

**Table 1a Summary of the included and critically reviewed publications on behavioural measures.**

Publication	Animal-based indicator	Environmental variables	No. of animals	No. of institutions	Experimental design	Method of assessing welfare or other focus of study	Reliability	Validity
Altman 1999	Object manipulation <sup>%</sup> , activity <sup>*</sup> , inactive <sup>%</sup>	<i>Enrichment objects</i>	2 (0.2)	1	Experimental (own control); repeated treatments (ABAB); quantitative	Monitored behavioural changes following provision of non-edible manipulative objects	None reported	Criterion
Ames 1993 (various case-studies)	Stereotypy <sup>*s%</sup> Foraging <sup>*</sup> aggressive interactions <sup>%</sup> anticipation <sup>s%</sup> proximity <sup>s%</sup> , Activity level <sup>s%</sup> : activity <sup>%</sup> , inactivity <sup>%</sup> Rubbing, feeding, lying, digging, object manipulation	<i>Feeding enrichment, substrate, group composition, feeding interval (feeding and starve days)</i>	14 (6.8)	7	Experimental; own control; observational; repeated measures; quantitative	Monitored behavioural changes following changes to the environment, over time (seasons) and compared activity budgets to wild conspecifics	None reported	Criterion
Ames 1994	Object manipulation <sup>s%</sup> , substrate preference <sup>s%</sup>	<i>Object and feeding enrichment, substrate</i>	14 (6.8)	7	Observational; descriptive; quantitative	Monitored behavioural change over time (seasons) and substrate preference	None reported	-
Canino & Powell 2010	Pacing <sup>%</sup> , object play <sup>%</sup> , rest <sup>%</sup> , activity budget	<i>Enrichment novelty (object)</i>	1 (1.0)	1	Experimental; own control; repeated treatments (ABAB); quantitative	Monitored behavioural differences between provision of novel and previously used enrichment items	None reported	Criterion
Cless <i>et al</i> 2015	Pacing, gait (step cycle and head height) <sup>*</sup> , locomotion	-	11 (4.7)	7	Observational; quantitative	Assessed whether pacing is quantifiably different from non-repetitive locomotion	None reported	Criterion
Cless & Lukas 2017	Pacing location <sup>°</sup> , pacing intensity <sup>*</sup> anticipatory nature <sup>°*</sup> , gait (step cycle)	-	10	7	Observational; survey questionnaire; quantitative; qualitative	Assessed intensity and frequency of pacing and investigated underlying motivation	None reported	Criterion
Cremers & Geutjes 2012	Stereotypic behaviour <sup>*</sup> , active, inactive <sup>%</sup> , attentiveness	<i>Feeding interval (feeding and starve days)*, keeper presence*, presence of conspecific*, noise level, enrichment items, substrate, exhibit traffic, employee count</i>	1 (1.0)	1	Observational; quantitative	Investigated how environmental factors affect behaviour	None reported	Criterion

