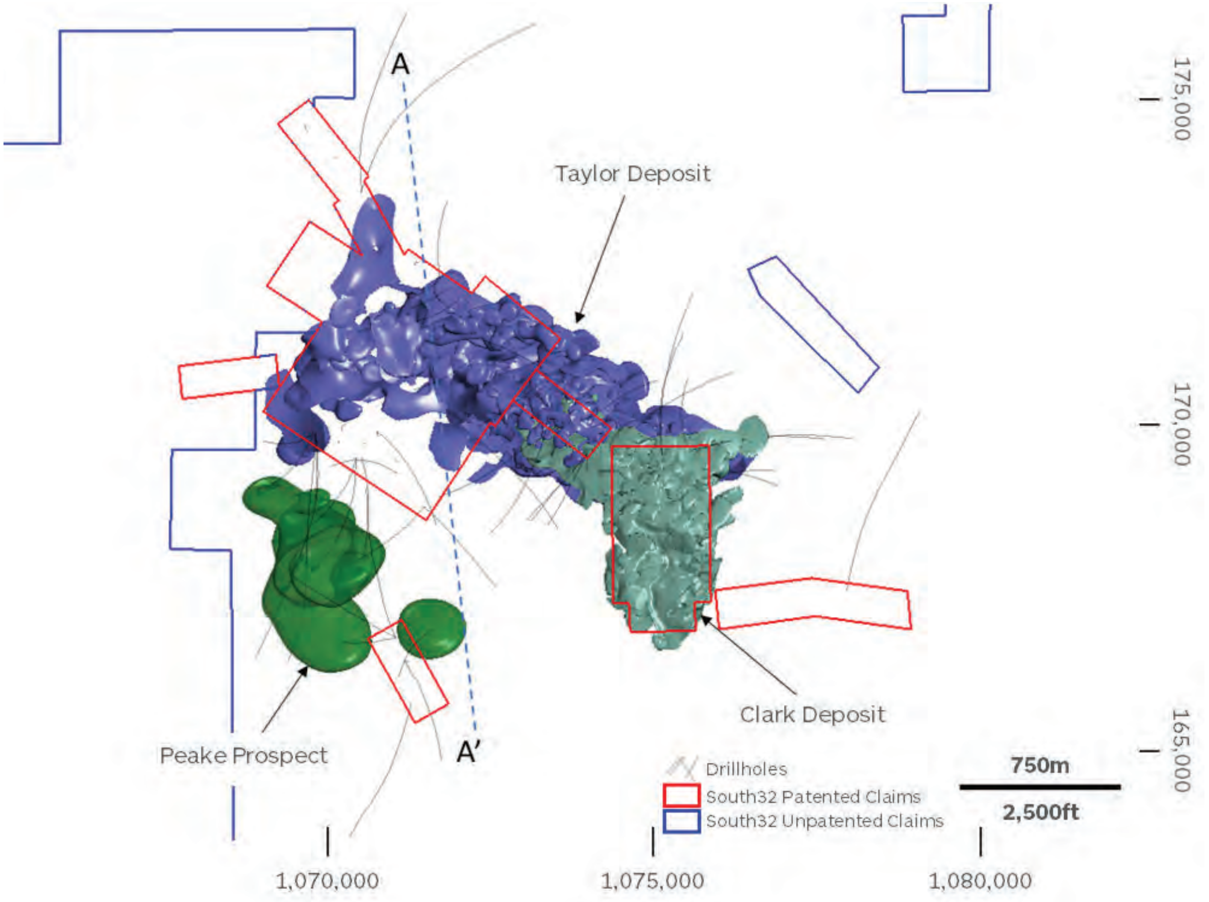


Figure 6: Cross-section through the Taylor and Clark mineralisation domains showing exploration drill holes, simplified geology, Taylor Thrust and the Peake Copper-Skarn Prospect – looking east

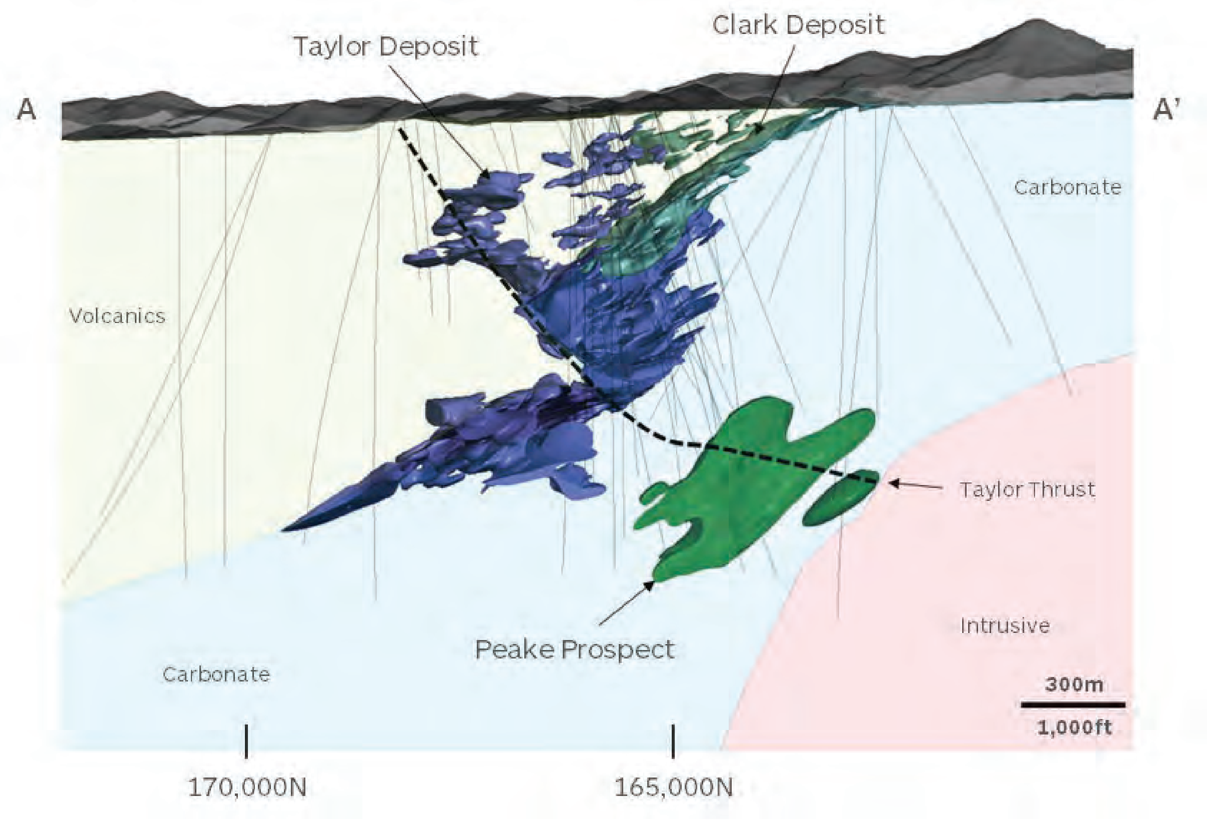


Table 1: Hole ID, collar location, dip, azimuth and drill depth

Hole ID	East (UTM)	North (UTM)	Elevation (m)	Dip	Azimuth	TD Depth (m)
HDS-345	525881	3480733	1603.2	-90	0	1257.9
HDS-353	525781	3480612	1592.8	-90	0	1701.5
HDS-372	526061	3481515	1564.6	-90	0	1780.9
HDS-380	526689	3480757	1580.8	-60	230	1321.9
HDS-395	525553	3482168	1502.4	-90	0	1642.0
HDS-420	525785	3480607	1592.8	-82	85	1372.8
HDS-428	526180	3481454	1578.1	-75	355	1633.6
HDS-443	526645	3480958	1525.9	-45	230	492.9
HDS-444	526347	3481088	1566.2	-65	230	825.1
HDS-451	526182	3481448	1579.4	-75	230	656.7
HDS-462	526223	3481409	1574.6	-75	230	792.8
HDS-465	526268	3481353	1569.8	-75	230	827.2
HDS-486	527398	3480552	1602.0	-75	85	1142.1
HDS-490	527406	3480648	1593.8	-60	70	1126.8
HDS-491	525690	3482016	1501.9	-90	0	1595.0
HDS-509	525701	3480691	1602.1	-90	0	1424.8
HDS-519	525822	3480685	1602.0	-90	0	1422.2
HDS-520	525963	3480611	1573.1	-90	0	1562.7
HDS-524	526002	3479665	1658.8	-90	0	1220.0
HDS-526	528068	3479975	1571.1	-65	15	1617.6
HDS-527	526339	3480706	1542.5	-63	125	1288.4
HDS-528	525716	3480747	1610.3	-90	0	1724.3
HDS-530	525583	3480735	1604.3	-82	230	1446.9
HDS-532	526001	3479666	1659.1	-60	150	1075.9
HDS-533	526092	3480386	1627.3	-65	120	1257.6
HDS-535	526026	3479462	1678.1	-60	190	1419.8
HDS-536	527211	3480625	1567.4	-60	0	1206.1
HDS-538	525878	3480741	1603.3	-70	130	1526.1
HDS-540	526101	3480387	1627.3	-70	220	1528.9
HDS-542	527211	3480624	1567.1	-70	0	1574.0
HDS-545	525960	3479775	1665.7	-60	335	1427.1
HDS-549	525585	3480738	1604.4	-78	200	1813.0
HDS-551	525963	3479774	1665.5	-75	270	1542.6
HDS-552	525806	3480620	1592.9	-70	165	1851.4
HDS-553	526860	3480624	1560.5	-75	220	1524.0
HDS-554	526992	3480642	1550.9	-65	35	1314.9
HDS-557	525963	3479776	1665.5	-60	300	1199.1
HDS-569	526861	3480630	1560.3	-62	205	900.1
HDS-571	526868	3480782	1543.4	-66	45	961.0
HDS-598	527348	3480633	1606.7	-75	333	1287.9
HDS-605	526678	3480806	1575.7	-66	185	1468.4
HDS-627	525814	3481856	1502.2	-60	20	1891.9
HDS-661	525782	3480619	1593.6	-72	179	1981.2
HDS-662	525782	3480619	1593.6	-76	190	1985.2
HDS-663	525592	3480733	1603.6	-70	175	1980.6
HDS-668	525817	3481856	1502.4	-60	20	1905.0
HDS-691	525592	3480734	1603.9	-68	180	2079.0

Hole ID	East (UTM)	North (UTM)	Elevation (m)	Dip	Azimuth	TD Depth (m)
HDS-711	526863	3480628	1560.2	-55	218	776.3
HDS-714	527351	3480641	1606.2	-52	73	1184.8
HDS-715	527404	3480509	1607.7	-65	75	817.2
HDS-717	525592	3480735	1603.9	-70	175	1782.5
HDS-763	525971	3479591	1629.9	-78	15	1943.4
HDS-797	526361	3481170	1560.0	-55	108	551.1

Table 2: Significant intersections

Hole ID	From (m)	To (m)	Cut off	Width (m)	Zinc (%)	Lead (%)	Silver (ppm)	Copper (%)
HDS-345	No significant intersection							
HDS-353	966.2	976.0	2% ZnEq	9.8	12.2	8.2	77	0.69
	Including							
	966.2	971.4	2% ZnEq	5.2	22.0	14.8	130	1.21
HDS-372	312.4	318.5	2% ZnEq	6.1	1.9	0.7	31	0.03
	458.1	463.6	2% ZnEq	5.5	4.8	2.1	90	0.04
HDS-380	878.1	880.4	2% ZnEq	2.3	2.6	1.8	362	0.33
	898.7	906.3	2% ZnEq	7.6	1.0	1.9	142	0.23