**Table 1a (continued)**

Publication	Animal-based indicator	Environmental variables	No. of animals	No. of institutions	Experimental design	Method of assessing welfare or other focus of study	Reliability	Validity
Folk <i>et al</i> 1973	Heart rate <sup>%</sup> (sleep budget, feeding, drinking, sitting, walking, standing)	-	2 (2.0)	1	Case report; descriptive	Investigated bradycardia	-	-
Forthman <i>et al</i> 1992	Abnormal behaviour <sup>%</sup> , active <sup>*</sup> , passive <sup>*</sup>	<i>Feeding enrichment*</i>	2 (1.1)	1	Experimental; own control; repeated treatments (ABAB); quantitative	Investigated effect of feeding enrichment on behaviour	IOR	Criterion
Hein <i>et al</i> 2020	Faecal glucocorticoid metabolites (FGM) <sup>* c</sup> , social tension <sup>c</sup>	<i>Environmental change*</i> , <i>various disturbances*</i> , <i>animal transport*</i>	8 (4.4)	12	Questionnaire; quantitative,	Validated a cortisol enzyme immunoassay and determined individual long-term FGM levels (in context of season and social relations)	None reported	Construct Criterion
Kelly <i>et al</i> 2014	Stereotypic behaviour <sup>s%</sup> , inactivity <sup>s%</sup> , activity <sup>s%</sup> , activity budget	<i>Visitor density</i>	3 (1.2)	1	Observational; descriptive; quantitative	Monitored how behaviour change according to season, social and environmental factors	IOR	-
Kuczaj <i>et al</i> 2002	Object interaction	<i>Enrichment item, variable presentation of enrichment</i>	1 (1.0)	1	Experimental; own control; repeated measures; quantitative	Investigated effect of variable presentation of enrichment objects on behaviour	None reported	Criterion
Kutska 2009	Stereotypic behaviour <sup>*</sup> , interaction with enrichment items <sup>*</sup>	<i>Naturalistic and un-naturalistic enrichment items</i>	2 (1.1)	1	Experimental; own control; repeated measures; survey questions	Investigated visitor perceptions of enclosure (and behavioural response of polar bears) in response to provision of naturalistic and un-naturalistic enrichment items	None reported	-
Linder <i>et al</i> 2020	Stereotypic behaviour <sup>*</sup> , activity in water <sup>*</sup> , inactivity <sup>*</sup> , activity on land, social play	<i>Novel odour objects*</i>	2 (0.2)	1	Experimental; own control; repeated measures; quantitative	Investigated application of behavioural instability as a tool for behavioural responses	None reported	Criterion
Poulsen <i>et al</i> 1996	Pace <sup>%</sup> , facial tic (abnormal) <sup>%</sup> , coughing/huffing (abnormal) <sup>%</sup> , non-stereotypical mobility <sup>%</sup> , immobility <sup>%</sup> , sleeping <sup>%</sup>	<i>(Drug administration)</i>	1 (0.1)	1	Experimental; own control; repeated treatments (ABA), quantitative; qualitative	Monitored behavioural changes following drug administration (fluoxetine)	None reported	-

**Table 1a (continued)**

Publication	Animal-based indicator	Environmental variables	No. of animals	No. of institutions	Experimental design	Method of assessing welfare or other focus of study	Reliability	Validity
Renner & Kelly 2006	Aggressive interactions, non-aggressive interactions, inter-individual distance	-	2 (0.2)	1	Observational; descriptive, quantitative	Investigated how polar bears manage inter-individual distance	None reported	-
Ross 2006	Stereotypic behaviour *, pacing *, social play *, swimming *, object manipulation, feeding, locomotion, attention to staff	<i>Off-exhibit access</i>	2 (1.1)	1	Experimental; own control; repeated measures; quantitative	Monitored behavioural changes following changes to the environment (off-exhibit access)	IOR	Criterion
Shepherdson <i>et al</i> 2004	Stereotypic behaviour *, FGM *	-	48 (22.26)	18	Epidemiological; observational; survey; questionnaire; quantitative; qualitative	Assessed differences in corticoid profiles of stereotypic bears and non-stereotypic bears	None reported	-
Shepherdson <i>et al</i> 2013	Pace <sup>c</sup> , FGM <sup>c</sup> , temperament <sup>c</sup> , time budget	<i>Animal transport, view out of exhibit*, enclosure size (dry land)*, enrichment and diversity*, no. of bears in group*, positive reinforcement training program</i>	55 (24.31)	20	Epidemiological; observational; experimental (novel object test); quantitative	Assessed relationship between environmental variables, temperament, stereotypic pacing and FGM	IOR	Construct Criterion
Wechsler 1991	Stereotypic behaviour, yawning, tongue-flicking, time budget, walking, sitting, lying, attentiveness, swimming		3 (1.2)	1	Observational; descriptive; quantitative; qualitative	Investigated spatial and temporal patterns of stereotypes and whether stereotypes reduce arousal level	None reported	-
Wechsler 1992	Stereotypy <sup>%</sup> , walking, standing, inactivity, sniffing *, attentiveness	<i>Odour marks</i>	2 (1.1)	1	Experimental; own control; repeated measures; quantitative	Investigated motivation behind stereotypic behaviour	None reported	Criterion

% : Percentage change in unit during study or between groups, not subjected to statistical analysis.

\* : Statistically significant change in unit during study, between groups significant or association with environmental factors.

c : Correlation or other significant relationship with animal-based indicators identified during the study.

s: Seasonal change.