HDS-395	448.7	454.3	2% ZnEq	5.6	3.3	3.7	55	0.08
HDS-420	452.5	465.3	2% ZnEq	12.8	2.5	1.1	73	0.11
HDS-428	266.4	269.3	2% ZnEq	2.9	3.6	1.2	108	0.01
	1507.7	1516.5	2% ZnEq	8.8	1.5	1.8	77	0.19
HDS-443	No significant intersection							
HDS-444	691.0	716.6	2% ZnEq	25.6	1.4	0.7	15	0.04
	Including							
	709.3	716.6	2% ZnEq	7.3	3.1	1.2	22	0.04
	790.0	793.1	2% ZnEq	3.1	2.5	1.2	273	0.00
	803.1	809.5	2% ZnEq	6.4	1.5	2.1	69	0.18
HDS-451	351.1	363.3	2% ZnEq	12.2	1.4	0.5	13	0.00
	Including							
	357.8	363.3	2% ZnEq	5.5	1.9	0.8	17	0.01
HDS-462	428.9	432.2	2% ZnEq	3.4	0.9	1.3	48	0.06
HDS-465	322.6	335.6	2% ZnEq	13.0	1.0	0.4	71	0.09
HDS-486	118.0	131.7	2% ZnEq	13.7	0.1	0.9	64	0.04
	155.4	189.6	2% ZnEq	34.1	0.1	0.6	86	0.09
	Including							
	169.8	189.6	2% ZnEq	19.8	0.1	1.0	101	0.15
	249.8	290.9	2% ZnEq	41.1	1.1	1.9	57	0.09
HDS-490	191.1	197.2	2% ZnEq	6.1	0.1	0.4	77	0.08
	364.8	401.4	2% ZnEq	36.6	0.1	1.1	69	0.04
	Including							
	379.5	399.9	2% ZnEq	20.4	0.1	1.6	97	0.05
	442.6	450.2	2% ZnEq	7.6	5.4	0.0	4	0.00
HDS-491	381.9	400.8	2% ZnEq	18.9	13.1	8.3	137	0.39
	Including							
	387.1	399.1	2% ZnEq	12.0	17.3	11.5	171	0.42
HDS-509	846.4	851.0	2% ZnEq	4.6	1.4	0.7	21	0.10
HDS-519	389.2	393.8	2% ZnEq	4.6	0.3	0.3	688	0.33
	731.5	736.1	2% ZnEq	4.6	3.1	1.6	32	0.10

Hole ID	From (m)	To (m)	Cut off	Width (m)	Zinc (%)	Lead (%)	Silver (ppm)	Copper (%)
HDS-520	684.9	689.3	2% ZnEq	4.4	2.7	1.6	39	0.37
	694.9	704.4	2% ZnEq	9.4	1.7	1.7	25	0.08
	1049.0	1053.7	2% ZnEq	4.7	1.5	1.7	37	0.37
HDS-524	No significant intersection							
HDS-526	46.3	52.7	2% ZnEq	6.4	0.0	0.1	100	0.01
	61.3	84.4	2% ZnEq	23.2	0.0	0.3	113	0.03
HDS-527	191.1	200.3	2% ZnEq	9.1	1.2	0.9	23	0.00
HDS-528	No significant intersection							
HDS-530	840.3	846.4	0.2% Cu	6.1	0.1	0.0	13	0.59
	904.3	910.4	0.2% Cu	6.1	0.3	0.1	14	0.39
	1407.6	1419.1	2% ZnEq	11.6	1.8	1.1	68	0.24
HDS-532	76.5	83.8	2% ZnEq	7.3	1.3	0.8	193	0.15
HDS-533	No significant intersection							
HDS-535	No significant intersection							
HDS-536	No significant intersection							
HDS-538	1445.4	1451.9	2% ZnEq	6.6	0.1	1.2	74	0.03
HDS-540	1279.2	1389.0	0.2% Cu	109.7	0.1	0.3	15	0.62
	Including							
	1303.6	1309.7	0.2% Cu	6.1	0.2	0.4	61	3.48
	1469.7	1488.0	0.2% Cu	18.3	0.0	0.0	10	0.63
HDS-542	128.6	133.2	2% ZnEq	4.6	0.0	0.5	80	0.03
	800.3	809.9	2% ZnEq	9.6	0.8	0.8	30	0.00
HDS-545	No significant intersection							
HDS-549	1169.5	1175.6	0.2% Cu	6.1	1.5	1.6	312	1.92
HDS-551	1100.6	1111.6	0.2% Cu	11.0	0.0	0.2	10	0.39
	1254.9	1280.8	0.2% Cu	25.9	0.0	0.0	10	0.54
	1294.5	1372.8	0.2% Cu	78.3	0.0	0.1	10	0.51
HDS-552	709.3	714.8	0.2% Cu	5.5	11.2	5.5	64	0.12
	1265.8	1273.9	0.2% Cu	8.1	0.2	0.5	27	0.39
	1308.2	1384.7	0.2% Cu	76.5	0.2	0.4	25	1.52
	Including							
	1309.9	1328.6	0.2% Cu	18.8	0.1	0.2	40	2.77
	And							
	1364.3	1384.7	0.2% Cu	20.4	0.1	0.3	37	2.44
	Including							
	1375.3	1384.7	0.2% Cu	9.5	0.1	0.3	62	4.45
	1478.9	1484.8	0.2% Cu	5.9	1.0	1.5	57	0.41
HDS-553	315.8	340.5	2% ZnEq	24.7	3.4	3.3	266	0.32
	Including							
	315.8	325.2	2% ZnEq	9.4	3.9	8.5	654	0.81
	332.8	340.5	2% ZnEq	7.6	5.8	0.1	40	0.03
HDS-554	181.7	197.8	2% ZnEq	16.2	0.4	5.8	139	0.06
	1138.3	1140.9	2% ZnEq	2.6	3.9	6.4	152	0.03
HDS-557	No significant intersection							
HDS-569	142.3	147.2	2% ZnEq	4.9	3.6	2.4	61	0.03
HDS-571	134.4	166.4	2% ZnEq	32.0	0.7	0.8	94	0.12
	691.6	698.9	2% ZnEq	7.3	4.7	3.4	56	0.14