Abbreviations: IOR: Inter-observer reliability, FGM: Faecal glucocorticoid metabolite concentration, ABA and ABAB: Repeated treatments design, AB: Repeated measures design, A: Baseline, B: Experimental (Swaisgood & Shepherdson 2005).

**Table 1b Summary of the included publications on physical and physiological measures (not critically reviewed).**

Publication	Animal-based indicator	Environmental variables	No. of animals	No. of institutions	Experimental design	Method of assessing welfare or other focus of study	Reliability	Validity
Abdelgawad <i>et al</i> 2014	Loss of appetite, heavy salivation, difficult breathing, saliva sampling	-	1 (1.0)	1	Case report	Zebra-borne equine herpesvirus type 1)	-	Content
Alroy <i>et al</i> 1980	Weight loss, skin abscesses, reduced appetite, reduced activity, blood values	-	1 (1.0)	1	Immunohistochemically case study	Case of multiple beta cell neoplasms	-	Content
Baba <i>et al</i> 2013	Stool (diarrhoea), vomiting, blood biochemical parameters	-	1 (1.0)	1	Case report	Crescentic Glomerulonephritis (kidney syndrome)	-	Content
Banks <i>et al</i> 1999	Anorexia, pruritus, vomiting, stool (diarrhoea)	-	3 (1.3) + other bears	1 (circus)	Case reports	Aujeszky's disease (herpesvirus 1)	-	Content
Dayaram <i>et al</i> 2018	Loss of appetite, stool (diarrhoea), tissue and blood sampling	-	1 (1.0)	1	Case report	Mastadenovirus	-	Content
Deem & Calle 2001	Lameness, foot abscess, tooth rot abscess (stereotypic behaviour)	-	1 (0.1)	1	Case report	Cellulitis and abscess formation	-	Content
DiVincenti <i>et al</i> 2019	Anorexia, blood values	-	1 (0.1)	1	Case report	<i>Babesia</i> sp. infection	-	Content
Donovan <i>et al</i> 2009	Muscle tremors, erratic circling, increased blinking, head shaking, ptialism, flexor rigidity, less responsive to stimulus	-	1 (0.1)	1	Case report	Meningoencephalitis	-	Content
Dutton <i>et al</i> 2009	Non-moving hind limb, anorexic, serum antibodies	-	1 (1.0)	1	Case report	Paraparesis	-	Content
Eo & Kwon 2014	Skin condition, coat condition, reluctance to swim, scratching	-	1 (0.1)	1	Case report	Dermatitis	-	Content
Fortin & Benoit-Biancamano 2014	Body condition	-	1 (1.0)	1	Case report	Pancreatic islet cell tumor	-	Content
Garner <i>et al</i> 1997	Anorexia	-	2	1	Case report	Hepatic sarcocystosis	-	Content

**Table 1b (continued)**

Publication	Animal-based indicator	Environmental variables	No. of animals	No. of institutions	Experimental design	Method of assessing welfare or other focus of study	Reliability	Validity
Kenny <i>et al</i> 1998	Vitamin levels (D, E, A, 5-OH-D) (sera, skin and milk)	-	36 captive (56 free-ranging)	6	Observational	Determined reference vitamin levels and compared levels of captive to free-ranging polar bears	-	Content
Kenny <i>et al</i> 2004	Hind limb weakness	-	1 (0.1)	1	Case report	Describing myasthenia gravis	-	Content
Lacasse <i>et al</i> 2006	Inappetence, tussis, dysphagia	-	1 (1.0)	1	Case report	Tracheitis, <i>Bordetella bronchiseptica</i>	-	Content
LaDouceur <i>et al</i> 2014	Vomiting, weight loss, alopecia, inappetence, polyuria–polydipsia, lameness, tooth and gum condition, skin condition, pruritus, abnormal rapid breathing, ataxia, pedal abscess, azotemia, anemia, hyperphosphatemia, isosthenuria, biochemical abnormalities	-	11 (1.10)	8	Retrospective study	Investigating end-stage-renal-disease	-	Content
Lin <i>et al</i> 2005	Vitamin D (25-OHD) serum levels, bone health, non-weight bearing limb	-	4 (2.2)	4	Retrospective, observational	Described fracture repair and 25-OHD levels	-	Content
Mendez-Angulo <i>et al</i> 2014	Vomiting, blood parameters	-	1 (0.1)	1	Case report	Omental torsion	-	Content
Monson <i>et al</i> 2014	Stool (chronic diarrhoea), stool quality	-	1 (1.0)	1	Case report	Feed trial (food allergy)	-	Content
Morris <i>et al</i> 1989	Anorexia, weight loss, hind leg weakness	-	1 (1.0)	1	Case report	Describing systemic blastomycosis	-	Content
Morrison <i>et al</i> 2017	Gait limitation, weight loss	-	1 (0.1)	1	Case report	Lumbar stenosis	-	Content
Smith & Cordes 1972	Lesions, fur loss, alopecia, matted, discoloured and dirty fur, scratching, reluctance to swim	-	6 (3.2.unknown)	1	Case report	Dermatitis caused by <i>Dermatophilus congolensis</i>	-	Content

**Table 1b (continued)**

<b>Publication</b>	<b>Animal-based indicator</b>	<b>Environmental variables</b>	<b>No. of animals</b>	<b>No. of institutions</b>	<b>Experimental design</b>	<b>Method of assessing welfare or other focus of study</b>	<b>Reliability</b>	<b>Validity</b>
Stamper <i>et al</i> 1999	Fur condition (urine scalding)	-	1 (1.0)	1	Case report	Hypospadias	-	Content
Velguth <i>et al</i> 2009	Body condition, vomiting, restlessness, muscle wasting	-	3 (3.1)	3	Case reports	Describes cases of umbilical hernias	-	Content
Zimmerman <i>et al</i> 2010	Non-bearing weight on limb, blood count	-	1 (0.1)	1	Case report	Fracture	-	Content

**Table 2a Summary of the identified behavioural indicators and the respective association with other animal-based parameters and/or effect of interventions or influence of environmental factors.**

<b>Indicator</b>	<b>Identified in</b>	<b>Change or association</b>	<b>Correlated or associated with (AB)</b>	<b>Affected by (RB and/or MB)</b>	<b>Reported reliability</b>	<b>Evidence of validity</b>
<b>Abnormal behaviour</b>	Ames 1993 Canino & Powell 2010 Cless & Lukas 2017 Cless <i>et al</i> 2015 Cremers & Geutjes 2012 Forthman <i>et al</i> 1992 Kelly <i>et al</i> 2014 Kutka 2009 Linder <i>et al</i> 2020 Poulsen <i>et al</i> 1996 Ross 2006 Shepherdson <i>et al</i> 2013 Shepherdson <i>et al</i> 2004 Wechsler 1992 Wechsler 1991	<b>Ames 1993</b> <b>Cremers &amp; Geutjes 2012</b> <b>Kutka 2009</b> <b>Linder <i>et al</i> 2020</b> <b>Ross 2006</b> <b>Shepherdson <i>et al</i> 2013</b> <b>Shepherdson <i>et al</i> 2004</b> Canino & Powell 2010 Forthman <i>et al</i> 1992 Kelly <i>et al</i> 2014 Poulsen <i>et al</i> 1996 Wechsler 1992	<b>FGM+</b> <b>(Temperament: slow-to-approach)+ (interest)-</b>	<b>Feeding -</b> <b>Naturalistic enrichment items (vs non-naturalistic items) -</b> <b>Odour marks -/+</b> <b>Off-exhibit access -</b> <b>View out of exhibit -</b> <b>No. of bears in group -</b> <b>Positive reinforcement training -</b> Novel enrichment items - Starve days + Keeper presence - Noise (over 70dB) + Feeding enrichment - Visitor density -/+ Drug administration (fluoxetine) -	IOR (seasonal change)	Construct Criterion
<b>Activity</b>	Altman 1999 Ames 1993 Forthman <i>et al</i> 1992 Kelly <i>et al</i> 2014 Linder <i>et al</i> 2020	<b>Altman 1999</b> <b>Forthman <i>et al</i> 1992</b> <b>Linder <i>et al</i> 2020</b> Ames 1993 Kelly <i>et al</i> 2014	None	<b>Enrichment objects +</b> <b>Feeding enrichment +</b> <b>Odour marks +</b>	IOR (seasonal change)	Criterion
<b>Anticipation</b>	Ames 1993 (Cless & Lukas 2017)	<b>(Cless &amp; Lukas 2017)</b> Ames 1993	<b>Pacing intensity +</b>	<b>Pacing location (holding doors) +</b> Feeding strategy	None	Criterion
<b>Attentiveness</b>	Cremers & Geutjes 2012 Ross 2006 Wechsler 1991 Wechsler 1992	None	None	Off-exhibit access +	None	None
<b>Feeding and foraging</b>	Ames 1993 Folk <i>et al</i> 1973 Ross 2006	<b>Ames 1993</b>	Heart rate	<b>Feeding enrichment +</b>	IOR	Criterion
<b>Inactivity</b>	Altman 1999 Ames 1993 Cremers & Geutjes 2012 Forthman <i>et al</i> 1992 Kelly <i>et al</i> 2014 Linder <i>et al</i> 2020 Poulsen <i>et al</i> 1996 Wechsler 1992	<b>Forthman <i>et al</i> 1992</b> <b>Linder <i>et al</i> 2020</b> Altman 1999 Ames 1993 Cremers & Geutjes 2012 Kelly <i>et al</i> 2014 Poulsen <i>et al</i> 1996	None	<b>Feeding enrichment -/0</b> <b>Odour marks +</b> Object enrichment - Substrate + Visitor density -/+ Drug administration (fluoxetine) +	IOR (seasonal change)	Criterion