	743.3	750.7	2% ZnEq	7.5	7.6	18.5	296	0.11
HDS-598	No significant intersection							

Hole ID	From (m)	To (m)	Cut off	Width (m)	Zinc (%)	Lead (%)	Silver (ppm)	Copper (%)
HDS-605	447.1	452.9	2% ZnEq	5.8	2.6	0.9	116	0.19
	512.2	531.6	2% ZnEq	19.4	0.2	1.2	51	0.08
	842.5	845.8	2% ZnEq	3.4	2.1	2.4	196	0.30
HDS-627	349.9	354.5	2% ZnEq	4.6	15.2	14.9	459	0.21
HDS-661	1298.4	1305.2	2% ZnEq	6.7	0.6	3.4	249	0.89
	1322.2	1374.6	0.2% Cu	52.4	0.1	1.1	105	1.73
	Including							
	1322.2	1346.0	0.2% Cu	23.8	0.1	0.8	81	3.32
	And							
	1322.2	1330.1	0.2% Cu	7.9	0.1	0.4	81	7.89
	1386.8	1460.6	0.2% Cu	73.8	0.5	0.7	67	1.06
	Including							
	1399.6	1410.3	0.2% Cu	10.7	0.7	1.5	227	2.84
	1555.1	1573.1	0.2% Cu	18.0	3.2	1.4	87	0.37
HDS-662	1316.4	1329.2	0.2% Cu	12.8	3.4	4.4	137	0.95
	1540.8	1546.7	2% ZnEq	5.9	5.9	2.1	250	0.45
HDS-663	1580.1	1591.8	0.2% Cu	11.7	0.1	0.0	16	0.95
	1615.9	1651.1	0.2% Cu	35.2	1.1	0.1	27	0.56
HDS-668	201.2	211.8	2% ZnEq	10.7	5.5	3.9	270	0.13
	221.0	233.2	2% ZnEq	12.2	5.7	3.9	129	0.03
	699.5	713.2	2% ZnEq	13.7	1.3	4.2	134	0.06
HDS-691	1343.6	1353.6	2% ZnEq	10.1	3.8	3.5	61	0.47
	1384.7	1395.4	0.2% Cu	10.7	2.7	2.9	38	1.03
	1405.9	1415.2	0.2% Cu	9.3	0.5	0.7	11	0.26
	1421.3	1452.1	0.2% Cu	30.8	0.7	0.8	22	0.59
	1463.6	1509.7	0.2% Cu	46.0	0.4	0.5	21	0.43
	1540.6	1549.3	0.2% Cu	8.7	0.3	0.9	51	0.61
	1563.9	1581.3	0.2% Cu	17.4	0.2	0.2	23	0.55
	1662.7	1677.9	0.2% Cu	15.2	2.8	1.1	155	1.19
	1683.4	1692.6	2% ZnEq	9.1	1.5	0.3	45	0.13
	1732.0	1735.2	2% ZnEq	3.2	6.2	0.3	107	0.18
	1994.6	1997.4	2% ZnEq	2.7	1.7	0.3	54	0.08
HDS-711	150.6	153.9	2% ZnEq	3.4	1.9	1.0	244	0.34
HDS-714	372.5	377.0	2% ZnEq	4.6	0.0	1.1	87	0.04
	410.6	415.1	2% ZnEq	4.6	0.0	1.2	65	0.02
	627.9	632.5	2% ZnEq	4.6	2.1	3.6	111	0.06
	682.8	688.8	2% ZnEq	6.1	3.0	3.9	109	0.09
HDS-715	119.5	127.4	2% ZnEq	7.9	0.0	1.7	53	0.05
	167.3	196.0	2% ZnEq	28.7	3.7	0.5	176	0.23
	Including							
	172.8	180.8	2% ZnEq	8.0	7.1	1.2	218	0.71
	300.1	342.3	2% ZnEq	42.2	2.1	1.8	94	0.09
	Including							
	333.3	342.3	2% ZnEq	9.0	6.8	0.7	42	0.08
	563.9	575.3	2% ZnEq	11.4	3.7	3.6	188	0.16
	Including							
	565.4	571.5	2% ZnEq	6.1	4.5	5.4	290	0.19
	591.3	598.9	2% ZnEq	7.6	4.7	2.1	92	0.14
	780.3	787.9	2% ZnEq	7.6	0.2	0.1	96	0.01

Hole ID	From (m)	To (m)	Cut off	Width (m)	Zinc (%)	Lead (%)	Silver (ppm)	Copper (%)
HDS-717	1065.3	1072.4	0.2% Cu	7.2	3.5	2.7	22	0.21
	1306.1	1318.3	0.2% Cu	12.2	1.8	1.8	63	0.82
	1444.1	1466.7	0.2% Cu	22.6	1.7	1.7	46	1.38
	Including							
	1456.6	1466.7	0.2% Cu	10.1	0.5	1.0	78	2.57
	1517.9	1522.2	2% ZnEq	4.3	3.0	1.8	49	0.03
	1718.6	1727.0	0.2% Cu	8.4	1.0	0.1	39	1.99
	1754.1	1763.3	2% ZnEq	9.1	1.4	0.5	42	0.13
HDS-763	1429.8	1439.6	2% ZnEq	9.8	2.3	0.1	3	0.02
HDS-797	No significant intersection							

Annexure 2: Material Assumptions for the Production Target and Forecast Financial Information

Criteria	Commentary
Mineral Resource estimate for conversion to Ore Reserves	• The Production Target is based on 20% Measured, 62% Indicated, 14% Inferred Mineral Resources and 4% Exploration Target. The Mineral Resources were declared as part of South32's Annual declaration of resources and reserves in the Annual Report published on 3 September 2021 and is available to view on www.south32.net. The details of the Exploration Target are included in this announcement (Annexure 1).