Table 2a (continued)

Indicator	Identified in	Change or association	Correlated or associated with (AB)	Affected by (RB and/or MB)	Reported reliability	Evidence of validity
<b>Locomotion</b>	Cless <i>et al</i> 2015 Poulsen <i>et al</i> 1996 Ross 2006 Wechsler 1991 Wechsler 1992	Poulsen <i>et al</i> 1996	None	Drug administration (fluoxetine) (+)	IOR	None
<b>Object manipulation and play</b>	Kutska 2009 Ames 1994 Altman 1999 Canino & Powell 2010 Ames 1993 Kuczaj <i>et al</i> 2002 Ross 2006	<b>Kutska 2009</b> Ames 1994 Altman 1999 Canino & Powell 2010	None	<b>Naturalistic enrichment items (vs non-naturalistic items) +</b> Object enrichment + Novel enrichment items +	IOR (seasonal change)	Criterion
<b>Rest and sleep</b>	Canino & Powell 2010 Poulsen <i>et al</i> 1996	Canino & Powell 2010 Poulsen <i>et al</i> 1996	None	Object enrichment - Drug administration (fluoxetine) (+)	None	Criterion
<b>Sniffing (investigation)</b>	Wechsler 1992	<b>Wechsler 1992</b>	None	<b>Odour marks +</b>	None	Criterion
<b>Swimming</b>	Ross 2006 Wechsler 1991	<b>Ross 2006</b>	None	<b>Off-exhibit access +</b>	IOR	Criterion
<b>Social play</b>	Ross 2006	<b>Ross 2006</b>	None	<b>Off-exhibit access +</b>	IOR	Criterion
<b>Social aggression/tension</b>	Ames 1993 Hein <i>et al</i> 2020 Renner & Kelly 2006	<b>Hein <i>et al</i> 2020</b> Ames 1993	<b>FGM +</b>	Mechanical feeder +	None	Construct
<b>Social behaviour (other)</b>	Ames 1993 Renner & Kelly 2006	None	None	None	(Seasonal change)	None

**Bold text** indicates significant findings (non-bold indicates % change not subjected to statistical analysis).

Effect/relationship with indicator is indicated by: + : positive relationship, - negative relationship, 0 no observed change/effect in conjunction with '/' to indicate separate contradicting findings between individuals or studies.

Abbreviations: AB: Animal-based, RB: Resource, MB: Management-based, IOR: Inter-observer reliability.