Study status	• A pre-feasibility study has been completed for the Taylor Deposit in compliance with the AACE International Class 4 estimate standard. • A technically achievable and economically viable mine plan has been determined by the study team. Material Modifying Factors have been considered and are included in this section of the report.
Cut-off parameters	• Taylor is a polymetallic deposit which uses an equivalent NSR value as a grade descriptor. NSR considers the remaining gross value of the in-situ revenue generating elements once processing recoveries, royalties, concentrate transport, refining costs and other deductions have been considered. • The elements of economic interest used for cut-off determination include silver (Ag), lead (Pb) and zinc (Zn). • The cut-off strategy employed at Taylor is to optimise the NPV of the operation. • An NSR cut-off grade of US$90/tonne was used in the development of mineable stope shapes.
Mining factors or assumptions	• The mining method applied is longhole open stoping with paste backfill. This is the preferred mining method based on a combination of productivity, cost, resource recovery and risk of surface subsidence. • Geotechnical recommendations based on deposit geology have been used to develop the stope shape dimensions. • The mining dilution is applied based on rock dilution or fill dilution dependent on the location of the stope being mined. Dilution factors are applied on a stope by stope basis using incremental dilution widths applied to the stope geometry. • The mining recovery factor is 95% and is applied to all ore tonnes. • Inferred Mineral Resources are incorporated into the stope designs and contribute to the overall weighted grades and NSR of the stope. Inferred Mineral Resources contribute approximately 14% and the Exploration Target contributes 4% of the total planned tonnes. A risk assessment was completed considering Inferred Mineral Resources and the Exploration Target as waste to ensure that the Production Target and forecast financial information as stated can be achieved. Accordingly, the Company believes it has a reasonable basis for reporting a Production Target including those Inferred Mineral Resources and the Exploration Target. • Primary access to the orebody will be through a main shaft and a ventilation shaft. Ore passes, haulage levels and ventilation raises will be established to move material internally within the mine and provide ventilation and cooling. Paste backfill will be produced in a surface backfill plant and distributed underground via a backfill reticulation system. • The proposed mining method with modifying factors applied supports a single-stage ramp-up to the preferred development scenario of up to 4.3Mt per annum.
Metallurgical factors or assumptions	• The Taylor processing plant will consist of well-established processing techniques. Primary crushing will be conducted underground, and crushed ore will be hoisted to the surface. Grinding will be conducted by a single-stage AG mill to a size suitable for flotation. Sequential flotation will be followed by pressure filtration for concentrates and tailings. • Metallurgical recovery is found to vary by geological domain and recovery ranges are applied based on geologic formation. Average process recoveries are: 90% for zinc in zinc concentrate; 91% for lead in lead concentrate and 81% for silver in lead concentrate. • Lead is found to occur primarily as galena and zinc is found to occur primarily as sphalerite with small amounts of non-sulphide zinc occurring in the geological domains close to surface. Galena and sphalerite are coarse grained and easily liberated for effective recovery by sequential flotation.

Criteria	Commentary
	• Manganese occurs in relatively high concentrations in gangue and can occur as an inclusion of sphalerite especially in the higher geological domains. This can cause manganese in zinc concentrate to exceed penalty limits for most smelters. No other deleterious elements are expected to exceed penalty limits for lead or zinc concentrates. • Metallurgical test work has been conducted using samples covering the ore body vertically and horizontally. All metallurgical test work and the process design have been reviewed by independent consultants.
Environmental factors or assumptions	• The project consists of patented claims surrounded by the Coronado National Forest and unpatented claims located within the surrounding Coronado National Forest and managed by the United Sates Forest Service. • A permitting schedule has been developed for obtaining critical state and federal approvals. • Waste rock generated from surface and underground excavations is delineated into potentially acid generating (PAG) or non-acid generating (NAG) rock. All PAG material will report to a lined facility as will most of the NAG material, except for a limited amount that will be used for construction material. • The tailings storage facilities have been designed in accordance with South32's Dam Management Standard and consistent with the International Council on Mining and Metals (ICMM) Tailings Governance Framework, in addition to the Australian National Committee on Large Dams (ANCOLD) guidelines. • Tailings from processing will be filtered and stored in purpose-built, lined, surface storage facilities or returned underground in the form of paste backfill. An existing tailings storage facility on patented claims will be used to store tailings from early operations.
Infrastructure	• Current site activity is supported by and consists of office buildings, core processing facilities, an existing tailings storage facility as part of the voluntary remediation program, a water treatment plant, ponds, road networks and laydown yards. • Planned infrastructure will be installed to support future operations and will consist of: o Dual shafts o Ventilation and refrigeration systems o Process comminution, flotation and concentrate loadout o Tailings filtration plant and tailings storage facilities o Paste backfill plant o Dewatering wells, another water treatment plant and pipelines o Surface shops, fuel bays, wash bays and office buildings o Powerlines and substations o Surface stockpile bins o Underground maintenance shops and ore/waste storage • A site layout plan and construction schedule support the above listed infrastructure.
Costs	• The capital cost estimate is supported by sufficient engineering scope and definition for preparation of a AACE International Class 4 estimate. • The operating cost estimate was developed in accordance with industry standards and South32 project requirements. o Mining costs were calculated primarily from first principles and substantiated by detailed labour rate calculations, vendor-provided equipment operating costs and budgetary quotations for materials and consumables. o Processing costs account for plant consumables/reagents, labour, power and maintenance materials and tailings storage facility costs. o General and administrative costs are based on current operating structures and optimised based on industry benchmarks and fit-for-purpose sizing. Permitting and environmental estimates are based on current permitting timelines. • Commodity price forecasts for silver, lead and zinc and foreign exchange are supplied by South32 Marketing. Price assumptions reflect South32's view on demand, supply, volume forecasts and competitor analysis. Price protocols will not be detailed as the information is commercially sensitive. • Transportation charges have been estimated using information on trucking costs, rail costs, export locations, transload capabilities and transit time associated with moving concentrate from site to port to market.

Criteria	Commentary
	- Treatment and Refining Charges used for the valuation are supplied by South32 Marketing and reflect South32's view on demand, supply, volume forecasts and competitor analysis. - Applicable royalties and property fees have been applied using on the current US federal and state rates.
Revenue factors	- The life of operation plan derived from the pre-feasibility study provides the mining and processing physicals such as volume, tonnes and grades to support the valuation. - Revenue is calculated by applying forecast metal prices and foreign exchange rates to the scheduled payable metal. Metal payabilities are based on contracted payability terms, typical for the lead and zinc concentrate markets.
Market assessment	- Internal price protocols reflect South32's view on demand, supply, and stock situations including customer analysis, competitor analysis and identification of major market windows and volume forecasts.
Economic	- Economic inputs are described in the cost, revenue and metallurgical factors commentary. - Sensitivity analyses have been completed on metal prices, metallurgical recoveries, mine operating costs, growth capital costs and use of Inferred Mineral Resources and the Exploration Target to understand the value drivers and impact on the valuation. - The pre-feasibility study evaluated alternate cases to assess the impact of longer than expected permitting timelines and associated capital spend profiles.
Social	- South32 maintains relationships with stakeholders in its host communities through structured and meaningful engagement activities including: community forums, industry involvement, employee participation, local procurement and local employment. - A Community Management Plan has been developed in accordance with the South32 Community Standard and includes baseline studies, community surveys, risk assessments, stakeholder identification, engagement plans, cultural heritage, community investment plans, closure and rehabilitation.
Other	- Hermosa has developed a comprehensive risk register and risk management system to address foreseeable risks that could impact the project and future operations. - No material naturally occurring risks have been identified and the project is not subject to any material legal agreements or marketing arrangements.