**Table 2b Summary of the identified physical and physiological indicators and the respective association with other animal-based parameters and/or effect of interventions or influence of environmental factors.**

<b>Indicator</b>	<b>Identified in</b>	<b>Change or association</b>	<b>Correlated or associated with (AB)</b>	<b>Affected by (RB and/or MB)</b>	<b>Reported reliability</b>	<b>Evidence of validity</b>
<b>Appetite</b>	Abdelgawad <i>et al</i> 2014 Alroy <i>et al</i> 1980 Banks <i>et al</i> 1999 Dayaram <i>et al</i> 2018 DiVincenti <i>et al</i> 2019 Dutton <i>et al</i> 2009 Garner <i>et al</i> 1997 Lacasse <i>et al</i> 2018 LaDouceur <i>et al</i> 2014 Morris <i>et al</i> 1989	NA	NA	Various health issues	NA	Content
<b>Body condition and weight</b>	Alroy <i>et al</i> 1980 Fortin & Benoit-Biancamano 2014 LaDouceur <i>et al</i> 2014 Morris <i>et al</i> 1989 Morisson <i>et al</i> 2017 Velguth <i>et al</i> 2009	NA	NA	Various health issues	NA	Content
<b>Dental condition</b>	Deem & Calle 2001 LaDouceur <i>et al</i> 2014	NA	NA	Health issue	NA	Content
<b>FGM</b>	Hein <i>et al</i> 2020 Shepherdson <i>et al</i> 2013 Shepherdson <i>et al</i> 2004	<b>Hein <i>et al</i> 2020 Shepherdson <i>et al</i> 2013 Shepherdson <i>et al</i> 2004</b>	<b>Social tension+ Pacing + Temperament (interest) -</b>	<b>Animal transfer + Environmental change + Various disturbances + Enclosure size (dry land) -</b>	(No seasonal change)	Construct Criterion
<b>Gait and limb problems</b>	Donovan <i>et al</i> 2009 Deem & Calle 2001 Dutton <i>et al</i> 2009 Kenny <i>et al</i> 2004 LaDouceur <i>et al</i> 2014 Lin <i>et al</i> 2005 Morris <i>et al</i> 1989 Morrison <i>et al</i> 2017 Zimmerman <i>et al</i> 2010	NA	NA	Various health issues	NA	Content
<b>Heart rate</b>	Folk <i>et al</i> 1973	Folk <i>et al</i> 1973	None	None	None	None

**Table 2b (continued)**

<b>Indicator</b>	<b>Identified in</b>	<b>Change or association</b>	<b>Correlated or associated with (AB)</b>	<b>Affected by (RB and/or MB)</b>	<b>Reported reliability</b>	<b>Evidence of validity</b>
<b>Haematological and biochemical parameters</b>	Alroy <i>et al</i> 1980 Abdelgawad <i>et al</i> 2014 Baba <i>et al</i> 2013 Banks <i>et al</i> 1999 Dayaram <i>et al</i> 2018 DiVincenti <i>et al</i> 2019 Dutton <i>et al</i> 2009 Kenny <i>et al</i> 1998 LaDouceur <i>et al</i> 2014 Lin <i>et al</i> 2005 Mendez-Angulo <i>et al</i> 2014 Morris <i>et al</i> 1989 Zimmerman <i>et al</i> 2010	NA	NA	Nutritional deficiencies, various health issues	NA	Content
<b>Pedal condition</b>	Deem & Calle 2001 LaDouceur <i>et al</i> 2014	NA	NA	Health issue	NA	Content
<b>Skin and coat condition</b>	Alroy <i>et al</i> 1980 Eo & Kwon 2014 Smith & Cordes 1972 LaDouceur <i>et al</i> 2014 Stamper <i>et al</i> 1999	NA	NA	Various health issues	NA	Content
<b>Stool quality</b>	Baba <i>et al</i> 2013 Banks <i>et al</i> 1999 Dayaram <i>et al</i> 2018 Monson <i>et al</i> 2014	NA	NA	Various health issues	NA	Content

**Bold text** indicates significant findings (non-bold indicates % change not subjected to statistical analysis).

Effect/relationship with indicator is indicated by: + : positive relationship, - negative relationship.

Abbreviations: AB: Animal-based, RB: Resource, MB: Management-based, IOR: Inter-observer reliability, NA: Not assessed in this review.

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